

**STATA  
LONGITUDINAL-DATA/PANEL-DATA  
REFERENCE MANUAL  
RELEASE 16**



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# Cross-referencing the documentation

When reading this manual, you will find references to other Stata manuals, for example, [U] 27 Overview of Stata estimation commands; [R] regress; and [D] reshape. The first example is a reference to chapter 27, *Overview of Stata estimation commands*, in the *User's Guide*; the second is a reference to the regress entry in the *Base Reference Manual*; and the third is a reference to the reshape entry in the *Data Management Reference Manual*.

All the manuals in the Stata Documentation have a shorthand notation:

[GSM]	Getting Started with Stata for Mac
[GSU]	Getting Started with Stata for Unix
[GSW]	Getting Started with Stata for Windows
[U]	Stata User's Guide
[R]	Stata Base Reference Manual
[BAYES]	Stata Bayesian Analysis Reference Manual
[CM]	Stata Choice Models Reference Manual
[D]	Stata Data Management Reference Manual
[DSGE]	Stata Dynamic Stochastic General Equilibrium Models Reference Manual
[ERM]	Stata Extended Regression Models Reference Manual
[FMM]	Stata Finite Mixture Models Reference Manual
[FN]	Stata Functions Reference Manual
[G]	Stata Graphics Reference Manual
[IRT]	Stata Item Response Theory Reference Manual
[LASSO]	Stata Lasso Reference Manual
[XT]	Stata Longitudinal-Data/Panel-Data Reference Manual
[META]	Stata Meta-Analysis Reference Manual
[ME]	Stata Multilevel Mixed-Effects Reference Manual
[MI]	Stata Multiple-Imputation Reference Manual
[MV]	Stata Multivariate Statistics Reference Manual
[PSS]	Stata Power, Precision, and Sample-Size Reference Manual
[P]	Stata Programming Reference Manual
[RPT]	Stata Reporting Reference Manual
[SP]	Stata Spatial Autoregressive Models Reference Manual
[SEM]	Stata Structural Equation Modeling Reference Manual
[SVY]	Stata Survey Data Reference Manual
[ST]	Stata Survival Analysis Reference Manual
[TS]	Stata Time-Series Reference Manual
[TE]	Stata Treatment-Effects Reference Manual: Potential Outcomes/Counterfactual Outcomes
[I]	Stata Glossary and Index
[M]	Mata Reference Manual

**Intro** — Introduction to longitudinal-data/panel-data manual

Description      [Also see](#)

## Description

This manual documents the xt commands and is referred to as [XT] in cross-references.

Following this entry, [\[XT\] xt](#) provides an overview of the xt commands. The other parts of this manual are arranged alphabetically. If you are new to Stata's xt commands, we recommend that you read the following sections first:

- [\[XT\] xt](#)      Introduction to xt commands
- [\[XT\] xtset](#)      Declare a dataset to be panel data
- [\[XT\] xtreg](#)      Fixed-, between-, and random-effects, and population-averaged linear models

Stata is continually being updated, and Stata users are always writing new commands. To find out about the latest cross-sectional time-series features, type `search panel data` after installing the latest official updates; see [\[R\] update](#).

## Also see

- [\[U\] 1.3 What's new](#)
- [\[R\] Intro](#) — Introduction to base reference manual

## Description

The **xt** series of commands provides tools for analyzing panel data (also known as longitudinal data or, in some disciplines, as cross-sectional time series when there is an explicit time component). Panel datasets have the form  $x_{it}$ , where  $x_{it}$  is a vector of observations for unit  $i$  and time  $t$ . The particular commands (such as **xtdescribe**, **xtsum**, and **xtreg**) are documented in alphabetical order in the entries that follow this entry. If you do not know the name of the command you need, try browsing the second part of this description section, which organizes the **xt** commands by topic. The next section, *Remarks and examples*, describes concepts that are common across commands.

The **xtset** command sets the panel variable and the time variable; see [XT] **xtset**. Most **xt** commands require that the panel variable be specified, and some require that the time variable also be specified. Once you **xtset** your data, you need not do it again. The **xtset** information is stored with your data.

If you have previously **tsset** your data by using both a panel and a time variable, these settings will be recognized by **xtset**, and you need not **xtset** your data.

If your interest is in general time-series analysis, see [U] **27.14 Time-series models** and the *Time-Series Reference Manual*. If your interest is in multilevel mixed-effects models, see [U] **27.16 Multilevel mixed-effects models** and the *Multilevel Mixed-Effects Reference Manual*. If you are interested in SAR (spatial autoregressive or simultaneously autoregressive) models for panel data, see [SP] **spxtregress**. If you are interested in extended panel-data regression models that address endogenous covariates, nonrandom treatment assignment, and endogenous sample selection, see the *Extended Regression Models Reference Manual*.

## Setup

**xtset**      Declare data to be panel data

## Data management and exploration tools

<b>xtdescribe</b>	Describe pattern of <b>xt</b> data
<b>xtsum</b>	Summarize <b>xt</b> data
<b>xttab</b>	Tabulate <b>xt</b> data
<b>xtdata</b>	Faster specification searches with <b>xt</b> data
<b>xtline</b>	Panel-data line plots

**Linear regression estimators**

<code>xtreg</code>	Fixed-, between-, and random-effects, and population-averaged linear models
<code>xtregar</code>	Fixed- and random-effects linear models with an AR(1) disturbance
<code>xtgls</code>	Fit panel-data models by using GLS
<code>xtpcse</code>	Linear regression with panel-corrected standard errors
<code>xthtaylor</code>	Hausman–Taylor estimator for error-components models
<code>xtfrontier</code>	Stochastic frontier models for panel data
<code>xtrc</code>	Random-coefficients model
<code>xtivreg</code>	Instrumental variables and two-stage least squares for panel-data models
<code>xtheckman</code>	Random-effects regression with sample selection
<code>xtregress</code>	Random-effects models with endogenous covariates, treatment, and sample selection

**Unit-root tests**

<code>xtunitroot</code>	Panel-data unit-root tests
-------------------------	----------------------------

**Cointegration tests**

<code>xtcointtest</code>	Panel-data cointegration tests
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**Dynamic panel-data estimators**

<code>xtabond</code>	Arellano–Bond linear dynamic panel-data estimation
<code>xtdpd</code>	Linear dynamic panel-data estimation
<code>xtdpdsys</code>	Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation

**Censored-outcome estimators**

<code>xttobit</code>	Random-effects tobit models
<code>xtintreg</code>	Random-effects interval-data regression models
<code>xteintreg</code>	Random-effects interval-data regression models with endogenous covariates, treatment, and sample selection

**Binary-outcome estimators**

<code>xtlogit</code>	Fixed-effects, random-effects, and population-averaged logit models
<code>xtprobit</code>	Random-effects and population-averaged probit models
<code>xtcloglog</code>	Random-effects and population-averaged cloglog models
<code>xtepribit</code>	Random-effects probit models with endogenous covariates, treatment, and sample selection

**Ordinal-outcome estimators**

<code>xtologit</code>	Random-effects ordered logistic models
<code>xtoprobit</code>	Random-effects ordered probit models
<code>xteoprobit</code>	Random-effects ordered probit models with endogenous covariates, treatment, and sample selection

**Count-data estimators**

<code>xtpoisson</code>	Fixed-effects, random-effects, and population-averaged Poisson models
<code>xtnbreg</code>	Fixed-effects, random-effects, & population-averaged negative binomial models

## Survival-time estimators

**xtstreg** Random-effects parametric survival models

## Generalized estimating equations estimator

**xtgee** Population-averaged panel-data models by using GEE

## Utility

**quadchk** Check sensitivity of quadrature approximation

## Remarks and examples

Consider having data on  $n$  units—individuals, firms, countries, or whatever—over  $T$  periods. The data might be income and other characteristics of  $n$  persons surveyed each of  $T$  years, the output and costs of  $n$  firms collected over  $T$  months, or the health and behavioral characteristics of  $n$  patients collected over  $T$  years. In panel datasets, we write  $x_{it}$  for the value of  $x$  for unit  $i$  at time  $t$ . The **xt** commands assume that such datasets are stored as a sequence of observations on  $(i, t, x)$ .

For a discussion of panel-data models, see [Baltagi \(2013\)](#), [Greene \(2018, chap. 11\)](#), [Hsiao \(2014\)](#), and [Wooldridge \(2010\)](#). [Cameron and Trivedi \(2010\)](#) illustrate many of Stata's panel-data estimators.

For an introduction to linear, nonlinear, and dynamic panel-data analysis in Stata, we offer NetCourse 471, *Introduction to Panel Data Using Stata*; see <https://www.stata.com/netcourse/panel-data-intro-nc471/>.

### ▷ Example 1

If we had data on pulmonary function (measured by forced expiratory volume, or FEV) along with smoking behavior, age, sex, and height, a piece of the data might be

```
. list in 1/6, separator(0) divider
```

	pid	yr_visit	fev	age	sex	height	smokes
1.	1071	1991	1.21	25	1	69	0
2.	1071	1992	1.52	26	1	69	0
3.	1071	1993	1.32	28	1	68	0
4.	1072	1991	1.33	18	1	71	1
5.	1072	1992	1.18	20	1	71	1
6.	1072	1993	1.19	21	1	71	0

The **xt** commands need to know the identity of the variable identifying patient, and some of the **xt** commands also need to know the identity of the variable identifying time. With these data, we would type

```
. xtset pid yr_visit
```

If we resaved the data, we need not respecify **xtset**.



## □ Technical note

Panel data stored as shown above are said to be in the long form. Perhaps the data are in the wide form with 1 observation per unit and multiple variables for the value in each year. For instance, a piece of the pulmonary function data might be

pid	sex	fev91	fev92	fev93	age91	age92	age93
1071	1	1.21	1.52	1.32	25	26	28
1072	1	1.33	1.18	1.19	18	20	21

Data in this form can be converted to the long form by using `reshape`; see [D] `reshape`. □

## ▷ Example 2

Data for some of the periods might be missing. That is, we have panel data on  $i = 1, \dots, n$  and  $t = 1, \dots, T$ , but only  $T_i$  of those observations are defined. With such missing periods—called unbalanced data—a piece of our pulmonary function data might be

```
. list in 1/6, separator(0) divider
```

	pid	yr_visit	fev	age	sex	height	smokes
1.	1071	1991	1.21	25	1	69	0
2.	1071	1992	1.52	26	1	69	0
3.	1071	1993	1.32	28	1	68	0
4.	1072	1991	1.33	18	1	71	1
5.	1072	1993	1.19	21	1	71	0
6.	1073	1991	1.47	24	0	64	0

Patient ID 1072 is not observed in 1992. The xt commands are robust to this problem. □

## □ Technical note

In many of the entries in [XT], we will use data from a subsample of the NLSY data (Center for Human Resource Research 1989) on young women aged 14–26 years in 1968. Women were surveyed in each of the 21 years 1968–1988, except for the six years 1974, 1976, 1979, 1981, 1984, and 1986. We use two different subsets: `nlswork.dta` and `union.dta`.

For `nlswork.dta`, our subsample is of 4,711 women in years when employed, not enrolled in school and evidently having completed their education, and with wages in excess of \$1/hour but less than \$700/hour.

```
. use https://www.stata-press.com/data/r16/nlswork, clear
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)

. describe
Contains data from https://www.stata-press.com/data/r16/nlswork.dta
obs:      28,534                               National Longitudinal Survey.
                                         Young Women 14-26 years of age
                                         in 1968
vars:      21                                     27 Nov 2018 08:14

```

variable name	storage type	display format	value label	variable label
idcode	int	%8.0g		NLS ID
year	byte	%8.0g		interview year
birth_yr	byte	%8.0g		birth year
age	byte	%8.0g		age in current year
race	byte	%8.0g	racelbl	race
msp	byte	%8.0g		1 if married, spouse present
nev_mar	byte	%8.0g		1 if never married
grade	byte	%8.0g		current grade completed
collgrad	byte	%8.0g		1 if college graduate
not_smsa	byte	%8.0g		1 if not SMSA
c_city	byte	%8.0g		1 if central city
south	byte	%8.0g		1 if south
ind_code	byte	%8.0g		industry of employment
occ_code	byte	%8.0g		occupation
union	byte	%8.0g		1 if union
wks_ue	byte	%8.0g		weeks unemployed last year
ttl_exp	float	%9.0g		total work experience
tenure	float	%9.0g		job tenure, in years
hours	int	%8.0g		usual hours worked
wks_work	int	%8.0g		weeks worked last year
ln_wage	float	%9.0g		ln(wage/GNP deflator)

Sorted by: idcode year

. summarize

Variable	Obs	Mean	Std. Dev.	Min	Max
idcode	28,534	2601.284	1487.359	1	5159
	28,534	77.95865	6.383879	68	88
	28,534	48.08509	3.012837	41	54
	28,510	29.04511	6.700584	14	46
	28,534	1.303392	.4822773	1	3
msp	28,518	.6029175	.4893019	0	1
	28,518	.2296795	.4206341	0	1
	28,532	12.53259	2.323905	0	18
	28,534	.1680451	.3739129	0	1
	28,526	.2824441	.4501961	0	1
c_city	28,526	.357218	.4791882	0	1
	28,526	.4095562	.4917605	0	1
	28,193	7.692973	2.994025	1	12
	28,413	4.777672	3.065435	1	13
	19,238	.2344319	.4236542	0	1
wks_ue	22,830	2.548095	7.294463	0	76
	28,534	6.215316	4.652117	0	28.88461
	28,101	3.123836	3.751409	0	25.91667
	28,467	36.55956	9.869623	1	168
	27,831	53.98933	29.03232	0	104
ln_wage	28,534	1.674907	.4780935	0	5.263916

Many of the variables in the `nlswork` dataset are indicator variables, so we have used factor variables (see [U] 11.4.3 Factor variables) in many of the examples in this manual. You will see terms like `c.age#c.age` or `2.race` in estimation commands. `c.age#c.age` is just `age` interacted with `age`, or `age-squared`, and `2.race` is just an indicator variable for black (`race = 2`).

Instead of using factor variables, you could type

```
. generate age2 = age*age
. generate black = (race==2)
```

and substitute `age2` and `black` in your estimation command for `c.age#c.age` and `2.race`, respectively.

There are advantages, however, to using factor variables. First, you do not actually have to create new variables, so the number of variables in your dataset is less.

Second, by using factor variables, we are able to take better advantage of postestimation commands. For example, if we specify the simple model

```
. xtreg ln_wage age age2, fe
```

then `age` and `age2` are completely separate variables. Stata has no idea that they are related—that one is the square of the other. Consequently, if we compute the average marginal effect of `age` on the log of wages,

```
. margins, dydx(age)
```

then the reported marginal effect is with respect to the `age` variable alone and not with respect to the true effect of `age`, which involves the coefficients on both `age` and `age2`.

If instead we fit our model using an interaction of `age` with itself for the square of `age`,

```
. xtreg ln_wage age c.age#c.age, fe
```

then Stata has a deep understanding that the coefficients `age` and `c.age#c.age` are related. After fitting this model, the marginal effect reported by `margins` includes the full effect of `age` on the log of income, including the contribution of both coefficients.

```
. margins, dydx(age)
```

There are other reasons for preferring factor variables; see [R] `margins` for examples.

For `union.dta`, our subset was sampled only from those with union membership information from 1970 to 1988. Our subsample is of 4,434 women. The important variables are `age` (16–46), `grade` (years of schooling completed, ranging from 0 to 18), `not_smsa` (28% of the person-time was spent living outside a standard metropolitan statistical area (SMSA), and `south` (41% of the person-time was in the South). The dataset also has variable `union`. Overall, 22% of the person-time is marked as time under union membership, and 44% of these women have belonged to a union.

```
. use https://www.stata-press.com/data/r16/union
(NLS Women 14-24 in 1968)
. describe
Contains data from https://www.stata-press.com/data/r16/union.dta
  obs:           26,200                           NLS Women 14-24 in 1968
  vars:            8                               4 May 2018 13:54
```

variable	storage name	display type	value format	variable label	label
<code>idcode</code>		int	%8.0g		NLS ID
<code>year</code>		byte	%8.0g		interview year
<code>age</code>		byte	%8.0g		age in current year
<code>grade</code>		byte	%8.0g		current grade completed
<code>not_smsa</code>		byte	%8.0g		1 if not SMSA
<code>south</code>		byte	%8.0g		1 if south
<code>union</code>		byte	%8.0g		1 if union
<code>black</code>		byte	%8.0g		race black

Sorted by: `idcode` `year`

```
. summarize
```

Variable	Obs	Mean	Std. Dev.	Min	Max
<code>idcode</code>	26,200	2611.582	1484.994	1	5159
<code>year</code>	26,200	79.47137	5.965499	70	88
<code>age</code>	26,200	30.43221	6.489056	16	46
<code>grade</code>	26,200	12.76145	2.411715	0	18
<code>not_smsa</code>	26,200	.2837023	.4508027	0	1
<code>south</code>	26,200	.4130153	.4923849	0	1
<code>union</code>	26,200	.2217939	.4154611	0	1
<code>black</code>	26,200	.274542	.4462917	0	1

In many of the examples where the `union` dataset is used, we also include an interaction between the `year` variable and the `south` variable—`south#c.year`. This interaction is created using factor-variables notation; see [U] 11.4.3 Factor variables.

With both datasets, we have typed

```
. xtset idcode year
```



## □ Technical note

The `xtset` command sets the *t* and *i* index for xt data by declaring them as characteristics of the data; see [P] **char**. The panel variable is stored in `_dta[iis]` and the time variable is stored in `_dta[tis]`.



## □ Technical note

Throughout the entries in [XT], when random-effects models are fit, a likelihood-ratio test that the variance of the random effects is zero is included. These tests occur on the boundary of the parameter space, invalidating the usual theory associated with such tests. However, these likelihood-ratio tests have been modified to be valid on the boundary. In particular, the null distribution of the likelihood-ratio test statistic is not the usual  $\chi_1^2$  but is rather a 50:50 mixture of a  $\chi_0^2$  (point mass at zero) and a  $\chi_1^2$ , denoted as  $\bar{\chi}_{01}^2$ . See Gutierrez, Carter, and Drukker (2001) for a full discussion.



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## Also see

[XT] **xtset** — Declare data to be panel data

**quadchk — Check sensitivity of quadrature approximation**[Description](#)  
[Options](#)[Quick start](#)  
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## Description

quadchk checks the quadrature approximation used in the random-effects estimators of the following commands:

[xtcloglog](#)  
[xtintreg](#)  
[xtlogit](#)  
[xtologit](#)  
[xtoprobit](#)  
[xtpoisson, re](#) with the `normal` option  
[xtprobit](#)  
[xtstreg](#)  
[xttobit](#)

quadchk refits the model for different numbers of quadrature points and then compares the different solutions. quadchk respects all options supplied to the original model except `or`, `vce()`, and the *maximize\_options*.

## Quick start

Check quadrature approximation using the default range of quadrature points

```
quadchk
```

As above, but use 8 and 16 quadrature points

```
quadchk 8 16
```

As above, but suppress the iteration log and output of the refitted models

```
quadchk 8 16, nooutput
```

Refit the model instead of using original estimates

```
quadchk 8 16, nooutput nofrom
```

## Menu

Statistics > Longitudinal/panel data > Setup and utilities > Check sensitivity of quadrature approximation

## Syntax

```
quadchk [#1 #2] [, nooutput nofrom]
```

#<sub>1</sub> and #<sub>2</sub> specify the number of quadrature points to use in the comparison runs of the previous model. The default is to use approximately  $2n_q/3$  and  $4n_q/3$  points, where  $n_q$  is the number of quadrature points used in the original estimation.

## Options

`nooutput` suppresses the iteration log and output of the refitted models.

`nofrom` forces the refitted models to start from scratch rather than starting from the previous estimation results. Specifying the `nofrom` option can level the playing field in testing estimation results.

## Remarks and examples

Remarks are presented under the following headings:

*What makes a good random-effects model fit?*

*How do I know whether I have a good quadrature approximation?*

*What can I do to improve my results?*

### What makes a good random-effects model fit?

Some random-effects estimators in Stata use adaptive or nonadaptive Gauss–Hermite quadrature to compute the log likelihood and its derivatives. As a rule, adaptive quadrature, which is the default integration method, is much more accurate. The `quadchk` command provides a means to look at the numerical accuracy of either quadrature approximation. A good random-effects model fit depends on both the goodness of the quadrature approximation and the goodness of the data.

The accuracy of the quadrature approximation depends on three factors. The first and second are how many quadrature points are used and where the quadrature points fall. These two factors directly influence the accuracy of the quadrature approximation. The number of quadrature points may be specified with the `intpoints()` option. However, once the number of points is specified, their abscissas (locations) and corresponding weights are completely determined. Increasing the number of points expands the range of the abscissas and, to a lesser extent, increases the density of the abscissas. For this reason, a function that undulates between the abscissas can be difficult to approximate.

Third, the smoothness of the function being approximated influences the accuracy of the quadrature approximation. Gauss–Hermite quadrature estimates integrals of the type

$$\int_{-\infty}^{\infty} e^{-x^2} f(x) dx$$

and the approximation is exact if  $f(x)$  is a polynomial of degree less than the number of integration points. Therefore,  $f(x)$  that are well approximated by polynomials of a given degree have integrals that are well approximated by Gauss–Hermite quadrature with that given number of integration points. Both large panel sizes and high  $\rho$  can reduce the accuracy of the quadrature approximation.

A final factor affects the goodness of the random-effects model: the data themselves. For high  $\rho$ , for example, there is high intrapanel correlation, and panels look like observations. The model becomes unidentified. Here, even with exact quadrature, fitting the model would be difficult.

## How do I know whether I have a good quadrature approximation?

quadchk is intended as a tool to help you know whether you have a good quadrature approximation. As a rule of thumb, if the coefficients do not change by more than a relative difference of  $10^{-4}$  (0.01%), the choice of quadrature points does not significantly affect the outcome, and the results may be confidently interpreted. However, if the results do change appreciably—greater than a relative difference of  $10^{-2}$  (1%)—then quadrature is not reliably approximating the likelihood.

## What can I do to improve my results?

If the quadchk command indicates that the estimation results are sensitive to the number of quadrature points, there are several things you can do. First, if you are not using adaptive quadrature, switch to adaptive quadrature.

Adaptive quadrature can improve the approximation by transforming the integrand so that the abscissas and weights sample the function on a more suitable range. Details of this transformation are in *Methods and formulas* for the given commands; for example, see [XT] **xtprobit**.

If the model still shows sensitivity to the number of quadrature points, increase the number of quadrature points with the `intpoints()` option. This option will increase the range and density of the sampling used for the quadrature approximation.

If neither of these works, you may then want to consider an alternative model, such as a fixed-effects, pooled, or population-averaged model. Alternatively, a different random-effects model whose likelihood is not approximated via quadrature (for example, `xtpoisson`, `re`) may be a better choice.

### ▷ Example 1

Here we synthesize data according to the model

$$E(y) = 0.05 x_1 + 0.08 x_2 + 0.08 x_3 + 0.1 x_4 + 0.1 x_5 + 0.1 x_6 + 0.1\epsilon$$

$$z = \begin{cases} 1 & \text{if } y \geq 0 \\ 0 & \text{if } y < 0 \end{cases}$$

where the intrapanel correlation is 0.5 and the `x1` variable is constant within panels. We first fit a random-effects probit model, and then we check the stability of the quadrature calculation:

```
. use https://www.stata-press.com/data/r16/quad1
. xtset id
    panel variable: id (balanced)
. xtprobit z x1-x6
(output omitted)

Random-effects probit regression
Group variable: id
Random effects u_i ~ Gaussian

Number of obs      =      6,000
Number of groups   =       300
Obs per group:
    min =          20
    avg =        20.0
    max =        20

Integration method: mvaghermite
Integration pts.   =        12
Wald chi2(6)      =     29.24
Prob > chi2       =    0.0001

Log likelihood = -3347.1097
```

	z	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
x1	.0043068	.0607058	0.07	0.943	-.1146743	.1232879
x2	.1000742	.066331	1.51	0.131	-.0299323	.2300806
x3	.1503539	.0662503	2.27	0.023	.0205057	.2802021
x4	.123015	.0377089	3.26	0.001	.0491069	.196923
x5	.1342988	.0657222	2.04	0.041	.0054856	.263112
x6	.0879933	.0455753	1.93	0.054	-.0013325	.1773192
_cons	.0757067	.060359	1.25	0.210	-.0425948	.1940083
/lnsig2u	-.0329916	.1026847			-.23425	.1682667
sigma_u	.9836395	.0505024			.889474	1.087774
rho	.4917528	.0256642			.4417038	.5419677

LR test of rho=0: chibar2(01) = 1582.67

Prob &gt;= chibar2 = 0.000

Quadrature check				
	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-3347.1097	-3347.1153 -.00561484 1.678e-06	-3347.1099 -.00014288 4.269e-08	Difference Relative difference
z:	.0043068	.0043068 8.983e-15 2.086e-12	.00430541 -1.388e-06 -.00032222	Difference Relative difference
z:	.10007418	.10007418 2.540e-15 2.538e-14	.10007431 1.362e-07 1.361e-06	Difference Relative difference
z:	.15035391	.15035391 6.356e-15 4.227e-14	.15035406 1.520e-07 1.011e-06	Difference Relative difference
z:	.12301495	.12301495 4.149e-15 3.373e-14	.12301506 1.099e-07 8.931e-07	Difference Relative difference
z:	.13429881	.13429881 4.913e-15 3.658e-14	.13429896 1.471e-07 1.096e-06	Difference Relative difference
z:	.08799332	.08799332 3.345e-15 3.801e-14	.08799346 1.363e-07 1.549e-06	Difference Relative difference
z:	.07570675	.07570675 1.964e-14 2.594e-13	.07570423 -2.516e-06 -.00003323	Difference Relative difference
/:	-.03299164	-.03299164 7.268e-14 -2.203e-12	-.03298184 9.798e-06 -.00029699	Difference Relative difference

We see that the largest difference is in the `x1` variable with a relative difference of 0.03% between the model with 12 integration points and 16. This example is somewhat rare in that the differences between eight quadrature points and 12 are smaller than those between 12 and 16. Usually the opposite occurs: the model results converge as you add quadrature points. Here we have an indication that perhaps some minor feature of the model was missed with eight points and 12 but seen with 16. Because all differences are very small, we could accept this model as is. We would like to have a largest relative difference of about 0.01%, and this is close. The differences and relative differences are small, indicating that refitting the random-effects probit model with a few more integration points will yield a satisfactory result. Indeed, refitting the model with the `intpoints(20)` option yields completely satisfactory results when checked with `quadchk`.

Nonadaptive Gauss–Hermite quadrature does not yield such robust results.

```

. xtprobit z x1-x6, intmethod(ghermite) nolog
Random-effects probit regression
Group variable: id
Random effects u_i ~ Gaussian
Integration method: ghermite
Log likelihood = -3349.6926

Number of obs      =     6,000
Number of groups  =      300
Obs per group:
    min =          20
    avg =        20.0
    max =        20

Integration pts. =       12
Wald chi2(6)      =     36.15
Prob > chi2       =     0.0000

```

	<i>z</i>	Coef.	Std. Err.	<i>z</i>	P>  <i>z</i>	[95% Conf. Interval]
	x1	.1156763	.0554925	2.08	0.037	.0069131 .2244396
	x2	.1005555	.066227	1.52	0.129	-.0292469 .230358
	x3	.1542187	.0660852	2.33	0.020	.0246941 .2837433
	x4	.1257616	.0375776	3.35	0.001	.0521108 .1994123
	x5	.1366003	.0654696	2.09	0.037	.0082823 .2649182
	x6	.0870325	.0453489	1.92	0.055	-.0018497 .1759147
	_cons	.1098393	.0500514	2.19	0.028	.0117404 .2079382
/lnsig2u		-.0791821	.0971063		-.2695071	.1111428
sigma_u		.9611824	.0466685		.8739313	1.057145
rho		.4802148	.0242386		.4330281	.5277571

LR test of rho=0: chibar2(01) = 1577.50 Prob >= chibar2 = 0.000

Quadrature check				
	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-3349.6926	-3354.6372 -4.9446636 .00147615	-3348.3881 1.3045063 -.00038944	Difference Relative difference
z:	.11567633	.16153998 .04586365 .39648262	.07007833 -.045598 -.39418608	Difference Relative difference
z:	.10055552	.10317831 .00262279 .02608297	.09937417 -.00118135 -.01174825	Difference Relative difference
z:	.1542187	.15465369 .00043499 .00282062	.15150516 -.00271354 -.0175954	Difference Relative difference
z:	.12576159	.12880254 .00304096 .02418032	.1243974 -.00136418 -.01084739	Difference Relative difference
z:	.13660028	.13475211 -.00184817 -.01352978	.13707075 .00047047 .00344411	Difference Relative difference
z:	.08703252	.08568342 -.0013491 -.0155011	.08738135 .00034883 .00400809	Difference Relative difference
z:	.10983928	.11031299 .00047371 .00431274	.09654975 -.01328953 -.12099067	Difference Relative difference
/:	-.07918212	-.18133821 -.10215609 1.2901408	-.05815644 .02102568 -.26553572	Difference Relative difference

Here we see that the `x1` variable (the one that was constant within panel) changed with a relative difference of nearly 40%! This example clearly demonstrates the benefit of adaptive quadrature methods.



## ▷ Example 2

Here we rerun the [previous](#) nonadaptive quadrature model, but using the `intpoints(120)` option to increase the number of integration points to 120. We get results close to those from adaptive quadrature and an acceptable `quadchk`. This example demonstrates the efficacy of increasing the number of integration points to improve the quadrature approximation.

<pre>. xtprobit z x1-x6, intmethod(ghermite) intpoints(120) nolog</pre>					
Random-effects probit regression				Number of obs	= 6,000
Group variable: id				Number of groups	= 300
Random effects u_i ~ Gaussian				Obs per group:	
				min =	20
				avg =	20.0
				max =	20
Integration method: ghermite				Integration pts.	= 120
				Wald chi2(6)	= 29.24
Log likelihood = -3347.1099				Prob > chi2	= 0.0001
z	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
x1	.0043059	.0607087	0.07	0.943	-.114681 .1232929
x2	.1000743	.0663311	1.51	0.131	-.0299322 .2300808
x3	.1503541	.0662503	2.27	0.023	.0205058 .2802023
x4	.1230151	.0377089	3.26	0.001	.049107 .1969232
x5	.134299	.0657223	2.04	0.041	.0054856 .2631123
x6	.0879935	.0455753	1.93	0.054	-.0013325 .1773194
_cons	.0757054	.0603621	1.25	0.210	-.0426021 .1940128
/lnsig2u	-.0329832	.1026863			-.2342446 .1682783
sigma_u	.9836437	.0505034			.8894764 1.08778
rho	.491755	.0256646			.4417052 .5419706

LR test of rho=0: chibar2(01) = 1582.67

Prob >= chibar2 = 0.000

Quadrature check				
	Fitted quadrature 120 points	Comparison quadrature 80 points	Comparison quadrature 160 points	
Log likelihood	-3347.1099	-3347.1099 -.00007138 2.133e-08	-3347.1099 2.440e-07 -7.289e-11	Difference Relative difference
z:	.00430592	.00431318 7.259e-06 .00168592	.00430553 -3.871e-07 -.00008991	Difference Relative difference
z:	.10007431	.10007415 -1.519e-07 -1.517e-06	.10007431 5.585e-09 5.580e-08	Difference Relative difference
z:	.15035406	.15035407 1.699e-08 1.130e-07	.15035406 7.636e-09 5.078e-08	Difference Relative difference
z:	.12301506	.12301512 6.036e-08 4.907e-07	.12301506 5.353e-09 4.352e-08	Difference Relative difference
z:	.13429895	.13429962 6.646e-07 4.949e-06	.13429896 4.785e-09 3.563e-08	Difference Relative difference
z:	.08799345	.08799334 -1.123e-07 -1.276e-06	.08799346 3.049e-09 3.465e-08	Difference Relative difference
z:	.07570536	.07570205 -3.305e-06 -.00004365	.07570442 -9.405e-07 -.00001242	Difference Relative difference
/:	-.03298317	-.03298909 -5.919e-06 .00017945	-.03298186 1.304e-06 -.00003952	Difference Relative difference



## ▷ Example 3

Here we synthesize data the same way as in the [previous example](#), but we make the intrapanel correlation equal to 0.1 instead of 0.5. We again fit a random-effects probit model and check the quadrature:

```
. use https://www.stata-press.com/data/r16/quad2
. xtset id
    panel variable: id (balanced)
. xtprobit z x1-x6
```

Fitting comparison model:

```
Iteration 0: log likelihood = -4142.2915
Iteration 1: log likelihood = -4120.4109
Iteration 2: log likelihood = -4120.4099
Iteration 3: log likelihood = -4120.4099
```

Fitting full model:

```
rho = 0.0      log likelihood = -4120.4099
rho = 0.1      log likelihood = -4065.7986
rho = 0.2      log likelihood = -4087.7703
```

```
Iteration 0: log likelihood = -4065.7986
Iteration 1: log likelihood = -4065.3157
Iteration 2: log likelihood = -4065.3144
Iteration 3: log likelihood = -4065.3144
```

```
Random-effects probit regression
Group variable: id
Random effects u_i ~ Gaussian
Number of obs      =       6,000
Number of groups  =        300
Obs per group:
    min =          20
    avg =         20.0
    max =          20
```

```
Integration method: mvaghermite
Integration pts. =        12
Wald chi2(6)     =      39.43
Prob > chi2      =     0.0000
Log likelihood   = -4065.3144
```

<i>z</i>	Coef.	Std. Err.	<i>z</i>	P>  <i>z</i>	[95% Conf. Interval]
x1	.0246943	.025112	0.98	0.325	-.0245243 .0739129
x2	.1300123	.0587906	2.21	0.027	.0147847 .2452398
x3	.1190409	.0579539	2.05	0.040	.0054533 .2326284
x4	.139197	.0331817	4.19	0.000	.0741621 .2042319
x5	.077364	.0578454	1.34	0.181	-.036011 .1907389
x6	.0862028	.0401185	2.15	0.032	.007572 .1648336
_cons	.0922653	.0244392	3.78	0.000	.0443653 .1401652
/lnsig2u	-2.343939	.1575275			-2.652687 -2.035191
sigma_u	.3097563	.0243976			.2654461 .3614631
rho	.0875487	.0125839			.0658236 .1155574

LR test of rho=0: chibar2(01) = 110.19

Prob >= chibar2 = 0.000

Quadrature check				
	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-4065.3144	-4065.3144 -2.268e-08 5.578e-12	-4065.3144 6.366e-12 -1.566e-15	Difference Relative difference
z:	.02469427	.02469427 -7.290e-12 -2.952e-10	.02469427 -8.007e-12 -3.242e-10	Difference Relative difference
z:	.13001229	.13001229 -3.131e-11 -2.408e-10	.13001229 -6.880e-13 -5.292e-12	Difference Relative difference
z:	.11904089	.11904089 -1.291e-11 -1.085e-10	.11904089 -3.030e-13 -2.546e-12	Difference Relative difference
z:	.13919697	.13919697 2.885e-12 2.072e-11	.13919697 1.693e-13 1.216e-12	Difference Relative difference
z:	.07736398	.07736398 -1.160e-11 -1.500e-10	.07736398 -4.557e-13 -5.890e-12	Difference Relative difference
z:	.08620282	.08620282 1.181e-11 1.370e-10	.08620282 3.191e-13 3.702e-12	Difference Relative difference
z:	.09226527	.09226527 -5.700e-12 -6.177e-11	.09226527 -1.837e-11 -1.991e-10	Difference Relative difference
/:	-2.3439389	-2.3439389 -5.892e-09 2.514e-09	-2.3439389 -2.172e-10 9.267e-11	Difference Relative difference

Here we see that the quadrature approximation is stable. With this result, we can confidently interpret the results. Satisfactory results are also obtained in this case with nonadaptive quadrature.



Description	Syntax Reference	Options Also see	Remarks and examples
Methods and formulas			

## Description

This entry describes the *vce\_options*, which are common to most xt estimation commands. Not all the options documented below work with all xt estimation commands; see the documentation for the particular estimation command. If an option is listed there, it is applicable.

The `vce()` option specifies how to estimate the variance–covariance matrix (VCE) corresponding to the parameter estimates. The standard errors reported in the table of parameter estimates are the square root of the variances (diagonal elements) of the VCE.

## Syntax

*estimation\_cmd* ... [ , *vce\_options* ... ]

<i>vce_options</i>	Description
<code>vce(oim)</code>	observed information matrix (OIM)
<code>vce(opg)</code>	outer product of the gradient (OPG) vectors
<code>vce(robust)</code>	Huber/White/sandwich estimator
<code>vce(cluster clustvar)</code>	clustered sandwich estimator
<code>vce(bootstrap</code> [ , <i>bootstrap_options</i> ])	bootstrap estimation
<code>vce(jackknife</code> [ , <i>jackknife_options</i> ])	jackknife estimation
<code>nmp</code>	use divisor $N - P$ instead of the default $N$
<code>scale(x2   dev   phi   #)</code>	override the default scale parameter; available only with population-averaged models

## Options

### SE/Robust

`vce(oim)` is usually the default for models fit using maximum likelihood. `vce(oim)` uses the observed information matrix (OIM); see [R] **ml**.

`vce(opg)` uses the sum of the outer product of the gradient (OPG) vectors; see [R] **ml**. This is the default VCE when the `technique(bhhh)` option is specified; see [R] **Maximize**.

`vce(robust)` uses the robust or sandwich estimator of variance. This estimator is robust to some types of misspecification so long as the observations are independent; see [U] **20.22 Obtaining robust variance estimates**.

If the command allows `pweights` and you specify them, `vce(robust)` is implied; see [U] **20.24.3 Sampling weights**.

`vce(cluster clustvar)` specifies that the standard errors allow for intragroup correlation, relaxing the usual requirement that the observations be independent. That is to say, the observations are independent across groups (clusters) but not necessarily within groups. `clustvar` specifies to which group each observation belongs, for example, `vce(cluster personid)` in data with repeated observations on individuals. `vce(cluster clustvar)` affects the standard errors and variance-covariance matrix of the estimators but not the estimated coefficients; see [U] 20.22 Obtaining robust variance estimates.

`vce(bootstrap [ , bootstrap_options ])` uses a nonparametric bootstrap; see [R] bootstrap. After estimation with `vce(bootstrap)`, see [R] bootstrap postestimation to obtain percentile-based or bias-corrected confidence intervals.

`vce(jackknife [ , jackknife_options ])` uses the delete-one jackknife; see [R] jackknife.

`nmp` specifies that the divisor  $N - P$  be used instead of the default  $N$ , where  $N$  is the total number of observations and  $P$  is the number of coefficients estimated.

`scale(x2 | dev | phi | #)` overrides the default scale parameter. By default, `scale(1)` is assumed for the discrete distributions (binomial, negative binomial, and Poisson), and `scale(x2)` is assumed for the continuous distributions (gamma, Gaussian, and inverse Gaussian).

`scale(x2)` specifies that the scale parameter be set to the Pearson chi-squared (or generalized chi-squared) statistic divided by the residual degrees of freedom, which is recommended by McCullagh and Nelder (1989) as a good general choice for continuous distributions.

`scale(dev)` sets the scale parameter to the deviance divided by the residual degrees of freedom. This option provides an alternative to `scale(x2)` for continuous distributions and for over- or underdispersed discrete distributions.

`scale(phi)` specifies that the scale parameter be estimated from the data. `xtgee`'s default scaling makes results agree with other estimators and has been recommended by McCullagh and Nelder (1989) in the context of GLM. When comparing results with calculations made by other software, you may find that the other packages do not offer this feature. In such cases, specifying `scale(phi)` should match their results.

`scale(#)` sets the scale parameter to  $#$ . For example, using `scale(1)` in `family(gamma)` models results in exponential-errors regression (if you assume independent correlation structure).

## Remarks and examples

When you are working with panel-data models, we strongly encourage you to use the `vce(bootstrap)` or `vce(jackknife)` option instead of the corresponding prefix command. For example, to obtain jackknife standard errors with `xtlogit`, type

```
. use https://www.stata-press.com/data/r16/clogitid
. xtlogit y x1 x2, fe vce(jackknife)
(running xtlogit on estimation sample)

Jackknife replications (66)
----- 1 ----- 2 ----- 3 ----- 4 ----- 5
..... 50
.....
Conditional fixed-effects logistic regression  Number of obs      =      369
Group variable: id                           Number of groups   =       66
                                                Obs per group:
                                                min =            2
                                                avg =          5.6
                                                max =          10
                                                F(      2,      65) =     4.58
Log likelihood = -123.41386                  Prob > F        =    0.0137
                                                (Replications based on 66 clusters in id)


```

y	Jackknife					
	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
x1	.653363	.3010608	2.17	0.034	.052103	1.254623
x2	.0659169	.0487858	1.35	0.181	-.0315151	.1633489

If you wish to specify more options to the bootstrap or jackknife estimation, you can include them within the `vce()` option. Below we refit our model requesting bootstrap standard errors based on 300 replications, we set the random-number seed so that our results can be reproduced, and we suppress the display of the replication dots.

```
. xtlogit y x1 x2, fe vce(bootstrap, reps(300) seed(123) nodots)
Conditional fixed-effects logistic regression  Number of obs      =      369
Group variable: id                           Number of groups   =       66
                                                Obs per group:
                                                min =            2
                                                avg =          5.6
                                                max =          10
                                                Wald chi2(2)    =     9.26
Log likelihood = -123.41386                  Prob > chi2       =    0.0097
                                                (Replications based on 66 clusters in id)


```

y	Observed	Bootstrap	Normal-based			
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
x1	.653363	.307093	2.13	0.033	.0514717	1.255254
x2	.0659169	.0477384	1.38	0.167	-.0276486	.1594824

## □ Technical note

To perform jackknife estimation on panel data, you must omit entire panels rather than individual observations. To replicate the output above using the `jackknife` prefix command, you would have to type

```
. jackknife, cluster(id): xtlogit y x1 x2, fe
(output omitted)
```

Similarly, bootstrap estimation on panel data requires you to resample entire panels rather than individual observations. The `vce(bootstrap)` and `vce(jackknife)` options handle this for you automatically.



## Methods and formulas

By default, Stata's maximum likelihood estimators display standard errors based on variance estimates given by the inverse of the negative Hessian (second derivative) matrix. If `vce(robust)`, `vce(cluster clustvar)`, or `pweights` are specified, standard errors are based on the robust variance estimator (see [U] 20.22 Obtaining robust variance estimates); likelihood-ratio tests are not appropriate here (see [SVY] Survey), and the model  $\chi^2$  is from a Wald test. If `vce(opg)` is specified, the standard errors are based on the outer product of the gradients; this option has no effect on likelihood-ratio tests, though it does affect Wald tests.

If `vce(bootstrap)` or `vce(jackknife)` is specified, the standard errors are based on the chosen replication method; here the model  $\chi^2$  or  $F$  statistic is from a Wald test using the respective replication-based covariance matrix. The  $t$  distribution is used in the coefficient table when the `vce(jackknife)` option is specified. `vce(bootstrap)` and `vce(jackknife)` are also available with some commands that are not maximum likelihood estimators.

## Reference

McCullagh, P., and J. A. Nelder. 1989. *Generalized Linear Models*. 2nd ed. London: Chapman & Hall/CRC.

## Also see

- [R] **bootstrap** — Bootstrap sampling and estimation
- [R] **jackknife** — Jackknife estimation
- [R] **ml** — Maximum likelihood estimation
- [U] **20 Estimation and postestimation commands**

**xtabond** — Arellano–Bond linear dynamic panel-data estimation

Description  
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Methods and formulas

## Description

`xtabond` fits a linear dynamic panel-data model where the unobserved panel-level effects are correlated with the lags of the dependent variable, known as the Arellano–Bond estimator. This estimator is designed for datasets with many panels and few periods, and it requires that there be no autocorrelation in the idiosyncratic errors.

## Quick start

Arellano–Bond estimation of `y` on `x1` and `x2` using `xtset` data

```
xtabond y x1 x2
```

One-step estimator with robust standard errors

```
xtabond y x1 x2, vce(robust)
```

Two-step estimator with bias-corrected robust standard errors

```
xtabond y x1 x2, vce(robust) twostep
```

Arellano–Bond estimation also including 2 lagged values of `y`

```
xtabond y x1 x2, lags(2)
```

## Menu

Statistics > Longitudinal/panel data > Dynamic panel data (DPD) > Arellano–Bond estimation

## Syntax

**xtabond** *depvar* [ *indepvars* ] [ *if* ] [ *in* ] [ , *options* ]

<i>options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term
<u>diffvars(</u> <i>varlist</i> <u>)</u>	already-differenced exogenous variables
<u>inst(</u> <i>varlist</i> <u>)</u>	additional instrument variables
<u>lags(</u> # <u>)</u>	use # lags of dependent variable as covariates; default is <u>lags(1)</u>
<u>maxldep(</u> # <u>)</u>	maximum lags of dependent variable for use as instruments
<u>maxlags(</u> # <u>)</u>	maximum lags of predetermined and endogenous variables for use as instruments
<u>twostep</u>	compute the two-step estimator instead of the one-step estimator
<b>Predetermined</b>	
<u>pre(</u> <i>varlist</i> <u>[ . . . ]</u>	predetermined variables; can be specified more than once
<b>Endogenous</b>	
<u>endogenous(</u> <i>varlist</i> <u>[ . . . ]</u>	endogenous variables; can be specified more than once
<b>SE/Robust</b>	
<u>vce(</u> <i>vcetype</i> <u>)</u>	<i>vcetype</i> may be <u>gmm</u> or <u>robust</u>
<b>Reporting</b>	
<u>level(</u> # <u>)</u>	set confidence level; default is <u>level(95)</u>
<u>artests(</u> # <u>)</u>	use # as maximum order for AR tests; default is <u>artests(2)</u>
<u>display_options</u>	control spacing and line width
<u>coeflegend</u>	display legend instead of statistics

A panel variable and a time variable must be specified; use **xtset**; see [XT] **xtset**.

*indepvars* and all *varlists*, except pre(*varlist*[ . . . ]) and endogenous(*varlist*[ . . . ]), may contain time-series operators; see [U] **11.4.4 Time-series varlists**. The specification of *depvar* may not contain time-series operators.

*by*, *statsby*, and *xi* are allowed; see [U] **11.1.10 Prefix commands**.

*coeflegend* does not appear in the dialog box.

See [U] **20 Estimation and postestimation commands** for more capabilities of estimation commands.

## Options

### Model

noconstant; see [R] **Estimation options**.

diffvars(*varlist*) specifies a set of variables that already have been differenced to be included as strictly exogenous covariates. diffvars() may not be used for models with a constant or models for which level-equation instruments are specified.

inst(*varlist*) specifies a set of variables to be used as additional instruments. These instruments are not differenced by **xtabond** before including them in the instrument matrix.

lags(#) sets *p*, the number of lags of the dependent variable to be included in the model. The default is *p* = 1.

`maxldep(#)` sets the maximum number of lags of the dependent variable that can be used as instruments. The default is to use all  $T_i - p - 2$  lags.

`maxlags(#)` sets the maximum number of lags of the predetermined and endogenous variables that can be used as instruments. For predetermined variables, the default is to use all  $T_i - p - 1$  lags. For endogenous variables, the default is to use all  $T_i - p - 2$  lags.

`twostep` specifies that the two-step estimator be calculated.

#### Predetermined

`pre(varlist[, lagstruct(prelags, premaxlags)])` specifies that a set of predetermined variables be included in the model. Optionally, you may specify that `prelags` lags of the specified variables also be included. The default for `prelags` is 0. Specifying `premaxlags` sets the maximum number of further lags of the predetermined variables that can be used as instruments. The default is to include  $T_i - p - 1$  lagged levels as instruments for predetermined variables. You may specify as many sets of predetermined variables as you need within the standard Stata limits on matrix size. Each set of predetermined variables may have its own number of `prelags` and `premaxlags`.

#### Endogenous

`endogenous(varlist[, lagstruct(endlags, endmaxlags)])` specifies that a set of endogenous variables be included in the model. Optionally, you may specify that `endlags` lags of the specified variables also be included. The default for `endlags` is 0. Specifying `endmaxlags` sets the maximum number of further lags of the endogenous variables that can be used as instruments. The default is to include  $T_i - p - 2$  lagged levels as instruments for endogenous variables. You may specify as many sets of endogenous variables as you need within the standard Stata limits on matrix size. Each set of endogenous variables may have its own number of `endlags` and `endmaxlags`.

#### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory and that are robust to some kinds of misspecification; see *Remarks and examples* below.

`vce(gmm)`, the default, uses the conventionally derived variance estimator for generalized method of moments estimation.

`vce(robust)` uses the robust estimator. After one-step estimation, this is the Arellano–Bond robust VCE estimator. After two-step estimation, this is the Windmeijer (2005) WC-robust estimator.

#### Reporting

`level(#);` see [R] **Estimation options**.

`artests(#)` specifies the maximum order of the autocorrelation test to be calculated. The tests are reported by `estat abond`; see [XT] **xtabond postestimation**. Specifying the order of the highest test at estimation time is more efficient than specifying it to `estat abond`, because `estat abond` must refit the model to obtain the test statistics. The maximum order must be less than or equal to the number of periods in the longest panel. The default is `artests(2)`.

`display_options`: `vsquish` and `nolstretch`; see [R] **Estimation options**.

The following option is available with `xtabond` but is not shown in the dialog box:

`coeflegend`; see [R] **Estimation options**.

## Remarks and examples

Linear dynamic panel-data models include  $p$  lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random. By construction, the unobserved panel-level effects are correlated with the lagged dependent variables, making standard estimators inconsistent. [Arellano and Bond \(1991\)](#) derived a consistent generalized method of moments (GMM) estimator for the parameters of this model; **xtabond** implements this estimator.

[Anderson and Hsiao \(1981, 1982\)](#) propose using further lags of the level or the difference of the dependent variable to instrument the lagged dependent variables that are included in a dynamic panel-data model after the panel-level effects have been removed by first-differencing. A version of this estimator can be obtained from **xtivreg** (see [\[XT\] xtivreg](#)). [Arellano and Bond \(1991\)](#) build upon this idea by noting that, in general, there are many more instruments available. Building on [Holtz-Eakin, Newey, and Rosen \(1988\)](#) and using the GMM framework developed by [Hansen \(1982\)](#), they identify how many lags of the dependent variable, the predetermined variables, and the endogenous variables are valid instruments and how to combine these lagged levels with first differences of the strictly exogenous variables into a potentially large instrument matrix. Using this instrument matrix, [Arellano and Bond \(1991\)](#) derive the corresponding one-step and two-step GMM estimators, as well as the robust VCE estimator for the one-step model. They also found that the robust two-step VCE was seriously biased. [Windmeijer \(2005\)](#) worked out a bias-corrected (WC) robust estimator for VCEs of two-step GMM estimators, which is implemented in **xtabond**. The test of autocorrelation of order  $m$  and the Sargan test of overidentifying restrictions derived by [Arellano and Bond \(1991\)](#) can be obtained with **estat abond** and **estat sargan**, respectively; see [\[XT\] xtabond postestimation](#).

The Arellano–Bond estimator is designed for datasets with many panels and few periods, and it requires that there be no autocorrelation in the idiosyncratic errors. For a related estimator that uses additional moment conditions, but still requires no autocorrelation in the idiosyncratic errors, see [\[XT\] xtdpdsys](#). For estimators that allow for some autocorrelation in the idiosyncratic errors, at the cost of a more complicated syntax, see [\[XT\] xtdpd](#).

### ▷ Example 1: One-step estimator

[Arellano and Bond \(1991\)](#) apply their new estimators and test statistics to a model of dynamic labor demand that had previously been considered by [Layard and Nickell \(1986\)](#) using data from an unbalanced panel of firms from the United Kingdom. All variables are indexed over the firm  $i$  and time  $t$ . In this dataset,  $n_{it}$  is the log of employment in firm  $i$  at time  $t$ ,  $w_{it}$  is the natural log of the real product wage,  $k_{it}$  is the natural log of the gross capital stock, and  $y_{s_it}$  is the natural log of industry output. The model also includes time dummies  $yr1980$ ,  $yr1981$ ,  $yr1982$ ,  $yr1983$ , and  $yr1984$ . In table 4 of [Arellano and Bond \(1991\)](#), the authors present the results they obtained from several specifications.

In column a1 of table 4, Arellano and Bond report the coefficients and their standard errors from the robust one-step estimators of a dynamic model of labor demand in which  $n_{it}$  is the dependent variable and its first two lags are included as regressors. To clarify some important issues, we will begin with the homoskedastic one-step version of this model and then consider the robust case. Here is the command using **xtabond** and the subsequent output for the homoskedastic case:

. use https://www.stata-press.com/data/r16/abdata						
. xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year, lags(2) noconstant						
Arellano-Bond dynamic panel-data estimation	Number of obs	=	611			
Group variable: id	Number of groups	=	140			
Time variable: year						
	Obs per group:					
	min =	4				
	avg =	4.364286				
	max =	6				
Number of instruments =	41					
	Wald chi2(16)	=	1757.07			
	Prob > chi2	=	0.0000			
One-step results						
n	Coef.	Std. Err.	z	P> z	[95% Conf.	Interval]
n						
L1.	.6862261	.1486163	4.62	0.000	.3949435	.9775088
L2.	-.0853582	.0444365	-1.92	0.055	-.1724523	.0017358
w						
--.	-.6078208	.0657694	-9.24	0.000	-.7367265	-.4789151
L1.	.3926237	.1092374	3.59	0.000	.1785222	.6067251
k						
--.	.3568456	.0370314	9.64	0.000	.2842653	.4294259
L1.	-.0580012	.0583051	-0.99	0.320	-.172277	.0562747
L2.	-.0199475	.0416274	-0.48	0.632	-.1015357	.0616408
ys						
--.	.6085073	.1345412	4.52	0.000	.3448115	.8722031
L1.	-.7111651	.1844599	-3.86	0.000	-1.0727	-.3496304
L2.	.1057969	.1428568	0.74	0.459	-.1741974	.3857912
yr1980	.0029062	.0212705	0.14	0.891	-.0387832	.0445957
yr1981	-.0404378	.0354707	-1.14	0.254	-.1099591	.0290836
yr1982	-.0652767	.048209	-1.35	0.176	-.1597646	.0292111
yr1983	-.0690928	.0627354	-1.10	0.271	-.1920521	.0538664
yr1984	-.0650302	.0781322	-0.83	0.405	-.2181665	.0881061
year	.0095545	.0142073	0.67	0.501	-.0182912	.0374002

Instruments for differenced equation

GMM-type: L(2/.).n

Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1980

D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year

The coefficients are identical to those reported in column a1 of table 4, as they should be. Of course, the standard errors are different because we are considering the homoskedastic case. Although the moment conditions use first-differenced errors, `xtabond` estimates the coefficients of the level model and reports them accordingly.

The footer in the output reports the instruments used. The first line indicates that `xtabond` used lags from 2 on back to create the GMM-type instruments described in Arellano and Bond (1991) and Holtz-Eakin, Newey, and Rosen (1988); also see *Methods and formulas* in [XT] `xtdpd`. The second and third lines indicate that the first difference of all the exogenous variables were used as standard instruments. GMM-type instruments use the lags of a variable to contribute multiple columns to the instrument matrix, whereas each standard instrument contributes one column to the instrument matrix. The notation `L(2/.).n` indicates that GMM-type instruments were created using lag 2 of `n` from on back. (`L(2/4).n` would indicate that GMM-type instruments were created using only lags 2, 3, and 4 of `n`.)

After **xtabond**, **estat sargan** reports the Sargan test of overidentifying restrictions.

```
. estat sargan
Sargan test of overidentifying restrictions
    H0: overidentifying restrictions are valid
        chi2(25)      =   65.81806
        Prob > chi2   =   0.0000
```

Only for a homoskedastic error term does the Sargan test have an asymptotic chi-squared distribution. In fact, [Arellano and Bond \(1991\)](#) show that the one-step Sargan test overrejects in the presence of heteroskedasticity. Because its asymptotic distribution is not known under the assumptions of the `vce(robust)` model, **xtabond** does not compute it when `vce(robust)` is specified. The Sargan test, reported by [Arellano and Bond \(1991, table 4, column a1\)](#), comes from the one-step homoskedastic estimator and is the same as the one reported here. The output above presents strong evidence against the null hypothesis that the overidentifying restrictions are valid. Rejecting this null hypothesis implies that we need to reconsider our model or our instruments, unless we attribute the rejection to heteroskedasticity in the data-generating process. Although performing the Sargan test after the two-step estimator is an alternative, [Arellano and Bond \(1991\)](#) found a tendency for this test to underreject in the presence of heteroskedasticity. (See [XT] **xtdpd** for an [example](#) indicating that this rejection may be due to misspecification.)

By default, **xtabond** calculates the Arellano–Bond test for first- and second-order autocorrelation in the first-differenced errors. (Use `artests()` to compute tests for higher orders.) There are versions of this test for both the homoskedastic and the robust cases, although their values are different. Use `estat abond` to report the test results.

```
. estat abond
Arellano-Bond test for zero autocorrelation in first-differenced errors
```

Order	z	Prob > z
1	-3.9394	0.0001
2	-.54239	0.5876

H0: no autocorrelation

When the idiosyncratic errors are independent and identically distributed (i.i.d.), the first-differenced errors are first-order serially correlated. So, as expected, the output above presents strong evidence against the null hypothesis of zero autocorrelation in the first-differenced errors at order 1. Serial correlation in the first-differenced errors at an order higher than 1 implies that the moment conditions used by **xtabond** are not valid; see [XT] **xtdpd** for an [example](#) of an alternative estimation method. The output above presents no significant evidence of serial correlation in the first-differenced errors at order 2.



► Example 2: A one-step estimator with robust VCE

Consider the output from the one-step robust estimator of the same model:

```
. xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year, lags(2) vce(robust)
> noconstant

Arellano-Bond dynamic panel-data estimation      Number of obs      =      611
Group variable: id                          Number of groups   =      140
Time variable: year

Obs per group:
    min =          4
    avg =     4.364286
    max =          6

Number of instruments =      41                  Wald chi2(16)    =    1727.45
                                                               Prob > chi2    =    0.0000
```

One-step results

(Std. Err. adjusted for clustering on id)

n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]
n					
L1.	.6862261	.1445943	4.75	0.000	.4028266 .9696257
L2.	-.0853582	.0560155	-1.52	0.128	-.1951467 .0244302
w					
--.	-.6078208	.1782055	-3.41	0.001	-.9570972 -.2585445
L1.	.3926237	.1679931	2.34	0.019	.0633632 .7218842
k					
--.	.3568456	.0590203	6.05	0.000	.241168 .4725233
L1.	-.0580012	.0731797	-0.79	0.428	-.2014308 .0854284
L2.	-.0199475	.0327126	-0.61	0.542	-.0840631 .0441681
ys					
--.	.6085073	.1725313	3.53	0.000	.2703522 .9466624
L1.	-.7111651	.2317163	-3.07	0.002	-1.165321 -.2570095
L2.	.1057969	.1412021	0.75	0.454	-.1709542 .382548
yr1980	.0029062	.0158028	0.18	0.854	-.0280667 .0338791
yr1981	-.0404378	.0280582	-1.44	0.150	-.0954307 .0145552
yr1982	-.0652767	.0365451	-1.79	0.074	-.1369038 .0063503
yr1983	-.0690928	.047413	-1.46	0.145	-.1620205 .0238348
yr1984	-.0650302	.0576305	-1.13	0.259	-.1779839 .0479235
year	.0095545	.0102896	0.93	0.353	-.0106127 .0297217

Instruments for differenced equation

GMM-type: L(2/.).n

Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1980

D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year

The coefficients are the same, but now the standard errors match that reported in [Arellano and Bond \(1991, table 4, column a1\)](#). Most of the robust standard errors are higher than those that assume a homoskedastic error term.

The Sargan statistic cannot be calculated after requesting a robust VCE, but robust tests for serial correlation are available.

```
. estat abond  
Arellano-Bond test for zero autocorrelation in first-differenced errors
```

Order	z	Prob > z
1	-3.5996	0.0003
2	-.51603	0.6058

H0: no autocorrelation

The value of the test for second-order autocorrelation matches those reported in [Arellano and Bond \(1991\)](#), table 4, column a1) and presents no evidence of model misspecification.



## ▷ Example 3: The Wald model test

`xtabond` reports the Wald statistic of the null hypothesis that all the coefficients except the constant are zero. Here the null hypothesis is that all the coefficients are zero, because there is no constant in the model. In our [previous example](#), the null hypothesis is soundly rejected. In column a1 of table 4, Arellano and Bond report a chi-squared test of the null hypothesis that all the coefficients are zero, except the time trend and the time dummies. Here is this test in Stata:

```
. test l.n 12.n w 1.w k 1.k 12.k ys 1.ys 12.ys  
( 1) L.n = 0  
( 2) L2.n = 0  
( 3) w = 0  
( 4) L.w = 0  
( 5) k = 0  
( 6) L.k = 0  
( 7) L2.k = 0  
( 8) ys = 0  
( 9) L.ys = 0  
(10) L2.ys = 0  
  
chi2( 10) =  408.29  
Prob > chi2 =  0.0000
```



## ▷ Example 4: A two-step estimator with Windmeijer bias-corrected robust VCE

The two-step estimator with the Windmeijer bias-corrected robust VCE of the same model produces the following output:

```
. xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year, lags(2) twostep
> vce(robust) noconstant

Arellano-Bond dynamic panel-data estimation      Number of obs      =      611
Group variable: id                          Number of groups   =      140
Time variable: year

Obs per group:
min =          4
avg =    4.364286
max =          6

Number of instruments =      41           Wald chi2(16)     =    1104.72
                                         Prob > chi2    =      0.0000

Two-step results
(Std. Err. adjusted for clustering on id)
```

n	Coef.	WC-Robust Std. Err.	z	P> z	[95% Conf. Interval]
n					
L1.	.6287089	.1934138	3.25	0.001	.2496248 1.007793
L2.	-.0651882	.0450501	-1.45	0.148	-.1534847 .0231084
w					
--.	-.5257597	.1546107	-3.40	0.001	-.828791 -.2227284
L1.	.3112899	.2030006	1.53	0.125	-.086584 .7091638
k					
--.	.2783619	.0728019	3.82	0.000	.1356728 .4210511
L1.	.0140994	.0924575	0.15	0.879	-.167114 .1953129
L2.	-.0402484	.0432745	-0.93	0.352	-.1250649 .0445681
ys					
--.	.5919243	.1730916	3.42	0.001	.252671 .9311776
L1.	-.5659863	.2611008	-2.17	0.030	-1.077734 -.0542381
L2.	.1005433	.1610987	0.62	0.533	-.2152043 .4162908
yr1980	.0006378	.0168042	0.04	0.970	-.0322978 .0335734
yr1981	-.0550044	.0313389	-1.76	0.079	-.1164275 .0064187
yr1982	-.075978	.0419276	-1.81	0.070	-.1581545 .0061986
yr1983	-.0740708	.0528381	-1.40	0.161	-.1776315 .02949
yr1984	-.0906606	.0642615	-1.41	0.158	-.2166108 .0352896
year	.0112155	.0116783	0.96	0.337	-.0116735 .0341045

## Instruments for differenced equation

GMM-type: L(2/.).n

Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1980

D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year

Arellano and Bond recommend against using the two-step nonrobust results for inference on the coefficients because the standard errors tend to be biased downward (see [Arellano and Bond 1991](#) for details). The output above uses the Windmeijer bias-corrected (WC) robust VCE, which [Windmeijer \(2005\)](#) showed to work well. The magnitudes of several of the coefficient estimates have changed, and one even switched its sign.

The test for autocorrelation presents no evidence of model misspecification:

```
. estat abond
Arellano-Bond test for zero autocorrelation in first-differenced errors
```

Order	z	Prob > z
1	-2.1255	0.0335
2	-.35166	0.7251

H0: no autocorrelation



Manuel Arellano (1957– ) was born in Elda in Alicante, Spain. He earned degrees in economics from the University of Barcelona and the London School of Economics. After various posts in Oxford and London, he returned to Spain as professor of econometrics at Madrid in 1991. He is a leading expert on panel-data econometrics.

Stephen Roy Bond (1963– ) earned degrees in economics from Cambridge and Oxford. Following various posts at Oxford, he now works mainly at the Institute for Fiscal Studies in London. His research interests include company taxation, dividends, and the links between financial markets, corporate control, and investment.

## ▷ Example 5: Including an estimator for the constant

Thus far we have been specifying the `noconstant` option to keep to the standard Arellano–Bond estimator, which uses instruments only for the difference equation. The constant estimated by `xtabond` is a constant in the level equation, and it is estimated from the level errors. The output below illustrates that including a constant in the model does not affect the other parameter estimates.

```
. xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year, lags(2) twostep vce(robust)
Arellano-Bond dynamic panel-data estimation      Number of obs      =       611
Group variable: id                          Number of groups   =       140
Time variable: year
                                                Obs per group:
                                                min =            4
                                                avg = 4.364286
                                                max =            6
Number of instruments =      42          Wald chi2(16)    =     1104.72
                                                Prob > chi2      =     0.0000
Two-step results
(Std. Err. adjusted for clustering on id)
```

n	WC-Robust					
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.6287089	.1934138	3.25	0.001	.2496248	1.007793
L2.	-.0651882	.0450501	-1.45	0.148	-.1534847	.0231084
w						
--.	-.5257597	.1546107	-3.40	0.001	-.828791	-.2227284
L1.	.3112899	.2030006	1.53	0.125	-.086584	.7091638
k						
--.	.2783619	.0728019	3.82	0.000	.1356728	.4210511
L1.	.0140994	.0924575	0.15	0.879	-.167114	.1953129
L2.	-.0402484	.0432745	-0.93	0.352	-.1250649	.0445681
ys						
--.	.5919243	.1730916	3.42	0.001	.252671	.9311776
L1.	-.5659863	.2611008	-2.17	0.030	-1.077734	-.0542381
L2.	.1005433	.1610987	0.62	0.533	-.2152043	.4162908
yr1980	.0006378	.0168042	0.04	0.970	-.0322978	.0335734
yr1981	-.0550044	.0313389	-1.76	0.079	-.1164275	.0064187
yr1982	-.075978	.0419276	-1.81	0.070	-.1581545	.0061986
yr1983	-.0740708	.0528381	-1.40	0.161	-.1776315	.02949
yr1984	-.0906606	.0642615	-1.41	0.158	-.2166108	.0352896
year	.0112155	.0116783	0.96	0.337	-.0116735	.0341045
_cons	-21.53725	23.23138	-0.93	0.354	-67.06992	23.99542

Instruments for differenced equation

GMM-type: L(2/.).n

Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1980

D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year

Instruments for level equation

Standard: \_cons

Including the constant does not affect the other parameter estimates because it is identified only by the level errors; see [XT] **xtdpd** for details.

◀

► Example 6: Including predetermined covariates

Sometimes we cannot assume strict exogeneity. Recall that a variable,  $x_{it}$ , is said to be strictly exogenous if  $E[x_{it}\epsilon_{is}] = 0$  for all  $t$  and  $s$ . If  $E[x_{it}\epsilon_{is}] \neq 0$  for  $s < t$  but  $E[x_{it}\epsilon_{is}] = 0$  for all  $s \geq t$ , the variable is said to be predetermined. Intuitively, if the error term at time  $t$  has some feedback on the subsequent realizations of  $x_{it}$ ,  $x_{it}$  is a predetermined variable. Because unforecastable errors today might affect future changes in the real wage and in the capital stock, we might suspect that the log of the real product wage and the log of the gross capital stock are predetermined instead of strictly exogenous. Here we treat **w** and **k** as predetermined and use lagged levels as instruments.

```
. xtabond n 1(0/1).ys yr1980-yr1984 year, lags(2) twostep pre(w, lag(1,.))
> pre(k, lag(2,.)) noconstant vce(robust)

Arellano-Bond dynamic panel-data estimation      Number of obs      =       611
Group variable: id                          Number of groups   =        140
Time variable: year

Obs per group:
min =           4
avg =      4.364286
max =           6

Number of instruments =     83          Wald chi2(15)      =     958.30
                                         Prob > chi2      =     0.0000

Two-step results
(Std. Err. adjusted for clustering on id)
```

n	Coef.	WC-Robust Std. Err.	z	P> z	[95% Conf. Interval]
n					
L1.	.8580958	.1265515	6.78	0.000	.6100594 1.106132
L2.	-.081207	.0760703	-1.07	0.286	-.2303022 .0678881
w					
--.	-.6910855	.1387684	-4.98	0.000	-.9630666 -.4191044
L1.	.5961712	.1497338	3.98	0.000	.3026982 .8896441
k					
--.	.4140654	.1382788	2.99	0.003	.1430439 .6850868
L1.	-.1537048	.1220244	-1.26	0.208	-.3928681 .0854586
L2.	-.1025833	.0710886	-1.44	0.149	-.2419143 .0367477
ys					
--.	.6936392	.1728623	4.01	0.000	.3548354 1.032443
L1.	-.8773678	.2183085	-4.02	0.000	-1.305245 -.449491
yr1980	-.0072451	.017163	-0.42	0.673	-.0408839 .0263938
yr1981	-.0609608	.030207	-2.02	0.044	-.1201655 -.0017561
yr1982	-.1130369	.0454826	-2.49	0.013	-.2021812 -.0238926
yr1983	-.1335249	.0600213	-2.22	0.026	-.2511645 -.0158853
yr1984	-.1623177	.0725434	-2.24	0.025	-.3045001 -.0201352
year	.0264501	.0119329	2.22	0.027	.003062 .0498381

Instruments for differenced equation

GMM-type: L(2/.).n L(1/.).L.w L(1/.).L2.k  
 Standard: D.ys LD.ys D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984  
 D.year

The footer informs us that we are now including GMM-type instruments from the first lag of L.w on back and from the first lag of L2.k on back.



## □ Technical note

The above example illustrates that `xtabond` understands `pre(w, lag(1, .))` to mean that `L.w` is a predetermined variable and `pre(k, lag(2, .))` to mean that `L2.k` is a predetermined variable. This is a stricter definition than the alternative that `pre(w, lag(1, .))` means only that `w` is predetermined but includes a lag of `w` in the model and that `pre(k, lag(2, .))` means only that `k` is predetermined but includes first and second lags of `k` in the model. If you prefer the weaker definition, `xtabond` still gives you consistent estimates, but it is not using all possible instruments; see [XT] `xtdpd` for an [example](#) of how to include all possible instruments. □

## ▷ Example 7: Including endogenous covariates

We might instead suspect that `w` and `k` are endogenous in that  $E[x_{it}\epsilon_{is}] \neq 0$  for  $s \leq t$  but  $E[x_{it}\epsilon_{is}] = 0$  for all  $s > t$ . By this definition, endogenous variables differ from predetermined variables only in that the former allow for correlation between the  $x_{it}$  and the  $\epsilon_{it}$  at time  $t$ , whereas the latter do not. Endogenous variables are treated similarly to the lagged dependent variable. Levels of the endogenous variables lagged two or more periods can serve as instruments. In this example, we treat `w` and `k` as endogenous variables.

. xtabond n l(0/1).ys yr1980-yr1984 year, lags(2) twostep > endogenous(w, lag(1,.)) endogenous(k, lag(2,.)) noconstant vce(robust)						
Arellano–Bond dynamic panel-data estimation	Number of obs = 611					
Group variable: id	Number of groups = 140					
Time variable: year						
	Obs per group:					
	min = 4					
	avg = 4.364286					
	max = 6					
Number of instruments = 71	Wald chi2(15) = 967.61					
	Prob > chi2 = 0.0000					
Two-step results	(Std. Err. adjusted for clustering on id)					
n	Coef.	WC-Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.6640937	.1278908	5.19	0.000	.4134323	.914755
L2.	-.041283	.081801	-0.50	0.614	-.2016101	.1190441
w						
--.	-.7143942	.13083	-5.46	0.000	-.9708162	-.4579721
L1.	.3644198	.184758	1.97	0.049	.0023008	.7265388
k						
--.	.5028874	.1205419	4.17	0.000	.2666296	.7391452
L1.	-.2160842	.0972855	-2.22	0.026	-.4067603	-.025408
L2.	-.0549654	.0793673	-0.69	0.489	-.2105225	.1005917
ys						
--.	.5989356	.1779731	3.37	0.001	.2501148	.9477564
L1.	-.6770367	.1961166	-3.45	0.001	-1.061418	-.2926553
yr1980	-.0061122	.0155287	-0.39	0.694	-.0365478	.0243235
yr1981	-.04715	.0298348	-1.58	0.114	-.1056252	.0113251
yr1982	-.0817646	.0486049	-1.68	0.093	-.1770285	.0134993
yr1983	-.0939251	.0675804	-1.39	0.165	-.2263802	.0385299
yr1984	-.117228	.0804716	-1.46	0.145	-.2749493	.0404934
year	.0208857	.0103485	2.02	0.044	.0006031	.0411684

**Instruments for differenced equation**

GMM-type: L(2/.).n L(2/.).L.w L(2/.).L2.k  
 Standard: D.ys LD.ys D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984  
 D.year

Although some estimated coefficients changed in magnitude, none changed in sign, and these results are similar to those obtained by treating w and k as predetermined. ◇

The Arellano–Bond estimator is for datasets with many panels and few periods. (Technically, the large-sample properties are derived with the number of panels going to infinity and the number of periods held fixed.) The number of instruments increases quadratically in the number of periods. If your dataset is better described by a framework in which both the number of panels and the number of periods is large, then you should consider other estimators such as those in [XT] **xtivreg** or **xtreg**, **fe** in [XT] **xtreg**; see Alvarez and Arellano (2003) for a discussion of this case.

## ► Example 8: Restricting the number of instruments

Treating variables as predetermined or endogenous quickly increases the size of the instrument matrix. (See [Methods and formulas](#) in [XT] **xtdpd** for a discussion of how this matrix is created and what determines its size.) GMM estimators with too many overidentifying restrictions may perform poorly in small samples. (See [Kiviet 1995](#) for a discussion of the dynamic panel-data case.)

To handle these problems, you can set a maximum number of lagged levels to be included as instruments for lagged-dependent or the predetermined variables. Here is an example in which a maximum of three lagged levels of the predetermined variables are included as instruments:

```
. xtabond n 1(0/1).ys yr1980-yr1984 year, lags(2) twostep
> pre(w, lag(1,3)) pre(k, lag(2,3)) noconstant vce(robust)

Arellano-Bond dynamic panel-data estimation      Number of obs      =      611
Group variable: id                          Number of groups   =      140
Time variable: year

Obs per group:
    min =          4
    avg =     4.364286
    max =          6

Number of instruments =      67              Wald chi2(15)     =     1116.89
                                                Prob > chi2       =     0.0000
```

### Two-step results

(Std. Err. adjusted for clustering on id)

n	Coef.	WC-Robust Std. Err.	z	P> z	[95% Conf. Interval]
n					
L1.	.931121	.1456964	6.39	0.000	.6455612 1.216681
L2.	-.0759918	.0854356	-0.89	0.374	-.2434425 .0914589
w					
--.	-.6475372	.1687931	-3.84	0.000	-.9783656 -.3167089
L1.	.6906238	.1789698	3.86	0.000	.3398493 1.041398
k					
--.	.3788106	.1848137	2.05	0.040	.0165824 .7410389
L1.	-.2158533	.1446198	-1.49	0.136	-.4993028 .0675962
L2.	-.0914584	.0852267	-1.07	0.283	-.2584997 .0755829
ys					
--.	.7324964	.176748	4.14	0.000	.3860766 1.078916
L1.	-.9428141	.2735472	-3.45	0.001	-1.478957 -.4066715
yr1980	-.0102389	.0172473	-0.59	0.553	-.0440431 .0235652
yr1981	-.0763495	.0296992	-2.57	0.010	-.1345589 -.0181402
yr1982	-.1373829	.0441833	-3.11	0.002	-.2239806 -.0507853
yr1983	-.1825149	.0613674	-2.97	0.003	-.3027928 -.0622369
yr1984	-.2314023	.0753669	-3.07	0.002	-.3791186 -.083686
year	.0310012	.0119167	2.60	0.009	.0076448 .0543576

### Instruments for differenced equation

GMM-type: L(2/.).n L(1/3).L.w L(1/3).L2.k  
 Standard: D.yS LD.yS D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984  
 D.year



## ► Example 9: Missing observations in the middle of panels

**xtabond** handles data in which there are missing observations in the middle of the panels. In this example, we deliberately set the dependent variable to missing in the year 1980:

```
. replace n=. if year==1980
(140 real changes made, 140 to missing)

. xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year, lags(2) noconstant
> vce(robust)
note: yr1980 dropped from div() because of collinearity
note: yr1981 dropped from div() because of collinearity
note: yr1982 dropped from div() because of collinearity
note: yr1980 dropped because of collinearity
note: yr1981 dropped because of collinearity
note: yr1982 dropped because of collinearity

Arellano-Bond dynamic panel-data estimation      Number of obs      =      115
Group variable: id                          Number of groups   =      101
Time variable: year

Obs per group:
    min =           1
    avg =      1.138614
    max =           2

Number of instruments =      18          Wald chi2(12)     =      44.48
                                         Prob > chi2      =      0.0000

One-step results
(Std. Err. adjusted for clustering on id)
```

n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]
n					
L1.	.1790577	.2204682	0.81	0.417	-.253052 .6111674
L2.	.0214253	.0488476	0.44	0.661	-.0743143 .1171649
w					
--.	-.2513405	.1402114	-1.79	0.073	-.5261498 .0234689
L1.	.1983952	.1445875	1.37	0.170	-.0849912 .4817815
k					
--.	.3983149	.0883352	4.51	0.000	.2251811 .5714488
L1.	-.025125	.0909236	-0.28	0.782	-.203332 .1530821
L2.	-.0359338	.0623382	-0.58	0.564	-.1581144 .0862468
ys					
--.	.3663201	.3824893	0.96	0.338	-.3833451 1.115985
L1.	-.6319976	.4823958	-1.31	0.190	-1.577476 .3134807
L2.	.5318404	.4105269	1.30	0.195	-.2727775 1.336458
yr1983	-.0047543	.024855	-0.19	0.848	-.0534692 .0439606
yr1984	0	(omitted)			
year	.0014465	.010355	0.14	0.889	-.0188489 .0217419

Instruments for differenced equation  
GMM-type: L(2/.).n  
Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1983  
D.yr1984 D.year

There are two important aspects to this example. First, **xtabond** reports that variables have been dropped from the model and from the `div()` instrument list. For **xtabond**, the `div()` instrument list is the list of instruments created from the strictly exogenous variables; see [XT] **xtdpd** for more about the `div()` instrument list. Second, because **xtabond** uses time-series operators in its computations,

**if** statements and missing values are not equivalent. An **if** statement causes the false observations to be excluded from the sample, but it computes the time-series operators wherever possible. In contrast, missing data prevent evaluation of the time-series operators that involve missing observations. Thus the example above is not equivalent to the following one:

<pre>. use https://www.stata-press.com/data/r16/abdata, clear . xtabond n l(0/1).w l(0/2).(k ys) yr1980-yr1984 year if year!=1980, &gt; lags(2) noconstant vce(robust) note: yr1980 dropped from div() because of collinearity note: yr1980 dropped because of collinearity</pre>						
<p>Arellano-Bond dynamic panel-data estimation      Number of obs = 473      Group variable: id      Number of groups = 140      Time variable: year</p>						
<p>Obs per group:      min = 3      avg = 3.378571      max = 5</p>						
<p>Number of instruments = 37      Wald chi2(15) = 1041.61      Prob &gt; chi2 = 0.0000</p>						
<p>One-step results</p>						
<p>(Std. Err. adjusted for clustering on id)</p>						
n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.7210062	.1321214	5.46	0.000	.4620531	.9799593
L2.	-.0960646	.0570547	-1.68	0.092	-.2078898	.0157606
w						
--.	-.6684175	.1739484	-3.84	0.000	-1.00935	-.3274849
L1.	.482322	.1647185	2.93	0.003	.1594797	.8051642
k						
--.	.3802777	.0728546	5.22	0.000	.2374853	.5230701
L1.	-.104598	.088597	-1.18	0.238	-.278245	.069049
L2.	-.0272055	.0379994	-0.72	0.474	-.101683	.0472721
ys						
--.	.4655989	.1864368	2.50	0.013	.1001895	.8310082
L1.	-.8562492	.2187886	-3.91	0.000	-1.285067	-.4274315
L2.	.0896556	.1440035	0.62	0.534	-.192586	.3718972
yr1981	-.0711626	.0205299	-3.47	0.001	-.1114005	-.0309247
yr1982	-.1212749	.0334659	-3.62	0.000	-.1868669	-.0556829
yr1983	-.1470248	.0461714	-3.18	0.001	-.2375191	-.0565305
yr1984	-.1519021	.0543904	-2.79	0.005	-.2585054	-.0452988
year	.0203277	.0108732	1.87	0.062	-.0009833	.0416387

#### Instruments for differenced equation

GMM-type: L(2/.).n  
 Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1981  
 D.yr1982 D.yr1983 D.yr1984 D.year

The year 1980 is dropped from the sample, but when the value of a variable from 1980 is required because a lag or difference is required, the 1980 value is used.



## Stored results

`xtabond` stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(t_min)</code>	minimum time in sample
<code>e(t_max)</code>	maximum time in sample
<code>e(chi2)</code>	$\chi^2$
<code>e(arm#)</code>	test for autocorrelation of order #
<code>e(artests)</code>	number of AR tests computed
<code>e(sig2)</code>	estimate of $\sigma_\epsilon^2$
<code>e(rss)</code>	sum of squared differenced residuals
<code>e(sargan)</code>	Sargan test statistic
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(zrank)</code>	rank of instrument matrix

### Macros

<code>e(cmd)</code>	<code>xtabond</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(twostep)</code>	<code>twostep</code> , if specified
<code>e(ivars)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(system)</code>	<code>system</code> , if system estimator
<code>e(transform)</code>	specified transform
<code>e(diffvars)</code>	already-differenced exogenous variables
<code>e(datasignature)</code>	checksum from <code>datasignature</code>
<code>e(datasignaturevars)</code>	variables used in calculation of checksum
<code>e(properties)</code>	<code>b V</code>
<code>e(estat_cmd)</code>	program used to implement <code>estat</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>

### Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

A dynamic panel-data model has the form

$$y_{it} = \sum_{j=1}^p \alpha_j y_{i,t-j} + \mathbf{x}_{it}\boldsymbol{\beta}_1 + \mathbf{w}_{it}\boldsymbol{\beta}_2 + \nu_i + \epsilon_{it} \quad i = 1, \dots, N \quad t = 1, \dots, T_i \quad (1)$$

where

the  $\alpha_j$  are  $p$  parameters to be estimated,  
 $\mathbf{x}_{it}$  is a  $1 \times k_1$  vector of strictly exogenous covariates,  
 $\beta_1$  is a  $k_1 \times 1$  vector of parameters to be estimated,  
 $\mathbf{w}_{it}$  is a  $1 \times k_2$  vector of predetermined and endogenous covariates,  
 $\beta_2$  is a  $k_2 \times 1$  vector of parameters to be estimated,  
 $\nu_i$  are the panel-level effects (which may be correlated with the covariates), and  
 $\epsilon_{it}$  are i.i.d. over the whole sample with variance  $\sigma_\epsilon^2$ .

The  $\nu_i$  and the  $\epsilon_{it}$  are assumed to be independent for each  $i$  over all  $t$ .

By construction, the lagged dependent variables are correlated with the unobserved panel-level effects, making standard estimators inconsistent. With many panels and few periods, estimators are constructed by first-differencing to remove the panel-level effects and using instruments to form moment conditions.

`xtabond` uses a GMM estimator to estimate  $\alpha_1, \dots, \alpha_p, \beta_1$ , and  $\beta_2$ . The moment conditions are formed from the first-differenced errors from (1) and instruments. Lagged levels of the dependent variable, the predetermined variables, and the endogenous variables are used to form GMM-type instruments. See Arellano and Bond (1991) and Holtz-Eakin, Newey, and Rosen (1988) for discussions of GMM-type instruments. First differences of the strictly exogenous variables are used as standard instruments.

`xtabond` uses `xtdpd` to perform its computations, so the formulas are given in *Methods and formulas* of [XT] `xtdpd`.

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## Also see

- [XT] **xtabond postestimation** — Postestimation tools for xtabond
  - [XT] **xtdpd** — Linear dynamic panel-data estimation
  - [XT] **xtdpdsys** — Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation
  - [XT] **xtivreg** — Instrumental variables and two-stage least squares for panel-data models
  - [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
  - [XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance
  - [XT] **xtset** — Declare data to be panel data
- [U] **20 Estimation and postestimation commands**

**xtabond postestimation** — Postestimation tools for xtabond

Postestimation commands  
Remarks and examples

predict  
Methods and formulas

margins  
Reference

estat  
Also see

## Postestimation commands

The following postestimation commands are of special interest after `xtabond`:

Command	Description
<code>estat abond</code>	test for autocorrelation
<code>estat sargan</code>	Sargan test of overidentifying restrictions

The following standard postestimation commands are also available:

Command	Description
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from <code>margins</code> (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

```
predict [type] newvar [if] [in] [, xb e stdp difference]
```

### Options for predict

---

Main

---

`xb`, the default, calculates the linear prediction.

`e` calculates the residual error.

`stdp` calculates the standard error of the prediction, which can be thought of as the standard error of the predicted expected value or mean for the observation's covariate pattern. The standard error of the prediction is also referred to as the standard error of the fitted value. `stdp` may not be combined with `difference`.

`difference` specifies that the statistic be calculated for the first differences instead of the levels, the default.

## margins

### Description for margins

`margins` estimates margins of responses for linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [ marginlist ] [ , options ]
margins [ marginlist ] , predict(statistic ...) [ options ]
```

<i>statistic</i>	Description
<code>xb</code>	linear prediction; the default
<code>e</code>	not allowed with <code>margins</code>
<code>stdp</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

## estat

### Description for estat

`estat abond` reports the Arellano–Bond test for serial correlation in the first-differenced residuals.

`estat sargan` reports the Sargan test of the overidentifying restrictions.

### Menu for estat

Statistics > Postestimation

### Syntax for estat

*Test for autocorrelation*

```
estat abond [ , artests(#) ]
```

*Sargan test of overidentifying restrictions*

```
estat sargan
```

## Option for **estat abond**

`artests(#)` specifies the highest order of serial correlation to be tested. By default, the tests computed during estimation are reported. The model will be refit when `artests(#)` specifies a higher order than that computed during the original estimation. The model can only be refit if the data have not changed.

## Remarks and examples

Remarks are presented under the following headings:

`estat abond`  
`estat sargan`

### **estat abond**

`estat abond` reports the Arellano–Bond test for serial correlation in the first-differenced errors at order  $m$ . Rejecting the null hypothesis of no serial correlation in the first-differenced errors at order zero does not imply model misspecification because the first-differenced errors are serially correlated if the idiosyncratic errors are independent and identically distributed. Rejecting the null hypothesis of no serial correlation in the first-differenced errors at an order greater than one implies model misspecification; see [example 5](#) in [\[XT\] xtdpd](#) for an alternative estimator that allows for idiosyncratic errors that follow a first-order moving average process.

After the one-step system estimator, the test can be computed only when `vce(robust)` has been specified. (The system estimator is used to estimate the constant in `xtabond`.)

See [Remarks and examples](#) in [\[XT\] xtabond](#) for more remarks about `estat abond` that are made in the context of the examples analyzed therein.

### **estat sargan**

The distribution of the Sargan test is known only when the errors are independent and identically distributed. For this reason, `estat sargan` does not produce a test statistic when `vce(robust)` was specified in the call to `xtabond`.

See [Remarks and examples](#) in [\[XT\] xtabond](#) for more remarks about `estat sargan` that are made in the context of the examples analyzed therein.

## Methods and formulas

See [\[XT\] xtdpd postestimation](#) for the formulas.

## Reference

Pinzon, E. 2015. `xtabond` cheat sheet. *The Stata Blog: Not Elsewhere Classified*.  
<http://blog.stata.com/2015/11/12/xtabond-cheat-sheet/>.

## Also see

- [XT] **xtabond** — Arellano–Bond linear dynamic panel-data estimation
- [U] **20 Estimation and postestimation commands**

**xtcloglog** — Random-effects and population-averaged cloglog models

Description	Quick start	Menu	Syntax
Options for RE model	Options for PA model	Remarks and examples	Stored results
Methods and formulas	References	Also see	

## Description

`xtcloglog` fits population-averaged and random-effects complementary log-log (cloglog) models for a binary dependent variable. Complementary log-log models are typically used when one of the outcomes is rare relative to the other.

## Quick start

Random-effects complementary log-log regression of `y` on `x1` and `x2` using `xtset` data

```
xtcloglog y x1 x2
```

Add indicators for levels of categorical variable `a` and interact `x1` with `x2`

```
xtcloglog y x1 x2 c.x1#c.x2 i.a
```

As above, but suppress iteration log

```
xtcloglog y x1 x2 c.x1#c.x2 i.a, nolog
```

Population-averaged model with an exchangeable correlation structure

```
xtcloglog y x1 x2 c.x1#c.x2 i.a, pa
```

Random-effects model with bootstrap standard errors

```
xtcloglog y x1 x2 c.x1#c.x2 i.a, vce(bootstrap)
```

Population-averaged model with an autoregressive correlation structure of order 1

```
xtcloglog y x1 x2 c.x1#c.x2 i.a, pa corr(ar 1)
```

## Menu

Statistics > Longitudinal/panel data > Binary outcomes > Complementary log-log regression (RE, PA)

## Syntax

*Random-effects (RE) model*

```
xtcloglog depvar [indepvars] [if] [in] [weight] [, re RE_options]
```

*Population-averaged (PA) model*

```
xtcloglog depvar [indepvars] [if] [in] [weight], pa PA_options
```

<i>RE_options</i>	Description
<hr/>	
Model	
<u>noconstant</u>	suppress constant term
<u>re</u>	use random-effects estimator; the default
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> ( <i>constraints</i> )	apply specified linear constraints
<u>asis</u>	retain perfect predictor variables
SE/Robust	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>lrmodel</u>	perform the likelihood-ratio model test instead of the default Wald test
<u>eform</u>	report exponentiated coefficients
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> ( <i>intmethod</i> )	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is <u>intpoints</u> (12)
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

---

<i>PA_options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term
<u>pa</u>	use population-averaged estimator
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<u>asis</u>	retain perfect predictor variables
<b>Correlation</b>	
<u>corr</u> ( <i>correlation</i> )	within-panel correlation structure
<u>force</u>	estimate even if observations unequally spaced in time
<b>SE/Robust</b>	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be conventional, <u>robust</u> , <u>bootstrap</u> , or <u>jackknife</u>
<u>nmp</u>	use divisor $N - P$ instead of the default $N$
<u>scale</u> ( <i>parm</i> )	overrides the default scale parameter; <i>parm</i> may be x2, dev, phi, or #
<b>Reporting</b>	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>eform</u>	report exponentiated coefficients
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Optimization</b>	
<u>optimize_options</u>	control the optimization process; seldom used
<u>coeflegend</u>	display legend instead of statistics
<i>correlation</i>	Description
<u>exchangeable</u>	exchangeable; the default
<u>independent</u>	independent
<u>unstructured</u>	unstructured
<u>fixed</u> <i>matname</i>	user-specified
<u>ar</u> #	autoregressive of order #
<u>stationary</u> #	stationary of order #
<u>nonstationary</u> #	nonstationary of order #

A panel variable must be specified. For **xtcloglog**, pa, correlation structures other than exchangeable and independent require that a time variable also be specified. Use **xtset**; see [XT] **xtset**.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

by, mi estimate, and statsby are allowed; see [U] 11.1.10 Prefix commands. fp is allowed for the random-effects model.

vce(bootstrap) and vce(jackknife) are not allowed with the mi estimate prefix; see [MI] mi estimate.

iweights, fweights, and pweights are allowed for the population-averaged model, and iweights are allowed for the random-effects model; see [U] 11.1.6 weight. Weights must be constant within panel.

collinear and coeflegend do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options for RE model

### Model

`noconstant`; see [R] [Estimation options](#).

`re` requests the random-effects estimator, which is the default.

`offset(varname)`, `constraints(constraints)`; see [R] [Estimation options](#).

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] [probit](#).

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtcloglog](#), `re` and the `robust` VCE estimator in *Methods and formulas*.

### Reporting

`level(#)`, `lrmmodel`; see [R] [Estimation options](#).

`eform` displays the exponentiated coefficients and corresponding standard errors and confidence intervals.

`nocnsreport`; see [R] [Estimation options](#).

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

### Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] [Estimation options](#).

### Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `rtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] [Maximize](#). These options are seldom used.

The following options are available with `xtcloglog` but are not shown in the dialog box:  
`collinear`, `coeflegend`; see [R] [Estimation options](#).

## Options for PA model

### Model

`noconstant`; see [R] [Estimation options](#).

`pa` requests the population-averaged estimator.

`offset(varname)`; see [R] [Estimation options](#)

**asis** forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] **probit**.

#### Correlation

**corr**(*correlation*) specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, **corr(exchangeable)**.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, **corr(ar 1)** or **corr(ar1)**.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word **fixed**, for example, **corr(fixed myr)**.

**force** specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify **force**, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

#### SE/Robust

**vce**(*vcetype*) specifies the type of standard error reported, which includes types that are derived from asymptotic theory (**conventional**), that are robust to some kinds of misspecification (**robust**), and that use bootstrap or jackknife methods (**bootstrap**, **jackknife**); see [XT] **vce\_options**.

**vce(conventional)**, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

**nmp**, **scale(x2 | dev | phi | #)**; see [XT] **vce\_options**.

#### Reporting

**level(#)**; see [R] **Estimation options**.

**eform** displays the exponentiated coefficients and corresponding standard errors and confidence intervals.

**display\_options**: **noci**, **nopvalues**, **noomitted**, **vsquish**, **noemptycells**, **baselevels**, **allbaselevels**, **nofvlabel**, **fwrap(#)**, **fvwrapon(style)**, **cformat(%fmt)**, **pformat(%fmt)**, **sformat(%fmt)**, and **nolstretch**; see [R] **Estimation options**.

#### Optimization

**optimize\_options** control the iterative optimization process. These options are seldom used.

**iterate(#)** specifies the maximum number of iterations. When the number of iterations equals **#**, the optimization stops and presents the current results, even if convergence has not been reached. The default is **iterate(100)**.

**tolerance(#)** specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to **#**, the optimization process is stopped. **tolerance(1e-6)** is the default.

**log** and **nolog** specify whether to display the iteration log. The iteration log is displayed by default unless you used **set iterlog off** to suppress it; see **set iterlog** in [R] **set iter**.

**trace** specifies that the current estimates be printed at each iteration.

The following option is available with `xtcloglog` but is not shown in the dialog box:  
`coeflegend`; see [R] **Estimation options**.

## Remarks and examples

`xtcloglog` may be used to fit a population-averaged model or a random-effects complementary log-log (cloglog) model. There is no command for a conditional fixed-effects model, as there does not exist a sufficient statistic allowing the fixed effects to be conditioned out of the likelihood. Unconditional fixed-effects cloglog models may be fit with `cloglog` with indicator variables for the panels. However, unconditional fixed-effects estimates are biased. We do not discuss fixed-effects further in this entry.

By default, the population-averaged model is an equal-correlation model; that is, `xtcloglog`, `pa` assumes `corr(exchangeable)`. Thus, `xtcloglog`, `pa` is a shortcut command for fitting the population-averaged model using `xtgee`; see [XT] **xtgee**. Typing

```
. xtcloglog ..., pa ...
```

is equivalent to typing

```
. xtgee ..., ... family(binomial) link(cloglog) corr(exchangeable)
```

Also see [XT] **xtgee** for information about `xtcloglog`.

By default or when `re` is specified, `xtcloglog` fits, via maximum likelihood, the random-effects model

$$\Pr(y_{it} \neq 0 | \mathbf{x}_{it}) = P(\mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

for  $i = 1, \dots, n$  panels, where  $t = 1, \dots, n_i$ ,  $\nu_i$  are i.i.d.,  $N(0, \sigma_\nu^2)$ , and  $P(z) = 1 - \exp\{-\exp(z)\}$ .

Underlying this model is the variance-components model

$$y_{it} \neq 0 \iff \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} > 0$$

where  $\epsilon_{it}$  are i.i.d. extreme-value (Gumbel) distributed with the mean equal to Euler's constant and variance  $\sigma_\epsilon^2 = \pi^2/6$ , independently of  $\nu_i$ . The nonsymmetric error distribution is an alternative to logit and probit analysis and is typically used when the positive (or negative) outcome is rare.

## ► Example 1

Suppose that we are studying unionization of women in the United States and are using the union dataset; see [XT] xt. We wish to fit a random-effects model of union membership:

```

. use https://www.stata-press.com/data/r16/union
(NLS Women 14-24 in 1968)

. xtcloglog union age grade not_smsa south##c.year
(output omitted)

Random-effects complementary log-log model           Number of obs     =    26,200
Group variable: idcode                            Number of groups  =    4,434
Random effects u_i ~ Gaussian                     Obs per group:
                                                               min =          1
                                                               avg =        5.9
                                                               max =       12

Integration method: mvaghermite                  Integration pts. =     12
                                                               Wald chi2(6)      =   248.58
Log likelihood = -10535.928                      Prob > chi2     = 0.0000



| union        | Coef.     | Std. Err. | z     | P> z  | [95% Conf. Interval] |
|--------------|-----------|-----------|-------|-------|----------------------|
| age          | .0128659  | .0119004  | 1.08  | 0.280 | -.0104586 .0361903   |
| grade        | .06985    | .0138135  | 5.06  | 0.000 | .042776 .096924      |
| not_smsa     | -.198416  | .0647943  | -3.06 | 0.002 | -.3254104 -.0714215  |
| 1.south      | -2.047645 | .488965   | -4.19 | 0.000 | -3.005999 -1.089291  |
| year         | -.0006432 | .0123569  | -0.05 | 0.958 | -.0248623 .0235759   |
| south#c.year |           |           |       |       |                      |
| 1            | .0164259  | .006065   | 2.71  | 0.007 | .0045387 .0283132    |
| _cons        | -3.269158 | .659029   | -4.96 | 0.000 | -4.560831 -1.977485  |
| /lnsig2u     | 1.24128   | .0461705  |       |       | 1.150787 1.331772    |
| sigma_u      | 1.860118  | .0429413  |       |       | 1.77783 1.946214     |
| rho          | .677778   | .0100834  |       |       | .6577057 .6972152    |



LR test of rho=0: chibar2(01) = 6009.36          Prob >= chibar2 = 0.000


```

The output includes the additional panel-level variance component, which is parameterized as the log of the standard deviation,  $\ln\sigma_\nu$  (labeled `lnsig2u` in the output). The standard deviation  $\sigma_\nu$  is also included in the output, labeled `sigma_u`, together with  $\rho$  (labeled `xho`).

$$\rho = \frac{\sigma_\nu^2}{\sigma_\nu^2 + \sigma_e^2}$$

which is the proportion of the total variance contributed by the panel-level variance component.

When  $\rho$  is zero, the panel-level variance component is not important, and the panel estimator is no different from the pooled estimator (`cloglog`). A likelihood-ratio test of this is included at the bottom of the output, which formally compares the pooled estimator with the panel estimator.

As an alternative to the random-effects specification, you might want to fit an equal-correlation population-averaged cloglog model by typing

. xtcloglog union age grade not_smsa south##c.year, pa						
Iteration 1: tolerance = .11878399						
Iteration 2: tolerance = .01424628						
Iteration 3: tolerance = .00075278						
Iteration 4: tolerance = .00003195						
Iteration 5: tolerance = 1.661e-06						
Iteration 6: tolerance = 8.308e-08						
GEE population-averaged model				Number of obs	=	26,200
Group variable:	idcode			Number of groups	=	4,434
Link:	cloglog			Obs per group:		
Family:	binomial			min	=	1
Correlation:	exchangeable			avg	=	5.9
				max	=	12
				Wald chi2(6)	=	234.66
Scale parameter:	1			Prob > chi2	=	0.0000
union	Coef.	Std. Err.	z	P> z	[95% Conf.	Interval]
age	.0153737	.0081156	1.89	0.058	-.0005326	.03128
grade	.0549518	.0095093	5.78	0.000	.0363139	.0735897
not_smsa	-.1045232	.0431082	-2.42	0.015	-.1890138	-.0200326
1.south	-1.714868	.3384558	-5.07	0.000	-2.378229	-1.051507
year	-.0115881	.0084125	-1.38	0.168	-.0280763	.0049001
south##c.year						
1	.0149796	.0041687	3.59	0.000	.0068091	.0231501
_cons	-1.488278	.4468005	-3.33	0.001	-2.363991	-.6125652



## ▷ Example 2

In [R] **cloglog**, we showed these results and compared them with **cloglog**, **vce(cluster id)**. **xtcloglog** with the **pa** option allows a **vce(robust)** option so we can obtain the population-averaged cloglog estimator with the robust variance calculation by typing

```
. xtcloglog union age grade not_smsa south##c.year, pa vce(robust)
(output omitted)

GEE population-averaged model
Group variable: idcode          Number of obs     = 26,200
Link:           cloglog          Number of groups = 4,434
Family:         binomial         Obs per group:
Correlation:   exchangeable      min =           1
                           avg =        5.9
                           max =       12
                           Wald chi2(6) = 157.24
Scale parameter: 1             Prob > chi2 = 0.0000
                           (Std. Err. adjusted for clustering on idcode)
```

union	Semirobust					
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0153737	.0079446	1.94	0.053	-.0001974	.0309448
grade	.0549518	.0117258	4.69	0.000	.0319697	.077934
not_smsa	-.1045232	.0548598	-1.91	0.057	-.2120465	.0030001
1.south	-1.714868	.4864999	-3.52	0.000	-2.66839	-.7613455
year	-.0115881	.0085742	-1.35	0.177	-.0283932	.005217
south#c.year						
1	.0149796	.0060548	2.47	0.013	.0031124	.0268468
_cons	-1.488278	.4924738	-3.02	0.003	-2.453509	-.5230472

These standard errors are similar to those shown for `cloglog`, `vce(cluster id)` in [R] **cloglog**.



## □ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [XT] **quadchk** for details and [XT] **xtprobit** for an example.

Because the `xtcloglog` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.



## Stored results

`xtcloglog, re` stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(l1_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	$\chi^2$
<code>e(chi2_c)</code>	$\chi^2$ for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(rho)</code>	$\rho$
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

### Macros

<code>e(cmd)</code>	<code>xtcloglog</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	
<code>e(wtype)</code>	<code>re</code>
<code>e(wexp)</code>	weight type
<code>e(title)</code>	weight expression
<code>e(clustvar)</code>	title in estimation output
<code>e(offset)</code>	name of cluster variable
<code>e(chi2type)</code>	linear offset variable
<code>e(chi2_ct)</code>	Wald or LR; type of model $\chi^2$ test
<code>e(vce)</code>	Wald or LR; type of model $\chi^2$ test corresponding to <code>e(chi2_c)</code>
<code>e(vcetype)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(intmethod)</code>	title used to label Std. Err.
<code>e(distrib)</code>	integration method
<code>e(opt)</code>	Gaussian; the distribution of the random effect
<code>e(which)</code>	type of optimization
<code>e(ml_method)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(user)</code>	type of <code>ml</code> method
<code>e(technique)</code>	name of likelihood-evaluator program
<code>e(properties)</code>	maximization technique
<code>e(predict)</code>	<code>b V</code>
<code>e(marginsdefault)</code>	program used to implement <code>predict</code>
<code>e(asbalanced)</code>	default <code>predict()</code> specification for <code>margins</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
	factor variables <code>fvset</code> as <code>asobserved</code>

### Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(iolog)</code>	iteration log
<code>e(gradient)</code>	gradient vector

`e(V)` variance–covariance matrix of the estimators  
`e(V_modelbased)` model-based variance

#### Functions

`e(sample)` marks estimation sample

**xtcloglog, pa** stores the following in `e()`:

#### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(chi2)</code>	$\chi^2$
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(df_pear)</code>	degrees of freedom for Pearson $\chi^2$
<code>e(chi2_dev)</code>	$\chi^2$ test of deviance
<code>e(chi2_dis)</code>	$\chi^2$ test of deviance dispersion
<code>e(deviance)</code>	deviance
<code>e(dispers)</code>	deviance dispersion
<code>e(phi)</code>	scale parameter
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(tol)</code>	target tolerance
<code>e(dif)</code>	achieved tolerance
<code>e(rc)</code>	return code

#### Macros

<code>e(cmd)</code>	<code>xtgee</code>
<code>e(cmd2)</code>	<code>xtcloglog</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(model)</code>	<code>pa</code>
<code>e(family)</code>	<code>binomial</code>
<code>e(link)</code>	<code>cloglog</code> ; link function
<code>e(corr)</code>	correlation structure
<code>e(scale)</code>	$x2$ , <code>dev</code> , <code>phi</code> , or <code>#</code> ; scale parameter
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald; type of model $\chi^2$ test
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(nmp)</code>	<code>nmp</code> , if specified
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

#### Matrices

<code>e(b)</code>	coefficient vector
<code>e(R)</code>	estimated working correlation matrix
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

#### Functions

`e(sample)` marks estimation sample

## Methods and formulas

`xtcloglog`, `pa` reports the population-averaged results obtained using `xtgee`, `family(binomial)` link(`cloglog`) to obtain estimates.

For the random-effects model, assume a normal distribution,  $N(0, \sigma_\nu^2)$ , for the random effects  $\nu_i$ ,

$$\Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i$$

where

$$F(y, z) = \begin{cases} 1 - \exp\{-\exp(z)\} & \text{if } y \neq 0 \\ \exp\{-\exp(z)\} & \text{otherwise} \end{cases}$$

The panel-level likelihood  $l_i$  is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with  $M$ -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the  $w_m^*$  denote the quadrature weights and the  $a_m^*$  denote the quadrature abscissas. The log likelihood,  $L$ , is the sum of the logs of the panel-level likelihoods  $l_i$ .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i)$$

where  $\hat{\sigma}_i$  and  $\hat{\mu}_i$  are the adaptive parameters for panel  $i$ . Therefore, with the definition of  $g(y_{it}, x_{it}, \nu_i)$ , the total log likelihood is approximated by

$$L \approx \sum_{i=1}^n w_i \log \left[ \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2\hat{\sigma}_i} a_m^* + \hat{\mu}_i)^2 / 2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \right. \\ \left. \prod_{t=1}^{n_i} F(y_{it}, x_{it}\beta + \sqrt{2\hat{\sigma}_i} a_m^* + \hat{\mu}_i) \right]$$

where  $w_i$  is the user-specified weight for panel  $i$ ; if no weights are specified,  $w_i = 1$ .

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for  $\hat{\mu}_i$  and  $\hat{\sigma}_i$  by following the method of [Naylor and Smith \(1982\)](#), further discussed in [Skrondal and Rabe-Hesketh \(2004\)](#). We start with  $\hat{\sigma}_{i,0} = 1$  and  $\hat{\mu}_{i,0} = 0$ , and the posterior means and variances are updated in the  $k$ th iteration. That is, at the  $k$ th iteration of the optimization for  $l_i$ , we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2\hat{\sigma}_{i,k-1}} a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2\hat{\sigma}_{i,k-1}} a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until  $\hat{\mu}_{i,k}$  and  $\hat{\sigma}_{i,k}$  have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of  $1e-6$ ; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature, the `int-method(ghermite)` option, where  $\rho = \sigma_\nu^2 / (\sigma_\nu^2 + 1)$ :

$$L = \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ \approx \sum_{i=1}^n w_i \log \left[ \frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left\{ y_{it}, \mathbf{x}_{it}\beta + a_m^* \left( \frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right]$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i)$$

is well approximated by a polynomial. As panel size and  $\rho$  increase, the quadrature approximation can become less accurate. For large  $\rho$ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] `quadchk`) to verify the quadrature approximation used in this command, whichever approximation you choose.

## xtcloglog, re and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] `_robust`, particularly *Introduction* and *Methods and formulas*. Wooldridge (2020) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2020), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in  $\epsilon_{it}$ .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

## References

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## Also see

- [XT] **xtcloglog postestimation** — Postestimation tools for xtcloglog
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtlogit** — Fixed-effects, random-effects, and population-averaged logit models
- [XT] **xtprobit** — Random-effects and population-averaged probit models
- [XT] **xtset** — Declare data to be panel data
- [ME] **mecloglog** — Multilevel mixed-effects complementary log-log regression
- [MI] **Estimation** — Estimation commands for use with mi estimate
- [R] **cloglog** — Complementary log-log regression
- [U] **20 Estimation and postestimation commands**

**xtcloglog postestimation** — Postestimation tools for xtcloglog

Postestimation commands predict margins Remarks and examples  
 Also see

## Postestimation commands

The following postestimation commands are available after `xtcloglog`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
* <code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
† <code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

\* `estat ic` is not appropriate after `xtcloglog`, pa.

† `forecast` is not appropriate with `mi` estimation results.

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as probabilities, linear predictions, standard errors, and equation-level scores.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

*Random-effects (RE) model*

```
predict [type] newvar [if] [in] [, RE_statistic nooffset]
```

*Population-averaged (PA) model*

```
predict [type] newvar [if] [in] [, PA_statistic nooffset]
```

<i>RE_statistic</i>	Description
<b>Main</b>	
<b>xb</b>	linear prediction; the default
<b>pr</b>	marginal probability of a positive outcome
<b>pu0</b>	probability of a positive outcome
<b>stdp</b>	standard error of the linear prediction

<i>PA_statistic</i>	Description
<b>Main</b>	
<b>mu</b>	predicted probability of <i>depvar</i> ; considers the <code>offset()</code> ; the default
<b>rate</b>	predicted probability of <i>depvar</i>
<b>xb</b>	linear prediction
<b>stdp</b>	standard error of the linear prediction
<b>score</b>	first derivative of the log likelihood with respect to $\mathbf{x}_{it}\beta$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

## Options for predict

### Main

**xb** calculates the linear prediction, which is  $\mathbf{x}_{it}\beta$  if `offset()` was not specified when the model was fit and  $\mathbf{x}_{it}\beta + \text{offset}_{it}$  if `offset()` was specified. This is the default for the random-effects model.

**pr** calculates the probability of a positive outcome that is marginal with respect to the random effect, which means that the probability is calculated by integrating the prediction function with respect to the random effect over its entire support.

**pu0** calculates the probability of a positive outcome, assuming that the random effect for that observation's panel is zero ( $\nu_i = 0$ ). This may not be similar to the proportion of observed outcomes in the group.

**stdp** calculates the standard error of the linear prediction.

**mu** and **rate** both calculate the predicted probability of `depvar`. **mu** takes into account the `offset()`. **rate** ignores those adjustments. **mu** and **rate** are equivalent if you did not specify `offset()`. **mu** is the default for the population-averaged model.

**score** calculates the equation-level score,  $u_{it} = \partial \ln L(\mathbf{x}_{it}\beta) / \partial (\mathbf{x}_{it}\beta)$ .

**nooffset** is relevant only if you specified `offset(varname)` for `xtcloglog`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\beta$  rather than  $\mathbf{x}_{it}\beta + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of responses for probabilities and linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist], predict(statistic ...) [predict(statistic ...) ...] [options]
```

Random-effects (RE) model

statistic	Description
-----------	-------------

<code>pr</code>	marginal probability of a positive outcome; the default
<code>pu0</code>	probability of a positive outcome
<code>xb</code>	linear prediction
<code>stdp</code>	not allowed with <code>margins</code>

Population-averaged (PA) model

statistic	Description
-----------	-------------

<code>mu</code>	predicted probability of <i>depvar</i> ; considers the <code>offset()</code> ; the default
<code>rate</code>	predicted probability of <i>depvar</i>
<code>xb</code>	linear prediction
<code>stdp</code>	not allowed with <code>margins</code>
<code>score</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

## Remarks and examples

### ▷ Example 1: Average marginal effects

In example 1 of [XT] **xtcloglog**, we fit the model

```
. use https://www.stata-press.com/data/r16/union
(NLS Women 14-24 in 1968)
. xtcloglog union age grade not_smsa south##c.year, pa
(output omitted)
```

Here we use **margins** to determine the average effect each regressor has on the probability of a positive response in the sample.

```
. margins, dydx(*)
Average marginal effects                               Number of obs      =     26,200
Model VCE       : Conventional
Expression     : Pr(union != 0), predict()
dy/dx w.r.t.  : age grade not_smsa 1.south year
```

	Delta-method					
	dy/dx	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0028297	.0014952	1.89	0.058	-.000101	.0057603
grade	.0101144	.0017498	5.78	0.000	.0066848	.013544
not_smsa	-.0192384	.0079304	-2.43	0.015	-.0347818	-.0036951
1.south	-.0913197	.0073101	-12.49	0.000	-.1056473	-.0769921
year	-.0012694	.001534	-0.83	0.408	-.004276	.0017371

Note: dy/dx for factor levels is the discrete change from the base level.

We see that an additional year of schooling (covariate **grade**) increases the probability that a woman belongs to a union by an average of about one percentage point.



## Also see

[XT] **xtcloglog** — Random-effects and population-averaged cloglog models

[U] **20 Estimation and postestimation commands**

**xtcointtest** — Panel-data cointegration tests

Description	Quick start	Menu	Syntax
Options	Remarks and examples	Stored results	Methods and formulas
References	Also see		

## Description

**xtcointtest** performs the Kao (1999), Pedroni (1999, 2004), and Westerlund (2005) tests of cointegration on a panel dataset. Panel-specific means (fixed effects) and panel-specific time trends may be included in the cointegrating regression model.

All tests have a common null hypothesis of no cointegration. The alternative hypothesis of the Kao tests and the Pedroni tests is that the variables are cointegrated in all panels. In one version of the Westerlund test, the alternative hypothesis is that the variables are cointegrated in some of the panels. In another version of the Westerlund test, the alternative hypothesis is that the variables are cointegrated in all the panels.

## Quick start

Kao test of no cointegration between *y* and *x* with the alternative hypothesis that they are cointegrated in all panels using `xtset` data

```
xtcointtest kao y x
```

Pedroni test of no cointegration using a panel-specific autoregressive (AR) term and panel-specific time trends with the alternative hypothesis of cointegration in all panels

```
xtcointtest pedroni y x, trend
```

As above, but use the same AR term in all panels

```
xtcointtest pedroni y x, trend ar(same)
```

Westerlund test of no cointegration with the alternative hypothesis that the variables are cointegrated in some of the panels

```
xtcointtest westерlund y x
```

Westerlund test of no cointegration with the alternative hypothesis of cointegration in all panels

```
xtcointtest westерlund y x, allpanels
```

## Menu

Statistics > Longitudinal/panel data > Cointegrated data > Tests for cointegration

## Syntax

*Kao test*

```
xtcointtest kao depvar varlist [if] [in] [, kao_options]
```

*Pedroni test*

```
xtcointtest pedroni depvar varlist [if] [in] [, pedroni_options]
```

*Westerlund test*

```
xtcointtest westerlund depvar varlist [if] [in] [, westerlund_options]
```

<i>kao_options</i>	Description
--------------------	-------------

Main

<u>lags</u> ( <i>lspec</i> )	specify lag structure for augmented Dickey–Fuller regressions
<u>kernel</u> ( <i>kspec</i> )	specify method to estimate long-run variance
<u>demean</u>	subtract cross-sectional means

<i>pedroni_options</i>	Description
------------------------	-------------

Main

<u>ar</u> ( <u>panelspecific</u>   <u>same</u> )	specify autoregressive parameter as panel specific or as the same for all panels; <u>ar</u> ( <u>panelspecific</u> ) is the default
<u>trend</u>	include panel-specific time trends
<u>noconstant</u>	suppress panel-specific means
<u>lags</u> ( <i>lspec</i> )	specify lag structure for augmented Dickey–Fuller regressions
<u>kernel</u> ( <i>kspec</i> )	specify method to estimate long-run variance
<u>demean</u>	subtract cross-sectional means

<i>westerlund_options</i>	Description
---------------------------	-------------

Main

<u>somepanels</u>	use alternative hypothesis of cointegration in some panels; the default
<u>allpanels</u>	use alternative hypothesis of cointegration in all panels
<u>trend</u>	include panel-specific time trends
<u>demean</u>	subtract cross-sectional means

*lspec* is

#	number of lags of series; 1 is the default
aic #	Akaike information criterion (AIC) with up to # lags
bic #	Bayesian information criterion (BIC) with up to # lags
hqic #	Hannan–Quinn information criterion (HQIC) with up to # lags

*kspec* is

<u>bartlett nwest</u>	Bartlett kernel with Newey–West lags; the default
<u>bartlett #</u>	Bartlett kernel with up to # lags
<u>parzen nwest</u>	Parzen kernel with Newey–West lags
<u>parzen #</u>	Parzen kernel with up to # lags
<u>quadraticspectral nwest</u>	quadratic spectral kernel with Newey–West lags
<u>quadraticspectral #</u>	quadratic spectral kernel with up to # lags

## Options

Options are presented under the following headings:

*Options for xtcointtest kao*  
*Options for xtcointtest pedroni*  
*Options for xtcointtest westerlund*

### Options for xtcointtest kao

Main

`lags(lspec)` specifies the lag structure to use for the augmented Dickey–Fuller (ADF) regressions performed in computing the test statistic.

`lags(#)` specifies that # lags of the series be used in the ADF regressions. # must be a nonnegative integer. The default is `lags(1)`.

`lags(aic|bic|hqic #)` specifies that `xtcointtest` fit ADF regressions with 1 to # lags and choose the number of lags for which the AIC, BIC, or HQIC is minimized.

`kernel(kspec)` specifies the method used to estimate the long-run variance of each panel's series. You may specify the kernel type and either #, the maximum number of lags as a positive integer, or `nwest`, the maximum number of lags selected by the bandwidth-selection algorithm given in [Newey and West \(1994\)](#). The kernel type may be `bartlett`, `parzen`, or `quadraticspectral`. The default is `kernel(bartlett nwest)`.

`demean` specifies that `xtcointtest` first subtract the cross-sectional averages from the series. When specified, for each time period `xtcointtest` computes the mean of the series across panels and subtracts this mean from the series. [Levin, Lin, and Chu \(2002\)](#) suggest this procedure to mitigate the impact of cross-sectional dependence.

## Options for xtcointtest pedroni

Main

`ar(panelspecific|same)` specifies whether the AR parameter for ADF or Phillips–Perron (PP) regressions is panel specific or the same across panels.

`ar(panelspecific)` specifies that the AR parameter be panel specific in the ADF or PP regressions.

The test statistics obtained from using this option are also known as group-mean statistics or between-dimension statistics. This is the default.

`ar(same)` specifies that the AR parameter be the same for all panels in the ADF or PP regressions.

The test statistics obtained from using this option are also known as panel cointegration statistics or within-dimension statistics.

`trend` includes panel-specific linear time trends in the model for the dependent variable on the covariates.

`noconstant` suppresses the panel-specific means in the model for the dependent variable on the covariates. Specifying `noconstant` imposes the assumption that the series has a mean of zero for all panels. This option may not be specified with `trend`.

`lags(`*lspec*`)` specifies the lag structure to use for the ADF regressions performed in computing the test statistic. See the description of `lags()` under *Options for xtcointtest kao* for additional details.

`kernel(`*kspec*`)` specifies the method used to estimate the long-run variance of each panel's series. See the description of `kernel()` under *Options for xtcointtest kao* for additional details.

`demean` specifies that `xtcointtest` first subtract the cross-sectional averages from the series. See the description of `demean` under *Options for xtcointtest kao* for additional details.

## Options for xtcointtest westerlund

Main

`somepanels` specifies that the test statistic for panel cointegration be computed using the alternative hypothesis that some of the panels are cointegrated. This statistic is also known as the group-mean variance-ratio (VR) statistic. This option uses a regression in which the AR parameter for Dickey–Fuller (DF) regressions is panel specific. This is the default.

`allpanels` specifies that the test statistic for panel cointegration be computed using the alternative hypothesis that all the panels are cointegrated, also known as the panel VR statistic. This option also implies that the AR parameter for DF regressions is the same for all panels.

`trend` includes panel-specific linear time trends in the model for dependent variable on the covariates.

`demean` specifies that `xtcointtest` first subtract the cross-sectional averages from the series. See the description of `demean` under *Options for xtcointtest kao* for additional details.

## Remarks and examples

Remarks are presented under the following headings:

- [Overview](#)
- [Test details](#)
- [Kao tests](#)
- [Pedroni tests](#)
- [Westerlund tests](#)

## Overview

A stationary process has a time-invariant mean and a time-invariant variance. By contrast, a nonstationary process has a time-varying mean, a time-varying variance, or both. A nonstationary process may wander arbitrarily over time because its first two moments vary over time.

When the first difference of a nonstationary process is stationary, the process is said to be integrated of order one, denoted  $I(1)$ . When a linear combination of several  $I(1)$  series is stationary, the series are said to be cointegrated (Engle and Granger 1987). We test for cointegration because cointegration implies that the  $I(1)$  series are in a long-run equilibrium; they move together, although the group of them can wander arbitrarily.

For example, income and consumption are  $I(1)$  series that wander over time. According to economic theory, income determines consumption in the long run. In practice, time-series data on income and consumption typically have periods where the series seem to wander in isolation, which is contrary to the theory. However, when we look at the overall trend, the two series are close to one another, implying a long-run relation. A test of cointegration provides evidence that indeed there is (or is not) a long-run relation between these series even if they tend to deviate temporarily.

`xtcointtest` implements tests of cointegration in panel data, which have many observations on each of many individual units. This type of sample is known as large-N-large-T-panel data. The popular Engle–Granger residual-based test for cointegration has low power when applied to a single time series but has good power when statistics from many individual panels are combined. The Kao tests, the Pedroni tests, and the Westerlund tests implemented in `xtcointtest` combine statistics computed for each individual in the panel, thereby producing a test with higher power. Furthermore, the limiting distribution of the combined test converges to a standard normal distribution after appropriate standardization, whereas tests for cointegration based on a single time series have nonstandard distributions.

All the tests in `xtcointtest` are based on the following panel-data model for the  $I(1)$  dependent variable  $y_{it}$ , where  $i = 1, \dots, N$  denotes the panel (individual) and  $t = 1, \dots, T_i$  denotes time:

$$y_{it} = \mathbf{x}'_{it}\beta_i + \mathbf{z}'_{it}\gamma_i + e_{it} \quad (1)$$

For each panel  $i$ , each of the covariates in  $\mathbf{x}_{it}$  is an  $I(1)$  series. All the tests require that the covariates are not cointegrated among themselves. The Pedroni and Westerlund tests allow a maximum of seven covariates in  $\mathbf{x}_{it}$ .  $\beta_i$  denotes the cointegrating vector, which may vary across panels.  $\gamma_i$  is a vector of coefficients on  $\mathbf{z}_{it}$ , the deterministic terms that control for panel-specific effects and linear time trends.  $e_{it}$  is the error term.

Depending on the options specified with `xtcointtest`, the vector  $\mathbf{z}_{it}$  allows for panel-specific means, panel-specific means and panel-specific time trends, or nothing. By default,  $\mathbf{z}_{it} = 1$ , so the term  $\mathbf{z}'_{it}\gamma_i$  represents panel-specific means (fixed effects). If `trend` is specified,  $\mathbf{z}'_{it} = (1, t)$  so  $\mathbf{z}'_{it}\gamma_i$  represents panel-specific means and panel-specific linear time trends. For tests that allow it, specifying `noconstant` omits the  $\mathbf{z}'_{it}\gamma_i$  term.

The tests share a common null hypothesis that  $y_{it}$  and  $\mathbf{x}_{it}$  are not cointegrated. `xtcointtest` tests for no cointegration by testing that  $e_{it}$  is nonstationary. Rejection of the null hypothesis implies that  $e_{it}$  is stationary and that the series  $y_{it}$  and  $\mathbf{x}_{it}$  are cointegrated. The alternative hypothesis of the Kao tests, the Pedroni tests, and the `allpanels` version of the Westerlund test is that the variables are cointegrated in all panels. The alternative hypothesis of the `somepanels` version of the Westerlund test is that the variables are cointegrated in some of the panels.

All tests allow unbalanced panels and require that  $N$  is large enough that the distribution of a sample average of panel-level statistics converges to its population distribution. They also require that each  $T_i$  is large enough to run time-series regressions using observations only from that panel. These

tests have nominal coverage only when both  $T$  and  $N$  are large. The smallest combinations of  $T$  and  $N$  for which the tests have close to nominal coverage and decent power differs by test and varies with the degree of serial correlation in the residuals. See [Test details](#) for more information. All the tests require that there be no gaps in any panel's series.

## Test details

The Kao, Pedroni, and Westerlund tests implement different types of tests for whether  $e_{it}$  is nonstationary. The DF  $t$  tests, ADF  $t$  tests, PP  $t$  tests, and their variants that are reported by `xtcointtest kao` and `xtcointtest pedroni` use different regression frameworks to handle serial correlation in  $e_{it}$ . The VR tests that are reported by `xtcointtest westerlund` and `xtcointtest pedroni` do not require modeling or accommodating for serial correlation; see [Westerlund \(2005\)](#).

All variants of the DF  $t$  test statistics are constructed by fitting the model in (1) using ordinary least squares, obtaining the predicted residuals ( $\hat{e}_{it}$ ), and then fitting the DF regression model

$$\hat{e}_{it} = \rho \hat{e}_{i,t-1} + \nu_{it} \quad (2)$$

where  $\rho$  is the AR parameter and  $\nu_{it}$  is a stationary error term. The DF  $t$  and the unadjusted DF  $t$  test whether the coefficient  $\rho$  is 1. By contrast, the modified DF  $t$  and the unadjusted modified DF  $t$  test whether  $\rho - 1 = 0$ . Nonstationarity under the null hypothesis causes a test of whether  $\rho = 1$  to differ from a test of whether  $\rho - 1 = 0$ ; see [Dickey and Fuller \(1979\)](#) and [Kao \(1999\)](#).

The variants of the PP  $t$  test statistics are also constructed by fitting the model in (1) using ordinary least squares and obtaining the predicted residuals ( $\hat{e}_{it}$ ). For the PP  $t$  tests, we then fit the DF regression model

$$\hat{e}_{it} = \rho_i \hat{e}_{i,t-1} + \nu_{it} \quad (3)$$

In this case, we have a panel-specific AR parameter  $\rho_i$ . The PP  $t$  tests whether the  $\rho_i$ s are 1, whereas the modified PP  $t$  tests whether  $\rho_i - 1 = 0$ . The PP  $t$  test statistic is nonparametrically adjusted for serial correlation in the residuals using the [Newey and West \(1987\)](#) heteroskedasticity- and autocorrelation-consistent (HAC) covariance matrix estimator.

The DF  $t$ , the modified DF  $t$ , the PP  $t$ , the modified PP  $t$ , and the modified VR tests are derived by specifying a data-generating process for the dependent variable and the regressors. This specification allows the regressors to be endogenous as well as serially correlated. Therefore, constructing the test statistics requires estimating the contemporaneous and dynamic covariances between the regressors and the dependent variable. The unadjusted DF  $t$  and the unadjusted modified DF  $t$  assume absence of serial correlation and strictly exogenous covariates and do not require any adjustments in the residuals.

Like the DF and PP tests, the ADF  $t$  tests that  $\rho = 1$ . However, the ADF test uses additional lags of the residuals to control for serial correlation instead of the Newey–West nonparametric adjustments. The ADF regression is

$$\hat{e}_{it} = \rho_i \hat{e}_{i,t-1} + \sum_{j=1}^p \rho_{ij} \Delta \hat{e}_{i,t-j} + \nu_{it}^* \quad (4)$$

where  $\Delta \hat{e}_{i,t-j}$  is the  $j$ th lag of the first difference of  $\hat{e}_{it}$  and  $j = 1, \dots, p$  is where  $p$  is the number of lag differences.

The VR tests are based on [Phillips and Ouliaris \(1990\)](#) and [Breitung \(2002\)](#), where the test statistic is constructed as a ratio of variances. These tests do not require modeling or accommodating serial correlation; see [Westerlund \(2005\)](#). VR tests also test for no cointegration by testing for the presence

of a unit root in the residuals. However, they do so using the ratio of variances of the predicted residuals. The modified VR test removes estimated conditional variances prior to computing the VR. For further details, see [Methods and formulas](#).

These tests get good coverage and power properties by combining panel-level statistics computed from a time-series regression using only the observations in that panel. [Kao \(1999\)](#) finds that his tests have nearly nominal size when  $T = 100$  and  $N = 300$ . [Pedroni \(2004\)](#) finds that his tests have nearly nominal size when  $T = 250$  and  $N = 60$ . [Westerlund \(2005\)](#) limited his simulations to datasets with  $T = 150$ , and he did not find a combination of  $T$  and  $N$  in which his tests had nearly nominal size. He said that  $T > 150$  should produce better coverage. Each author used a different data-generating process; see [Kao \(1999\)](#), [Pedroni \(2004\)](#), and [Westerlund \(2005\)](#) for details.

## □ Technical note

The asymptotic distribution of all the test statistics are obtained using sequential limit theory, denoted as  $(T, N) \rightarrow_{\text{seq}} \infty$ , in which the time dimension goes to infinity followed by the number of panels going to infinity. See [Phillips and Moon \(2000\)](#) for an introduction to asymptotic theory that depend on both  $N$  and  $T$  and their relation to nonstationary panels. [Phillips and Moon \(1999\)](#) contains a more technical discussion of “multi-indexed” asymptotic theory. □

## Kao tests

The tests derived in [Kao \(1999\)](#) assume a cointegrating vector that is the same across all panels, which restricts  $\beta_i = \beta$  in (1). Kao tests estimate panel-specific means and do not allow a time trend, so  $\mathbf{z}$  from (1) is always a vector of 1s for Kao tests. This yields the cointegrating relationship

$$y_{it} = \gamma_i + \mathbf{x}'_{it}\beta + e_{it}$$

where  $\gamma_i$  denotes panel-specific means (fixed effects). The null hypothesis of the Kao test is that there is no cointegration among the series. The alternative hypothesis is that the series in all panels are cointegrated with the same cointegrating vector.

`xtcointtest kao` reports the modified DF  $t$ , DF  $t$ , ADF  $t$ , unadjusted modified DF  $t$ , and unadjusted DF  $t$  statistics. They are constructed using the estimated  $\rho$  from DF and ADF regressions; see [Test details](#). The test statistics differ in how they formulate the hypothesis and in how they control for serial correlation in  $e_{it}$ . See [Test details](#) for an overview of the differences in the test statistics and see [Kao tests](#) in [Methods and formulas](#) for further discussion.

## ▷ Example 1: Kao tests assuming a constant cointegrating vector

We are interested in the long-run effect of domestic research and development (R&D) and foreign R&D on an economy’s productivity. The fictitious dataset, `xtcoint.dta`, is a balanced panel on 100 countries observed from 1973q3 to 2010q4. It contains quarterly data on the log of productivity (productivity), log of domestic R&D capital stock (`rddomestic`), and log of foreign R&D (`rdforeign`).

The cointegrating relationship is specified as

$$\text{productivity}_{it} = \gamma_i + \beta_1 \text{rddomestic}_{it} + \beta_2 \text{rdforeign}_{it} + e_{it}$$

where  $\gamma_i$  is the panel-specific mean and the cointegrating parameters,  $\beta_1$  and  $\beta_2$ , are the same across panels. We assume that each series is  $I(1)$ . A formal test for the presence of a unit root in panel data may be performed using `xtunitroot`. We perform the Kao test of cointegration by typing

. use https://www.stata-press.com/data/r16/xtcoint (Fictitious cointegration data)	
. xtcointtest kao productivity rddomestic rdforeign	Kao test for cointegration
<hr/>	
Ho: No cointegration	Number of panels = 100
Ha: All panels are cointegrated	Number of periods = 148
<hr/>	
Cointegrating vector: Same	
Panel means: Included	Kernel: Bartlett
Time trend: Not included	Lags: 3.60 (Newey-West)
AR parameter: Same	Augmented lags: 1
<hr/>	
	Statistic      p-value
<hr/>	
Modified Dickey-Fuller t	-23.6733      0.0000
Dickey-Fuller t	-15.1293      0.0000
Augmented Dickey-Fuller t	-3.6909      0.0001
Unadjusted modified Dickey-Fuller t	-46.7561      0.0000
Unadjusted Dickey-Fuller t	-20.2521      0.0000
<hr/>	

We used a model with panel-specific means and no time trend, as reported in the header. The AR parameter that determines the presence or lack of cointegration is assumed to be the same for all panels and is thus labeled as `Same` in the header.

By default, `xtcointtest kao` uses a Bartlett kernel with [Newey and West \(1994\)](#) automatic lag selection algorithm. In this example, the algorithm chose an average of 3.6 lags across all panels to correct for serial correlation. To choose different kernels and the number of lags, specify the `kernel()` option. The ADF *t* statistic also includes lagged differences of the dependent variable to control for serial correlation. The number of lags is reported in `Augmented lags`. By default, `xtcointtest kao` uses the first lag. To include more lags, specify the `lags()` option.

The output reports the values of all test statistics with their respective *p*-values. All test statistics reject the null hypothesis of no cointegration in favor of the alternative hypothesis of the existence of a cointegrating relation among `productivity`, `rddomestic`, and `rdforeign`. The modified DF *t*, the DF *t*, and the ADF *t* test statistics are adjusted for serial correlation using the HAC estimator; see [Methods and formulas](#).



## Pedroni tests

The tests derived by [Pedroni \(1999, 2004\)](#) allow for panel-specific cointegrating vectors. This heterogeneity distinguishes Pedroni tests from those derived by Kao. Another difference is that the Pedroni tests allow the AR coefficient ( $\rho_i$ ) to vary over panels as in (3), while the Kao tests assumed the same AR coefficient. These panel-specific AR coefficients are the default in the Pedroni tests, but the `ar(same)` option restricts the AR coefficients ( $\rho_i = \rho$ ) to be the same over panels.

[Pedroni \(1999, 2004\)](#) refers to the tests based on panel-specific AR parameters as “between-dimension tests” and refers to the tests based on the same AR parameters as “within-dimension tests”.

See [Test details](#) and [Methods and formulas](#) for further discussion of the specific tests.

► Example 2: Pedroni cointegration test with panel-specific AR parameter

Continuing with [example 1](#), we perform the Pedroni test of cointegration between `productivity`, `rddomestic`, and `rdforeign`, assuming panel-specific cointegrating vectors and autoregressive parameters. The cointegrating relationship is specified as

$$\text{productivity}_{it} = \gamma_i + \beta_{1i}\text{rddomestic}_{it} + \beta_{2i}\text{rdforeign}_{it} + e_{it}$$

where  $\beta_{1i}$  and  $\beta_{2i}$  represent panel-specific cointegration parameters.

```
. xtcointtest pedroni productivity rddomestic rdforeign
```

Pedroni test for cointegration

Ho: No cointegration	Number of panels	=	100
Ha: All panels are cointegrated	Number of periods	=	149
<hr/>			
Cointegrating vector: Panel specific			
Panel means:	Included	Kernel:	Bartlett
Time trend:	Not included	Lags:	4.00 (Newey-West)
AR parameter:	Panel specific	Augmented lags:	1
<hr/>			
	Statistic	p-value	
Modified Phillips-Perron t	-26.1145	0.0000	
Phillips-Perron t	-21.2436	0.0000	
Augmented Dickey-Fuller t	-25.3701	0.0000	

All the test statistics reject the null hypothesis of no cointegration in favor of the alternative hypothesis that `productivity`, `rddomestic`, and `rdforeign` are cointegrated in all panels with a panel-specific cointegrating vector.

The model underlying the reported statistics includes panel-specific means and panel-specific AR parameters and does not include a time trend. All three statistics used a Bartlett kernel with four lags, as selected by the Newey–West methods, to adjust for serial correlation. The ADF test used a regression with only one additional lag.



► Example 3: Pedroni cointegration test with a common AR parameter

The alternative hypothesis in [example 2](#) allows for panel-specific AR parameters. In this example, we use the `ar(same)` option to specify an alternative hypothesis that assumes the same AR parameter across all panels.

```
. xtcointtest pedroni productivity rddomestic rdforeign, ar(same)
```

Pedroni test for cointegration

Ho: No cointegration	Number of panels	=	100
Ha: All panels are cointegrated	Number of periods	=	149
<hr/>			
Cointegrating vector: Panel specific			
Panel means:	Included	Kernel:	Bartlett
Time trend:	Not included	Lags:	4.00 (Newey-West)
AR parameter:	Same	Augmented lags:	1
<hr/>			
	Statistic	p-value	
Modified variance ratio	14.8852	0.0000	
Modified Phillips-Perron t	-23.0042	0.0000	
Phillips-Perron t	-17.6735	0.0000	
Augmented Dickey-Fuller t	-21.1119	0.0000	

All test statistics reject the null hypothesis of no cointegration in favor of the alternative hypothesis of cointegration between `productivity`, `rddomestic`, and `rdforeign`.

The header reports `Same` for the AR parameter, reminding us that we are now using an alternative hypothesis that assumes a constant  $\rho$  for all panels.



## Westerlund tests

[Westerlund \(2005\)](#) derived a pair of VR test statistics for the null hypothesis of no cointegration. The default test uses a model in which the AR parameter is panel specific and for which the alternative hypothesis is that the series in some of the panels are cointegrated. Specifying the `allpanels` option produces the results for a test in which the alternative hypothesis is that the series in all the panels are cointegrated, and this test uses a model in which the AR parameter is the same over the panels. More specifically, the alternative hypothesis using the `allpanels` option restricts  $\rho_i = \rho$  in (3).

See [Test details](#) and [Methods and formulas](#) for further discussion of the specific tests.

### ▷ Example 4: Westerlund test with some panels cointegrated under the alternative

Continuing with [example 1](#), we perform the Westerlund test of cointegration between `productivity`, `rddomestic`, and `rdforeign`. The cointegrating relationship is specified as

$$\text{productivity}_{it} = \gamma_i + \beta_{1i}\text{rddomestic}_{it} + \beta_{2i}\text{rdforeign}_{it} + e_{it}$$

where  $\beta_{1i}$  and  $\beta_{2i}$  are panel-specific cointegration parameters. We now test the null hypothesis of no cointegration under the alternative that some of the  $\beta_{1i}$  and  $\beta_{2i}$  produce cointegrated series:

. xtcointtest westerlund productivity rddomestic rdforeign	
<b>Westerlund test for cointegration</b>	
<hr/>	
Ho: No cointegration	Number of panels = 100
Ha: Some panels are cointegrated	Number of periods = 150
<hr/>	
Cointegrating vector: Panel specific	
Panel means: Included	
Time trend: Not included	
AR parameter: Panel specific	
<hr/>	
	Statistic      p-value
<hr/>	
Variance ratio	-8.0237      0.0000
<hr/>	

The VR test statistic rejects the null hypothesis of no cointegration between `productivity`, `rddomestic`, and `rdforeign` in favor of the alternative that at least some panels are cointegrated.

The header tells us that the cointegrating vectors vary by panel, that panel-specific means were included in the model, that no time trend was included in the model, and that the AR parameter varies by panel.



► Example 5: Westerlund test with all panels cointegrated under the alternative

In this example, we use the `allpanels` option to test the null hypothesis of no cointegration under the alternative hypothesis that all panels are cointegrated. This test is based on a model in which the AR parameter is the same over the panels.

.	<code>xtcointtest westerlund productivity rddomestic rdforeign, allpanels</code>	
<b>Westerlund test for cointegration</b>		
Ho: No cointegration	Number of panels = 100	
Ha: All panels are cointegrated	Number of periods = 150	
Cointegrating vector: Panel specific		
Panel means:	Included	
Time trend:	Not included	
AR parameter:	Same	
	<b>Statistic</b>	<b>p-value</b>
<b>Variance ratio</b>	-5.9709	0.0000

The VR statistic rejects the null hypothesis of no cointegration. This implies all panels are cointegrated.



## Stored results

`xtcointtest kao` stores the following in `r()`:

### Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(hac_lagm)</code>	average lags used in HAC variance estimator
<code>r(adf_lags)</code>	lags used in ADF regressions

### Macros

<code>r(test)</code>	<code>kao</code>
<code>r(hac_kernel)</code>	kernel used in HAC variance estimator
<code>r(hac_method)</code>	HAC lag-selection algorithm
<code>r(adf_method)</code>	ADF regression lag-selection criterion
<code>r(demean)</code>	demean, if the data were demeaned
<code>r(deterministics)</code>	constant

### Matrices

<code>r(stats)</code>	Kao test statistics
<code>r(p)</code>	<i>p</i> -values

`xtcointtest pedroni` stores the following in `r()`:

### Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(hac_lagm)</code>	average lags used in HAC variance estimator
<code>r(adf_lags)</code>	lags used in ADF regressions

### Macros

<code>r(test)</code>	<code>pedroni</code>
<code>r(hac_kernel)</code>	kernel used in HAC variance estimator
<code>r(hac_method)</code>	HAC lag-selection algorithm

<code>r(adf_method)</code>	ADF regression lag-selection criterion
<code>r(demean)</code>	demean, if the data were demeaned
<code>r(deterministics)</code>	noconstant, constant, or trend
Matrices	
<code>r(stats)</code>	Pedroni test statistics
<code>r(p)</code>	p-values
<b>xtcointtest westerlund</b> stores the following in <code>r()</code> :	
Scalars	
<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(stat)</code>	Westerlund test statistic
<code>r(p)</code>	p-value
Macros	
<code>r(test)</code>	westerlund
<code>r(demean)</code>	demean, if the data were demeaned
<code>r(deterministics)</code>	constant or trend

## Methods and formulas

Methods and formulas are presented under the following headings:

- [Overview](#)
- [Kao tests](#)
- [Pedroni tests](#)
- [Westerlund tests](#)
- [Long-run variance](#)

## Overview

Consider the panel-data model

$$y_{it} = \mathbf{x}'_{it}\beta_i + \mathbf{z}'_{it}\gamma_i + e_{it} \quad (4)$$

where  $i = 1, \dots, N$  denotes the panel and  $t = 1, \dots, T_i$  denotes time. For each  $i$ ,  $y_{it}$  is a nonstationary dependent variable for which the first difference is stationary, which is to say that  $y_{it}$  is integrated of order 1—denoted  $I(1)$ —for each panel. Similarly,  $\mathbf{x}_{it}$  is a  $k \times 1$  vector of  $I(1)$  variables.  $\beta_i$  denotes the cointegrating vector that may vary across panels.  $\mathbf{z}_{it}$  contains terms to control for panel-specific effects and or panel-specific time trends.  $\gamma_i$  denotes the coefficients on the deterministic terms such as panel-specific means and panel-specific linear time trends.  $e_{it}$  is an error term.

The vector  $\mathbf{z}_{it}$  allows for panel-specific means, panel-specific means and panel-specific time trends, or nothing, depending on the options specified to `xtcointtest`. By default,  $\mathbf{z}_{it} = 1$ , so the term  $\mathbf{z}'_{it}\gamma_i$  represents panel-specific means (fixed effects). If `trend` is specified, then  $\mathbf{z}'_{it} = (1, t)$ , so  $\mathbf{z}'_{it}\gamma_i$  represents panel-specific means and panel-specific linear time trends. For tests that allow it, specifying `noconstant` omits the  $\mathbf{z}'_{it}\gamma_i$  term.

The data-generating process for  $y_{it}$  and  $\mathbf{x}_{it}$  is given by

$$y_{it} = y_{i,t-1} + u_{it}$$

$$\mathbf{x}_{it} = \mathbf{x}_{i,t-1} + \epsilon_{it}$$

Let  $\mathbf{w}_{it} = (u_{it}, \epsilon_{it})'$  denote a  $(k + 1) \times 1$  vector process with zero mean and long-run covariance matrix  $\Omega_i$ . (A long-run covariance matrix is a covariance matrix that accounts for the serial correlation in the process; see Hall (2005, sec. 3.5) for an introduction.) The long-run matrix can be decomposed as  $\Omega_i = \Sigma_i + \Gamma'_i + \Gamma_i$ , where  $\Sigma_i$  and  $\Gamma_i$  denote the contemporaneous and autocovariance matrices for a given panel  $i$ . The elements of long-run and contemporaneous matrices  $\Omega_i$  and  $\Sigma_i$  are given by

$$\Omega_i = \begin{bmatrix} \omega_{u,i}^2 & \Omega_{u\epsilon,i} \\ \Omega'_{u\epsilon,i} & \Omega_{\epsilon,i} \end{bmatrix}$$

$$\Sigma_i = \begin{bmatrix} \sigma_{u,i}^2 & \Sigma_{u\epsilon,i} \\ \Sigma'_{u\epsilon,i} & \Sigma_{\epsilon,i} \end{bmatrix}$$

We obtain consistent estimators  $\widehat{\Omega}_i$  and  $\widehat{\Sigma}_i$  using Newey and West (1987).

## Kao tests

Kao (1999) assumes the same cointegrating vector  $\beta_i = \beta$  in (4) so that all panels share a common slope coefficient. This implies a common long-run covariance matrix given by  $\Omega = \Sigma + \Gamma' + \Gamma$ . The regression model is

$$y_{it} = \gamma_i + \mathbf{x}'_{it}\beta + e_{it}$$

where  $\gamma_i$  denotes panel-specific fixed effects and  $\beta$  is the same cointegrating vector.

Kao (1999) proposes five test statistics. The DF  $t$ , the modified DF  $t$ , the unadjusted DF  $t$ , and the unadjusted modified DF  $t$  are based on the DF regression

$$\widehat{e}_{it} = \rho \widehat{e}_{i,t-1} + \nu_{it}$$

where  $\rho$  is the common AR parameter of the estimated residuals.

The test statistics based on DF regressions are

$$\text{DF } t = \frac{t_\rho + \frac{\sqrt{6N} \widehat{\sigma}_\nu}{2\widehat{\omega}_\nu}}{\sqrt{\frac{\widehat{\omega}_\nu^2}{2\sigma_\nu^2} + \frac{3\sigma_\nu^2}{10\widehat{\omega}_\nu^2}}}$$

$$\text{Modified DF } t = \frac{\sqrt{NT}(\widehat{\rho} - 1) + \frac{3\sqrt{N} \widehat{\sigma}_\nu^2}{\widehat{\omega}_\nu^2}}{\sqrt{3 + \frac{36\widehat{\sigma}_\nu^4}{5\widehat{\omega}_\nu^4}}}$$

where  $\widehat{\rho}$  is the estimated value of  $\rho$ .  $\widehat{\sigma}_\nu^2$  and  $\widehat{\omega}_\nu^2$  are scalar terms that are consistent estimates of  $\sigma_\nu^2 = \sigma_u^2 - \Sigma'_{u\epsilon} \Sigma_\epsilon \Sigma_{u\epsilon}$  and  $\omega_\nu^2 = \omega_u^2 - \Omega'_{u\epsilon} \Omega_\epsilon \Omega_{u\epsilon}$ .  $t_\rho$  is the  $t$  statistic for testing the null hypothesis  $H_0: \rho = 1$ .

The DF test statistics that assume strict exogeneity and absence of serial correlation are given by

$$\text{Unadjusted DF } t = \sqrt{\frac{5t_\rho}{4}} + \sqrt{\frac{15N}{8}}$$

$$\text{Unadjusted modified DF } t = \frac{\sqrt{NT}(\widehat{\rho} - 1) + 3\sqrt{N}}{\sqrt{51/5}}$$

The ADF regression is given by

$$\hat{e}_{it} = \rho \hat{e}_{i,t-1} + \sum_{j=1}^p \rho_j \Delta \hat{e}_{i,t-j} + \nu_{it}^* \quad (5)$$

where  $p$  is the number of lagged difference terms.

The test statistic based on ADF regression is

$$\text{ADF } t = \frac{t_{\text{ADF}} + \frac{\sqrt{6N}\sigma_\nu}{2\hat{\omega}_\nu}}{\sqrt{\frac{\hat{\omega}_\nu^2}{2\sigma_\nu^2} + \frac{3\hat{\omega}_\nu^2}{10\hat{\omega}_\nu^2}}}$$

where

$$t_{\text{ADF}} = \frac{\hat{\rho}}{\widehat{\text{SE}}(\hat{\rho})}$$

is computed from the ADF regression.

The asymptotic distribution of all test statistics converge to  $N(0, 1)$ .

## Pedroni tests

[Pedroni \(1999\)](#) assumes a panel-specific cointegrating vector as in (4), where all panels have individual slope coefficients. The panel cointegration tests are obtained by testing for a unit root in the estimated residuals using the ADF regression in (5) but allowing panel-specific  $\rho_i$  instead of  $\rho$  or using the PP regressions given in [Pedroni \(1999\)](#).

[Pedroni \(1999, 2004\)](#) derives test statistics based on a model in which the AR parameter either is panel-specific or is the same over the panels. [Pedroni \(1999, 2004\)](#) calls the panel-specific-AR test statistics “group-mean statistics” and the same-AR test statistics “panel cointegration statistics”.

The panel-specific-AR test statistics are

$$\begin{aligned} \text{Modified PP } t &= TN^{-1/2} \sum_{i=1}^N \left( \sum_{t=1}^T \hat{e}_{i,t-1}^2 \right)^{-1} \sum_{t=1}^T (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \\ \text{PP } t &= N^{-1/2} \sum_{i=1}^N \left( \hat{\sigma}_i^2 \sum_{t=1}^T \hat{e}_{i,t-1}^2 \right)^{-1/2} \sum_{t=1}^T (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \\ \text{ADF } t &= N^{-1/2} \sum_{i=1}^N \left( \sum_{t=1}^T \hat{s}_i^{*2} \hat{e}_{i,t-1}^2 \right)^{-1/2} \sum_{t=1}^T \hat{e}_{i,t-1} \Delta \hat{e}_{i,t} \end{aligned}$$

where  $\hat{e}_{it}$  are the residuals from the panel-data regression model in (4). We calculate

$$\hat{\lambda}_i = \frac{1}{2} (\hat{\sigma}_i^2 - \hat{s}_i^{*2})$$

where  $\hat{s}_i^{*2}$  and  $\hat{\sigma}_i^2$  are the individual contemporaneous and long-run variances of the residuals from the DF regression in (3).  $\hat{s}_i^{*2}$  is the individual contemporaneous variance of the residuals from the ADF regression in (5) but with panel-specific  $\rho_i$  instead of  $\rho$ .

The same-AR test statistics are

$$\begin{aligned}\text{Modified VR} &= T^2 N^{3/2} \left( \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \right)^{-1} \\ \text{Modified PP } t &= T\sqrt{N} \left( \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \right)^{-1} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \\ \text{PP } t &= \left( \tilde{\sigma}_{N,T}^2 \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \right)^{-1/2} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \\ \text{ADF } t &= \left( \tilde{s}_{N,T}^{*2} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2 \right)^{-1/2} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1} \Delta \hat{e}_{i,t}\end{aligned}$$

where the residuals are as defined above and where

$$\tilde{\sigma}_{N,T}^2 = \frac{1}{N} \sum_{i=1}^N \hat{L}_{11i}^{-2} \hat{\sigma}_i^2$$

$$\hat{L}_{11i} = \hat{\omega}_{u,i}^2 - \hat{\Omega}_{u\epsilon,i} \hat{\Omega}_{\epsilon,i} \hat{\Omega}_{u\epsilon,i}'$$

and

$$\tilde{s}_{N,T}^{*2} = \frac{1}{N} \sum_{i=1}^N \tilde{s}_i^{*2}$$

The asymptotic distribution of all test statistics, after appropriate standardization, converges to  $N(0, 1)$ . The adjustment is given by

$$\frac{\chi - \mu\sqrt{N}}{\sqrt{\nu}}$$

where  $\chi$  is any of the test statistics given above, and the parameters  $\mu$  and  $\nu$  are the mean and variance of the test statistic obtained through simulation. Refer to [Pedroni \(1999\)](#) for details and an algorithm to obtain the predicted residuals. The adjusted statistics are reported in the output.

## Westerlund tests

[Westerlund \(2005\)](#) assumes panel-specific cointegrating vectors as in (4), where all panels have individual slope coefficients. The VR test statistics are obtained by testing for a unit root in the predicted residuals using the DF regression in (3).

[Westerlund \(2005\)](#) derives test statistics based on a model in which the AR parameter either is panel-specific or is the same over the panels.

The panel-specific-AR test statistic is used to test the null hypothesis of no cointegration against the alternative hypothesis that some panels are cointegrated. The same-AR test statistic is used to test the null hypothesis of no cointegration against the alternative hypothesis that all the panels are cointegrated.

The panel-specific-AR test statistic is given by

$$\text{VR} = \sum_{i=1}^N \sum_{t=1}^T \widehat{E}_{it}^2 \widehat{R}_i^{-1}$$

The same-AR test statistic is given by

$$\text{VR} = \sum_{i=1}^N \sum_{t=1}^T \widehat{E}_{it}^2 \left( \sum_{i=1}^N \widehat{R}_i \right)^{-1}$$

where  $\widehat{E}_{it} = \sum_{j=1}^t \widehat{e}_{ij}$ ,  $\widehat{R}_i = \sum_{t=1}^T \widehat{e}_{it}^2$ , and  $\widehat{e}_{it}$  are the residuals from the panel-data regression model in (4). The asymptotic distribution of all test statistics, after appropriate standardization, converges to  $N(0, 1)$ .

## Long-run variance

We use the Newey and West (1987) estimator to consistently estimate the long-run variance matrix  $\Omega_i$ , given by

$$\widehat{\Omega}_i = \frac{1}{T} \sum_{t=1}^T \widehat{\mathbf{w}}_{it} \widehat{\mathbf{w}}'_{it} + \frac{1}{T} \sum_{j=1}^m K(j, m) \sum_{t=j+1}^T (\widehat{\mathbf{w}}_{it} \widehat{\mathbf{w}}'_{it} + \widehat{\mathbf{w}}_{i,t-j} \widehat{\mathbf{w}}'_{it})$$

where  $m$  is the maximum number of lags and  $K(j, m)$  is the kernel weight function. Define  $z = j/(m + 1)$ . If *kernel* is `bartlett`, then

$$K(j, m) = \begin{cases} 1 - z & 0 \leq z \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

If *kspec* is `parzen`, then

$$K(j, m) = \begin{cases} 1 - 6z^2 + 6z^3 & 0 \leq z \leq 0.5 \\ 2(1-z)^3 & 0.5 < z \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

If *kernel* is `quadraticspectral`, then

$$K(j, m) = \begin{cases} 1 & z = 0 \\ 3\{\sin(\theta)/\theta - \cos(\theta)\}/\theta^2 & \text{otherwise} \end{cases}$$

where  $\theta = 6\pi z/5$ . If we request automatic bandwidth (lag) selection using the Newey–West algorithm, then the method documented in *Methods and formulas* of [R] `ivregress` with  $\mathbf{z}_i = \mathbf{h} = 1$  is used.

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## Also see

- [XT] **xtunitroot** — Panel-data unit-root tests
- [TS] **dfglss** — DF-GLS unit-root test
- [TS] **dfuller** — Augmented Dickey–Fuller unit-root test
- [TS] **pperron** — Phillips–Perron unit-root test

**xtdata** — Faster specification searches with xt data[Description](#)  
[Options](#)[Quick start](#)  
[Remarks and examples](#)[Menu](#)  
[Methods and formulas](#)[Syntax](#)  
[Also see](#)

## Description

`xtdata` produces a transformed dataset of the variables specified in *varlist* or of all the variables in the data. Once the data are transformed, Stata's `regress` command may be used to perform specification searches more quickly than `xtreg`; see [R] `regress` and [XT] `xtreg`. Using `xtdata`, `re` also creates a variable named `constant`. When using `regress` after `xtdata`, `re`, specify `noconstant` and include `constant` in the regression. After `xtdata`, `be` and `xtdata`, `fe`, you need not include `constant` or specify `regress`'s `noconstant` option.

## Quick start

Convert data to a form suitable for random-effects estimation using `xtset` data

```
xtdata, re
```

As above, but convert only variables `v1`, `v2` and `v3`

```
xtdata v1 v2 v3, re
```

Convert all variables beginning with `prefix` to a form suitable for fixed-effects estimation

```
xtdata prefix*, fe
```

Convert data for between estimation if the dataset has changed since last `save`

```
xtdata, be clear
```

## Menu

Statistics > Longitudinal/panel data > Setup and utilities > Faster specification searches with xt data

## Syntax

`xtdata [varlist] [if] [in] [, options]`

<i>options</i>	Description
<b>Main</b>	
<code>re</code>	convert data to a form suitable for random-effects estimation
<code>ratio(#)</code>	ratio of random effect to pure residual (standard deviations)
<code>be</code>	convert data to a form suitable for between estimation
<code>fe</code>	convert data to a form suitable for fixed-effects (within) estimation
<code>nodouble</code>	keep original variable type; default is to recast type as <code>double</code>
<code>clear</code>	overwrite current data in memory

A panel variable must be specified; use `xtset`; see [XT] `xtset`.

## Options

### Main

`re` specifies that the data be converted into a form suitable for random-effects estimation. `re` is the default if `be`, `fe`, or `re` is not specified. `ratio()` must also be specified.

`ratio(#)` (use with `xtdata`, `re` only) specifies the ratio  $\sigma_\nu/\sigma_\epsilon$ , which is the ratio of the random effect to the pure residual. This is the ratio of the standard deviations, not the variances.

`be` specifies that the data be converted into a form suitable for between estimation.

`fe` specifies that the data be converted into a form suitable for fixed-effects (within) estimation.

`nodouble` specifies that transformed variables keep their original types, if possible. The default is to recast variables to `double`.

Remember that `xtdata` transforms variables to be differences from group means, pseudodifferences from group means, or group means. Specifying `nodouble` will decrease the size of the resulting dataset but may introduce roundoff errors in these calculations.

`clear` specifies that the data may be converted even though the dataset has changed since it was last saved on disk.

## Remarks and examples

If you have not read [XT] `xt` and [XT] `xtreg`, please do so.

The formal estimation commands of `xtreg`—see [XT] `xtreg`—do not produce results instantaneously, especially with large datasets. Equations (2), (3), and (4) of [XT] `xtreg` describe the data necessary to fit each of the models with OLS. The idea here is to transform the data once to the appropriate form and then use `regress` to fit such models more quickly.

### Example 1

We will use the `example` in [XT] `xtreg` demonstrating between-effects regression. Another way to estimate the between equation is to convert the data in memory to the between data:

```
. use https://www.stata-press.com/data/r16/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)

. generate age2=age^2
(24 missing values generated)

. generate ttl_exp2 = ttl_exp^2
. generate tenure2=tenure^2
(433 missing values generated)

. generate byte black = race==2

. xtdata ln_w grade age* ttl_exp* tenure* black not_smsa south, be clear

. regress ln_w grade age* ttl_exp* tenure* black not_smsa south
```

Source	SS	df	MS	Number of obs	=	4,697
Model	415.021613	10	41.5021613	F(10, 4686)	=	450.23
Residual	431.954995	4,686	.092179896	Prob > F	=	0.0000
				R-squared	=	0.4900
Total	846.976608	4,696	.180361288	Adj R-squared	=	0.4889
				Root MSE	=	.30361
ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf.	Interval
grade	.0607602	.0020006	30.37	0.000	.0568382	.0646822
age	.0323158	.0087251	3.70	0.000	.0152105	.0494211
age2	-.0005997	.0001429	-4.20	0.000	-.0008799	-.0003194
(output omitted)						
south	-.0993378	.010136	-9.80	0.000	-.1192091	-.0794665
_cons	.3339113	.1210434	2.76	0.006	.0966093	.5712133

The output is the same as that produced by `xtreg, be`; the reported  $R^2$  is the  $R^2$  between. Using `xtdata` followed by just one `regress` does not save time. Using `xtdata` is justified when you intend to explore the specification of the model by running many alternative regressions.



## □ Technical note

When using `xtdata`, you must eliminate any variables that you do not intend to use and that have missing values. `xtdata` follows a casewise-deletion rule, which means that an observation is excluded from the conversion if it is missing on any of the variables. In the [example above](#), we specified that the variables be converted on the command line. We could also drop the variables first, and it might even be useful to preserve our estimation sample:

```
. use https://www.stata-press.com/data/r16/nlswork, clear
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)

. generate age2=age^2
(24 missing values generated)

. generate ttl_exp2 = ttl_exp^2
. generate tenure2=tenure^2
(433 missing values generated)

. generate byte black = race==2

. keep id year ln_w grade age* ttl_exp* tenure* black not_smsa south
. save xtdataasmpl
file xtdataasmpl.dta saved
```



## ▷ Example 2

**xtdata** with the **fe** option converts the data so that results are equivalent to those from estimating by using **xtreg** with the **fe** option.

Source	SS	df	MS	Number of obs	=	28,091
Model	412.443881	8	51.5554852	F(8, 28082)	=	732.64
Residual	1976.12232	28,082	.070369714	Prob > F	=	0.0000
Total	2388.5662	28,090	.085032617	R-squared	=	0.1727
				Adj R-squared	=	0.1724
				Root MSE	=	.26527
ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
grade	0 (omitted)					
age	.0359987	.0030903	11.65	0.000	.0299415	.0420558
age2	-.000723	.0000486	-14.88	0.000	-.0008183	-.0006277
ttl_exp	.0334668	.0027061	12.37	0.000	.0281627	.0387708
ttl_exp2	.0002163	.0001166	1.86	0.064	-.0000122	.0004447
tenure	.0357539	.0016871	21.19	0.000	.0324472	.0390606
tenure2	-.0019701	.0001141	-17.27	0.000	-.0021937	-.0017465
black	0 (omitted)					
not_smsa	-.0890108	.0086982	-10.23	0.000	-.1060597	-.0719619
south	-.0606309	.0099761	-6.08	0.000	-.0801845	-.0410772
_cons	1.03732	.0443093	23.41	0.000	.9504716	1.124168

The coefficients reported by **regress** after **xtdata, fe** are the same as those reported by **xtreg, fe**, but the standard errors are slightly smaller. This is because no adjustment has been made to the estimated covariance matrix for the estimation of the person means. The difference is small, however, and results are adequate for a specification search.



## ▷ Example 3

To use **xtdata, re**, you must specify the ratio  $\sigma_\nu/\sigma_\epsilon$ , which is the ratio of the standard deviations of the random effect and pure residual. Merely to show the relationship of **regress** after **xtdata, re** to **xtreg, re**, we will specify this ratio as  $0.25790526/0.29068923 = 0.88721987$ , which is the number **xtreg** reports when the model is fit from the outset; see the [random-effects example in \[XT\] xtreg](#). For specification searches, however, it is adequate to specify this number more crudely, and, when performing the specification search for this manual entry, we used **ratio(1)**.

```
. use https://www.stata-press.com/data/r16/xtdatasmpl, clear
(National Longitudinal Survey. Young Women 14–26 years of age in 1968)
. xtdata, clear re ratio(.88721987)
```

theta				
min	5%	median	95%	max
0.2520	0.2520	0.5499	0.7016	0.7206

**xtdata** reports the distribution of  $\theta$  based on the specified ratio. If these were balanced data,  $\theta$  would have been constant.

When running regressions with these data, you must specify the `noconstant` option and include the variable `constant`:

<pre>. regress ln_w grade age* ttl_exp* tenure* black not_smsa south constant, &gt; noconstant</pre>						
Source	SS	df	MS	Number of obs	=	28,091
Model	13271.7208	11	1206.52007	F(11, 28080)	=	14302.56
Residual	2368.74223	28,080	.084356917	Prob > F	=	0.0000
Total	15640.463	28,091	.556778435	R-squared	=	0.8486
				Adj R-squared	=	0.8485
				Root MSE	=	.29044
<hr/>						
ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]	
grade	.0646499	.0017812	36.30	0.000	.0611587	.0681411
age	.0368059	.0031195	11.80	0.000	.0306915	.0429203
age2	-.0007133	.00005	-14.27	0.000	-.0008113	-.0006153
<i>(output omitted)</i>						
south	-.0868922	.0073032	-11.90	0.000	-.1012068	-.0725775
constant	.2387206	.049469	4.83	0.000	.141759	.3356822

Results are the same coefficients and standard errors that `xtreg, re` estimated in example 4 of [XT] `xtreg`. The summaries at the top, however, should be ignored, as they are expressed in terms of (4) of [XT] `xtreg`, and, moreover, for a model without a constant.

□

## □ Technical note

Using `xtdata` requires some caution. The following guidelines may help:

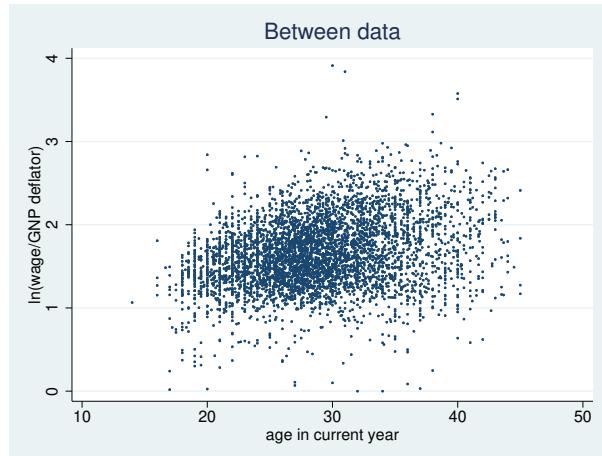
1. `xtdata` is intended for use only during the specification search phase of analysis. Results should be estimated with `xtreg` on unconverted data.
2. After converting the data, you may use `regress` to obtain estimates of the coefficients and their standard errors. For `regress` after `xtdata, fe`, the standard errors are too small, but only slightly.
3. You may loosely interpret the coefficient's significance tests and confidence intervals. However, for results after `xtdata, fe` and `re`, an incorrect (but close to correct) distribution is assumed.
4. You should ignore the summary statistics reported at the top of `regress`'s output.
5. After converting the data, you may form linear, but not nonlinear, combinations of regressors; that is, if your data contained `age`, it would not be correct to convert the data and then form `age squared`. All nonlinear transformations should be done before conversion. (For `xtdata, be`, you can get away with forming nonlinear combinations *ex post*, but the results will not be exact.)

□

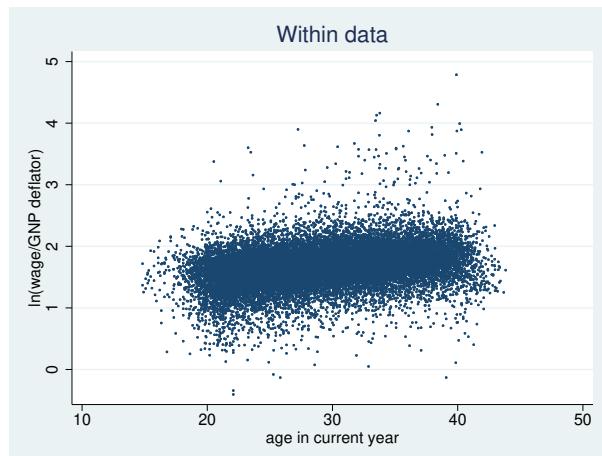
## □ Technical note

The **xtdata** command can be used to help you examine data, especially with **scatter**.

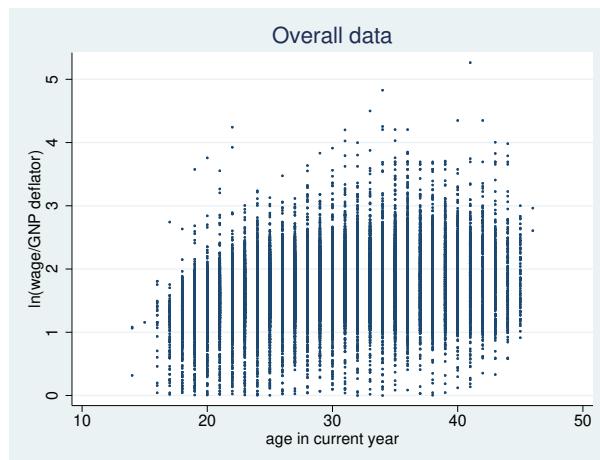
```
. use https://www.stata-press.com/data/r16/xtdatasmpl, clear  
(National Longitudinal Survey. Young Women 14–26 years of age in 1968)  
. xtdata, be  
. scatter ln_wage age, title(Between data) msymbol(o) msizes(tiny)
```



```
. use https://www.stata-press.com/data/r16/xtdatasmpl, clear  
(National Longitudinal Survey. Young Women 14–26 years of age in 1968)  
. xtdata, fe  
. scatter ln_wage age, title(Within data) msymbol(o) msizes(tiny)
```



```
. use https://www.stata-press.com/data/r16/xtdatasmpl, clear
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. scatter ln_wage age, title(Overall data) msymbol(o) msize(tiny)
```



□

## Methods and formulas

(This section is a continuation of the [Methods and formulas](#) of [\[XT\] xtreg](#).)

`xtdata`, `be`, `fe`, and `re` transform the data according to (2), (3), and (4), respectively, of [\[XT\] xtreg](#), except that `xtdata`, `fe` adds back in the overall mean, thus forming the transformation

$$\mathbf{x}_{it} - \bar{\mathbf{x}}_i + \bar{\mathbf{x}}$$

`xtdata`, `re` requires the user to specify  $r$  as an estimate of  $\sigma_\nu/\sigma_\epsilon$ .  $\theta_i$  is calculated from

$$\theta_i = 1 - \frac{1}{\sqrt{T_i r^2 + 1}}$$

## Also see

[\[XT\] xtsum](#) — Summarize xt data

**xtdescribe** — Describe pattern of xt data

Description  
Options

Quick start  
Remarks and examples

Menu  
Reference

Syntax  
Also see

## Description

`xtdescribe` describes the participation pattern of cross-sectional time-series (xt) data.

## Quick start

Describe the 9 most common participation patterns of `xtset` data

```
xtdescribe
```

Describe up to 15 of the most common participation patterns

```
xtdescribe, patterns(15)
```

As above, but list all participation patterns

```
xtdescribe, patterns(1000)
```

Describe patterns only for study subjects, denoted by binary variable `insample = 1`

```
xtdescribe if insample
```

## Menu

Statistics > Longitudinal/panel data > Setup and utilities > Describe pattern of xt data

## Syntax

`xtdescribe [if] [in] [, options]`

<i>options</i>	Description
----------------	-------------

---

### Main

<code>patterns(#)</code>	maximum participation patterns; default is <code>patterns(9)</code>
<code>width(#)</code>	display # width of participation patterns; default is <code>width(100)</code>

A panel variable and a time variable must be specified; use `xtset`; see [XT] `xtset`.  
`by` is allowed; see [D] `by`.

## Options

---

### Main

`patterns(#)` specifies the maximum number of participation patterns to be reported; `patterns(9)` is the default. Specifying `patterns(50)` would list up to 50 patterns. Specifying `patterns(1000)` is taken to mean `patterns( $\infty$ )`: all the patterns will be listed.

`width(#)` specifies the desired width of the participation patterns to be displayed; `width(100)` is the default. If the number of times is greater than `width()`, then each column in the participation pattern represents multiple periods as indicated in a footnote at the bottom of the table. The actual width may differ slightly from the requested width depending on the span of the time variable and the number of periods.

## Remarks and examples

If you have not read [XT] `xt`, please do so.

`xtdescribe` describes the cross-sectional and time-series aspects of the data in memory.

## ▷ Example 1

In [XT] **xt**, we introduced data based on a subsample of the NLSY data on young women aged 14–26 years in 1968. Here is a description of the data used in many of the [XT] **xt** examples:

. use https://www.stata-press.com/data/r16/nlswork							
(National Longitudinal Survey. Young Women 14–26 years of age in 1968)							
. xtdescribe							
idcode: 1, 2, ..., 5159					n =	4711	
year: 68, 69, ..., 88					T =	15	
Delta(year) = 1 unit							
Span(year) = 21 periods							
(idcode*year uniquely identifies each observation)							
Distribution of T_i:	min	5%	25%	50%	75%	95%	max
	1	1	3	5	9	13	15
Freq.	Percent	Cum.	Pattern				
136	2.89	2.89	1.....				
114	2.42	5.31	.....1				
89	1.89	7.20	.....1.11				
87	1.85	9.04	.....11				
86	1.83	10.87	111111.1.11.1.11.1.11				
61	1.29	12.16	.....11.1.11				
56	1.19	13.35	11.....				
54	1.15	14.50	.....1.11				
54	1.15	15.64	.....1.11.1.11.1.11				
3974	84.36	100.00	(other patterns)				
4711	100.00		XXXXXX.X.XX.X.XX.X.XX				

**xtdescribe** tells us that we have 4,711 women in our data and that the **idcode** that identifies each ranges from 1 to 5,159. We are also told that the maximum number of individual years over which we observe any woman is 15, though the **year** variable spans 21 years. The delta or periodicity of **year** is one unit, meaning that in principle we could observe each woman yearly. We are reassured that **idcode** and **year**, taken together, uniquely identify each observation in our data. We are also shown the distribution of  $T_i$ ; 50% of our women are observed 5 years or less. Only 5% of our women are observed for 13 years or more.

Finally, we are shown the participation pattern. A 1 in the pattern means one observation that year; a dot means no observation. The largest fraction of our women (still only 2.89%) was observed in the single year 1968 and not thereafter; the next largest fraction was observed in 1988 but not before; and the next largest fraction was observed in 1985, 1987, and 1988.

At the bottom is the sum of the participation patterns, including the patterns that were not shown. We can see that none of the women were observed in six of the years (there are six dots). (The survey was not administered in those six years.)

We could see more of the patterns by specifying the **patterns()** option, or we could see all the patterns by specifying **patterns(1000)**.



## ▷ Example 2

The strange participation patterns shown above have to do with our subsampling of the data, not with the administrators of the survey. Here are the data from which we drew the sample used in [XT] **xt**:

Distribution of T_i:			min	5%	25%	50%	75%	95%	max
Freq.	Percent	Cum.		Pattern					
1034	20.04	20.04	1	2	11	15	16	19	30
153	2.97	23.01	2	.....					
147	2.85	25.86	3	112111.1.11.1.11.1.11					
130	2.52	28.38	4	111112.1.11.1.11.1.11					
122	2.36	30.74	5	111211.1.11.1.11.1.11					
113	2.19	32.93	6	11.....					
84	1.63	34.56	7	111111.1.11.1.11.1.12					
79	1.53	36.09	8	111111.1.12.1.11.1.11					
67	1.30	37.39	9	111111.1.11.1.11.1.1.					
3230	62.61	100.00	10	(other patterns)					
5159	100.00			XXXXXX.X.XX.X.XX.X.XX					

We have multiple observations per year. In the pattern, 2 indicates that a woman appears twice in the year, 3 indicates 3 times, and so on—X indicates 10 or more, should that be necessary.

In fact, this is a dataset that was itself extracted from the NLSY, in which  $t$  is not time but job number. To simplify exposition, we made a simpler dataset by selecting the last job in each year.



## ▷ Example 3

When the number of periods is greater than the width of the participation pattern, each column will represent more than one period.

Distribution of T_i:			min	5%	25%	50%	75%	95%	max
Freq.	Percent	Cum.		Pattern*					
21	70.00	70.00	1	2222222222222222					
4	13.33	83.33	2	1222222222222222					
3	10.00	93.33	3	222222222222222.					
2	6.67	100.00	4	.2222222222222222					
30	100.00			XXXXXXXXXXXXXXXXXX					

\*Each column represents 2 periods.

We have data for 30 patients who were observed hourly between 4:00 PM on March 9, 2007, and 11:00 PM on March 10, a span of 32 hours. We have complete records for 21 of the patients. The

footnote indicates that each column in the pattern represents two periods, so for four patients we have an observation taken at either 4:00 PM or 5:00 PM on March 9, but we do not have observations for both times. There are three patients for whom we are missing both the 10:00 PM and 11:00 PM observations on March 10, and there are two patients for whom we are missing the 4:00 PM and 5:00 PM observations for March 9.



## Reference

Cox, N. J. 2007. Speaking Stata: Counting groups, especially panels. *Stata Journal* 7: 571–581.

## Also see

[XT] **xtsum** — Summarize xt data

[XT] **xttab** — Tabulate xt data

**xtdpd** — Linear dynamic panel-data estimation[Description](#)[Options](#)[Acknowledgment](#)[Quick start](#)[Remarks and examples](#)[References](#)[Menu](#)[Stored results](#)[Also see](#)[Syntax](#)[Methods and formulas](#)

## Description

`xtdpd` fits a linear dynamic panel-data model where the unobserved panel-level effects are correlated with the lags of the dependent variable. The command can fit Arellano–Bond and Arellano–Bover/Blundell–Bond models like those fit by `xtabond` and `xtdpdsys`. However, it also allows models with low-order moving-average correlation in the idiosyncratic errors or predetermined variables with a more complicated structure than allowed for `xtabond` or `xtdpdsys`.

## Quick start

Arellano–Bond model of `y` on `L.y` and `x` with the first difference of `x` as an instrument for the difference equation using `xtset` data

```
xtdpd y L.y x, div(x) dgmmiv(y)
```

Add the first difference of the lag of `x` as an instrument for the level equation

```
xtdpd y L.y x, div(x) dgmmiv(y) lgmmiv(x)
```

Use lags 3 to 5 of `x` as instruments for the difference equation

```
xtdpd y L.y x, div(x) dgmmiv(y, lagrange(3 5))
```

## Menu

Statistics > Longitudinal/panel data > Dynamic panel data (DPD) > Linear DPD estimation

## Syntax

**xtdpd** *depvar* [*indepvars*] [*if*] [*in*], **dgmmiv**(*varlist* [...]) [*options*]

<i>options</i>	Description
<b>Model</b>	
* <u><b>dgmmiv</b></u> ( <i>varlist</i> [...])	GMM-type instruments for the difference equation; can be specified more than once
<u><b>lgmmiv</b></u> ( <i>varlist</i> [...])	GMM-type instruments for the level equation; can be specified more than once
<b>iv</b> ( <i>varlist</i> [...])	standard instruments for the difference and level equations; can be specified more than once
<b>div</b> ( <i>varlist</i> [...])	standard instruments for the difference equation only; can be specified more than once
<b>liv</b> ( <i>varlist</i> )	standard instruments for the level equation only; can be specified more than once
<u><b>noconstant</b></u>	suppress constant term
<u><b>twostep</b></u>	compute the two-step estimator instead of the one-step estimator
<u><b>hascons</b></u>	check for collinearity only among levels of independent variables; by default checks occur among levels and differences
<u><b>fodeviation</b></u>	use forward-orthogonal deviations instead of first differences
<b>SE/Robust</b>	
<b>vce</b> ( <i>vcetype</i> )	<i>vcetype</i> may be <b>gmm</b> or <u><b>robust</b></u>
<b>Reporting</b>	
<u><b>level</b></u> (#)	set confidence level; default is <b>level</b> (95)
<u><b>artests</b></u> (#)	use # as maximum order for AR tests; default is <b>artests</b> (2)
<u><b>display_options</b></u>	control spacing and line width
<u><b>coeflegend</b></u>	display legend instead of statistics

\* **dgmmiv**() is required.

A panel variable and a time variable must be specified; use **xtset**; see [XT] **xtset**.

*depvar*, *indepvars*, and all *varlists* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

*by*, *statsby*, and *xi* are allowed; see [U] 11.1.10 Prefix commands.

*coeflegend* does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

**dgmmiv**(*varlist* [, **lagrange**(*flag* [*llag*])]) specifies GMM-type instruments for the difference equation. Levels of the variables are used to form GMM-type instruments for the difference equation. All possible lags are used, unless **lagrange**(*flag* *llag*) restricts the lags to begin with *flag* and end with *llag*. You may specify as many sets of GMM-type instruments for the difference equation as you need within the standard Stata limits on matrix size. Each set may have its own *flag* and *llag*. **dgmmiv**() is required.

**lgmmiv**(*varlist* [, **lag**(#)]) specifies GMM-type instruments for the level equation. Differences of the variables are used to form GMM-type instruments for the level equation. The first lag of the

differences is used unless `lag(#)` is specified, indicating that #th lag of the differences be used. You may specify as many sets of GMM-type instruments for the level equation as you need within the standard Stata limits on matrix size. Each set may have its own `lag`.

`iv(varlist [ , nodifference ])` specifies standard instruments for both the differenced and level equations. Differences of the variables are used as instruments for the differenced equations, unless `nodifference` is specified, which requests that levels be used. Levels of the variables are used as instruments for the level equations. You may specify as many sets of standard instruments for both the differenced and level equations as you need within the standard Stata limits on matrix size.

`div(varlist [ , nodifference ])` specifies additional standard instruments for the difference equation. Specified variables may not be included in `iv()` or in `liv()`. Differences of the variables are used, unless `nodifference` is specified, which requests that levels of the variables be used as instruments for the difference equation. You may specify as many additional sets of standard instruments for the difference equation as you need within the standard Stata limits on matrix size.

`liv(varlist)` specifies additional standard instruments for the level equation. Specified variables may not be included in `iv()` or in `div()`. Levels of the variables are used as instruments for the level equation. You may specify as many additional sets of standard instruments for the level equation as you need within the standard Stata limits on matrix size.

`noconstant`; see [\[R\] Estimation options](#).

`twostep` specifies that the two-step estimator be calculated.

`hascons` specifies that `xtdpd` check for collinearity only among levels of independent variables; by default checks occur among levels and differences.

`fodeviation` specifies that forward-orthogonal deviations be used instead of first differences. `fodeviation` is not allowed when there are gaps in the data or when `lgmmiv()` is specified.

#### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory and that are robust to some kinds of misspecification; see [Methods and formulas](#).

`vce(gmm)`, the default, uses the conventionally derived variance estimator for generalized method of moments estimation.

`vce(robust)` uses the robust estimator. For the one-step estimator, this is the Arellano–Bond robust VCE estimator. For the two-step estimator, this is the [Windmeijer \(2005\)](#) WC-robust estimator.

#### Reporting

`level(#)`; see [\[R\] Estimation options](#).

`artests(#)` specifies the maximum order of the autocorrelation test to be calculated. The tests are reported by `estat abond`; see [\[XT\] xtdpd postestimation](#). Specifying the order of the highest test at estimation time is more efficient than specifying it to `estat abond`, because `estat abond` must refit the model to obtain the test statistics. The maximum order must be less than or equal to the number of periods in the longest panel. The default is `artests(2)`.

`display_options`: `vsquish` and `nolstretch`; see [\[R\] Estimation options](#).

The following option is available with `xtdpd` but is not shown in the dialog box:

`coeflegend`; see [\[R\] Estimation options](#).

## Remarks and examples

If you have not read [XT] **xtabond** and [XT] **xtdpdsys**, you should do so before continuing.

Linear dynamic panel-data models include  $p$  lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random. By construction, the unobserved panel-level effects are correlated with the lagged dependent variables, making standard estimators inconsistent. **xtdpd** fits a dynamic panel-data model by using the Arellano–Bond (1991) or the Arellano–Bover/Blundell–Bond (1995, 1998) estimator.

Consider the dynamic panel-data model

$$y_{it} = \sum_{j=1}^p \alpha_j y_{i,t-j} + \mathbf{x}_{it}\beta_1 + \mathbf{w}_{it}\beta_2 + \nu_i + \epsilon_{it} \quad i = \{1, \dots, N\}; \quad t = \{1, \dots, T_i\} \quad (1)$$

where

the  $\alpha_1, \dots, \alpha_p$  are  $p$  parameters to be estimated,

$\mathbf{x}_{it}$  is a  $1 \times k_1$  vector of strictly exogenous covariates,

$\beta_1$  is a  $k_1 \times 1$  vector of parameters to be estimated,

$\mathbf{w}_{it}$  is a  $1 \times k_2$  vector of predetermined covariates,

$\beta_2$  is a  $k_2 \times 1$  vector of parameters to be estimated,

$\nu_i$  are the panel-level effects (which may be correlated with  $x_{it}$  or  $w_{it}$ ), and

and  $\epsilon_{it}$  are i.i.d. or come from a low-order moving-average process, with variance  $\sigma_\epsilon^2$ .

Building on the work of Anderson and Hsiao (1981, 1982) and Holtz-Eakin, Newey, and Rosen (1988), Arellano and Bond (1991) derived one-step and two-step GMM estimators using moment conditions in which lagged levels of the dependent and predetermined variables were instruments for the difference equation. Blundell and Bond (1998) show that the lagged-level instruments in the Arellano–Bond estimator become weak as the autoregressive process becomes too persistent or the ratio of the variance of the panel-level effect  $\nu_i$  to the variance of the idiosyncratic error  $\epsilon_{it}$  becomes too large. Building on the work of Arellano and Bover (1995), Blundell and Bond (1998) proposed a system estimator that uses moment conditions in which lagged differences are used as instruments for the level equation in addition to the moment conditions of lagged levels as instruments for the difference equation. The additional moment conditions are valid only if the initial condition  $E[\nu_i \Delta y_{i2}] = 0$  holds for all  $i$ ; see Blundell and Bond (1998) and Blundell, Bond, and Windmeijer (2000).

**xtdpd** fits dynamic panel-data models by using the Arellano–Bond or the Arellano–Bover/Blundell–Bond system estimator. The parameters of many standard models can be more easily estimated using the Arellano–Bond estimator implemented in **xtabond** or using the Arellano–Bover/Blundell–Bond system estimator implemented in **xtdpdsys**; see [XT] **xtabond** and [XT] **xtdpdsys**. **xtdpd** can fit more complex models at the cost of a more complicated syntax. That the idiosyncratic errors follow a low-order MA process and that the predetermined variables have a more complicated structure than accommodated by **xtabond** and **xtdpdsys** are two common reasons for using **xtdpd** instead of **xtabond** or **xtdpdsys**.

The standard GMM robust two-step estimator of the VCE is known to be seriously biased. Windmeijer (2005) derived a bias-corrected robust estimator for two-step VCEs from GMM estimators known as the WC-robust estimator, which is implemented in **xtdpd**.

The Arellano–Bond test of autocorrelation of order  $m$  and the Sargan test of overidentifying restrictions derived by Arellano and Bond (1991) are computed by **xtdpd** but reported by **estat abond** and **estat sargan**, respectively; see [XT] **xtdpd postestimation**.

Because xtdpd extends xtabond and xtdpdsys, [XT] **xtabond** and [XT] **xtdpdsys** provide useful background.

## ▷ Example 1: An Arellano–Bond estimator

Arellano and Bond (1991) apply their new estimators and test statistics to a model of dynamic labor demand that had previously been considered by Layard and Nickell (1986), using data from an unbalanced panel of firms from the United Kingdom. All variables are indexed over the firm  $i$  and time  $t$ . In this dataset,  $n_{it}$  is the log of employment in firm  $i$  inside the United Kingdom at time  $t$ ,  $w_{it}$  is the natural log of the real product wage,  $k_{it}$  is the natural log of the gross capital stock, and  $ys_{it}$  is the natural log of industry output. The model also includes time dummies  $yr1980$ ,  $yr1981$ ,  $yr1982$ ,  $yr1983$ , and  $yr1984$ . To gain some insight into the syntax for xtdpd, we reproduce the first example from [XT] **xtabond** using xtdpd:

```
. use https://www.stata-press.com/data/r16/abdata
. xtdpd L(0/2).n L(0/1).w L(0/2).(k ys) yr1980-yr1984 year, noconstant
> div(L(0/1).w L(0/2).(k ys) yr1980-yr1984 year) dgmmiv(n)

Dynamic panel-data estimation
Number of obs = 611
Group variable: id
Number of groups = 140
Time variable: year
Obs per group:
min = 4
avg = 4.364286
max = 6
Number of instruments = 41
Wald chi2(16) = 1757.07
Prob > chi2 = 0.0000
```

### One-step results

n	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
n					
L1.	.6862261	.1486163	4.62	0.000	.3949435 .9775088
L2.	-.0853582	.0444365	-1.92	0.055	-.1724523 .0017358
w					
--.	-.6078208	.0657694	-9.24	0.000	-.7367265 -.4789151
L1.	.3926237	.1092374	3.59	0.000	.1785222 .6067251
k					
--.	.3568456	.0370314	9.64	0.000	.2842653 .4294259
L1.	-.0580012	.0583051	-0.99	0.320	-.172277 .0562747
L2.	-.0199475	.0416274	-0.48	0.632	-.1015357 .0616408
ys					
--.	.6085073	.1345412	4.52	0.000	.3448115 .8722031
L1.	-.7111651	.1844599	-3.86	0.000	-1.0727 -.3496304
L2.	.1057969	.1428568	0.74	0.459	-.1741974 .3857912
yr1980	.0029062	.0212705	0.14	0.891	-.0387832 .0445957
yr1981	-.0404378	.0354707	-1.14	0.254	-.1099891 .0290836
yr1982	-.0652767	.048209	-1.35	0.176	-.1597646 .0292111
yr1983	-.0690928	.0627354	-1.10	0.271	-.1920521 .0538664
yr1984	-.0650302	.0781322	-0.83	0.405	-.2181665 .0881061
year	.0095545	.0142073	0.67	0.501	-.0182912 .0374002

### Instruments for differenced equation

GMM-type: L(2/..).n  
 Standard: D.w LD.w D.k LD.k L2D.k D.ys LD.ys L2D.ys D.yr1980  
 D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year

Unlike most instrumental-variables estimation commands, the independent variables in the varlist are not automatically used as instruments. In this example, all the independent variables are strictly exogenous, so we include them in `div()`, a list of variables whose first differences will be instruments for the difference equation. We include the dependent variable in `dgmiv()`, a list of variables whose lagged levels will be used to create GMM-type instruments for the difference equation. (GMM-type instruments are discussed in a [technical note](#) below.)

The footer in the output reports the instruments used. The first line indicates that `xtdpd` used lags from 2 on back to create the GMM-type instruments described in [Arellano and Bond \(1991\)](#) and [Holtz-Eakin, Newey, and Rosen \(1988\)](#). The second line says that the first difference of all the variables included in the `div()` varlist were used as standard instruments for the difference equation.

□

## □ Technical note

GMM-type instruments are built from lags of one variable. Ignoring the strictly exogenous variables for simplicity, our model is

$$n_{it} = \alpha_1 n_{it-1} + \alpha_2 n_{it-2} + \nu_i + \epsilon_{it} \quad (2)$$

After differencing we have

$$\Delta n_{it} = \Delta \alpha_1 n_{it-1} + \Delta \alpha_2 n_{it-2} + \Delta \epsilon_{it} \quad (3)$$

Equation (3) implies that we need instruments that are not correlated with either  $\epsilon_{it}$  or  $\epsilon_{it-1}$ . Equation (2) shows that `L2.n` is the first lag of `n` that is not correlated with  $\epsilon_{it}$  or  $\epsilon_{it-1}$ , so it is the first lag of `n` that can be used to instrument the difference equation.

Consider the following data from one of the complete panels in the [previous example](#):

```
. list id year n L2.n d12.n if id==140
```

id	year	n	L2.		L2D. n
			n	n	
1023.	140	1976	.4324315	.	.
1024.	140	1977	.3694925	.	.
1025.	140	1978	.3541718	.4324315	.
1026.	140	1979	.3632532	.3694925	-.0629391
1027.	140	1980	.3371863	.3541718	-.0153207
1028.	140	1981	.285179	.3632532	.0090815
1029.	140	1982	.1756326	.3371863	-.026067
1030.	140	1983	.1275133	.285179	-.0520073
1031.	140	1984	.0889263	.1756326	-.1095464

The missing values in `L2D.n` show that we lose 3 observations because of lags and the difference that removes the panel-level effects. The first nonmissing observation occurs in 1979 and observations on `n` from 1976 and 1977 are available to instrument the 1979 difference equation. The table below gives the observations available to instrument the differenced equation for the data above.

Year of difference errors	Years of instruments	Number of instruments
1979	1976–1977	2
1980	1976–1978	3
1981	1976–1979	4
1982	1976–1980	5
1983	1976–1981	6
1984	1976–1982	7

The table shows that there are a total of 27 GMM-type instruments.

The output in the example above informs us that there were a total of 41 instruments applied to the difference equation. Because there are 14 standard instruments, there must have been 27 GMM-type instruments, which matches our above calculation.  $\square$

## ▷ Example 2: An Arellano–Bond estimator with predetermined variables

Sometimes we cannot assume strict exogeneity. Recall that a variable  $x_{it}$  is said to be strictly exogenous if  $E[x_{it}\epsilon_{is}] = 0$  for all  $t$  and  $s$ . If  $E[x_{it}\epsilon_{is}] \neq 0$  for  $s < t$  but  $E[x_{it}\epsilon_{is}] = 0$  for all  $s \geq t$ , the variable is said to be predetermined. Intuitively, if the error term at time  $t$  has some feedback on the subsequent realizations of  $x_{it}$ ,  $x_{it}$  is a predetermined variable. In the output below, we use xtdpd to reproduce example 6 in [XT] xtabond.

```
. xtdpd L(0/2).n L(0/1).(w ys) L(0/2).k yr1980-yr1984 year,
> div(L(0/1).(ys) yr1980-yr1984 year) dgmmiv(n) dgmmiv(L.w L2.k, lag(1 .))
> twostep noconstant vce(robust)

Dynamic panel-data estimation
Number of obs      =          611
Group variable: id
Number of groups   =          140
Time variable: year
Obs per group:
    min =           4
    avg =     4.364286
    max =           6
Number of instruments =      83
Wald chi2(15)      =     958.30
Prob > chi2        =     0.0000
```

## Two-step results

(Std. Err. adjusted for clustering on id)

n	Coef.	WC-Robust Std. Err.	z	P> z	[95% Conf. Interval]
L1.	.8580958	.1265515	6.78	0.000	.6100594 1.106132
	-.081207	.0760703	-1.07	0.286	-.2303022 .0678881
L1.	-.6910855	.1387684	-4.98	0.000	-.9630666 -.4191044
	.5961712	.1497338	3.98	0.000	.3026982 .8896441
L1.	.6936392	.1728623	4.01	0.000	.3548354 1.032443
	-.8773678	.2183085	-4.02	0.000	-1.305245 -.449491
L1.	.4140654	.1382788	2.99	0.003	.1430439 .6850868
	-.1537048	.1220244	-1.26	0.208	-.3928681 .0854586
L1.	-.1025833	.0710886	-1.44	0.149	-.2419143 .0367477
yr1980	-.0072451	.017163	-0.42	0.673	-.0408839 .0263938
yr1981	-.0609608	.030207	-2.02	0.044	-.1201655 -.0017561
yr1982	-.1130369	.0454826	-2.49	0.013	-.2021812 -.0238926
yr1983	-.1335249	.0600213	-2.22	0.026	-.2511645 -.0158853
yr1984	-.1623177	.0725434	-2.24	0.025	-.3045001 -.0201352
year	.0264501	.0119329	2.22	0.027	.003062 .0498381

## Instruments for differenced equation

GMM-type: L(2/.).n L(1/.).L.w L(1/.).L2.k  
 Standard: D.ys LD.ys D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984  
 D.year

The footer informs us that we are now including GMM-type instruments from the first lag of L.w on back and from the first lag of L2.k on back.



## ▷ Example 3: A weaker definition of predetermined variables

As discussed in [XT] **xtabond** and [XT] **xtdpdsys**, **xtabond** and **xtdpdsys** both use a strict definition of predetermined variables with lags. In the strict definition, the most recent lag of the variable in `pre()` is considered predetermined. (Here specifying `pre(w, lag(1, .))` to **xtabond** means that L.w is a predetermined variable and `pre(k, lag(2, .))` means that L2.k is a predetermined variable.) In a weaker definition, the current observation is considered predetermined, but subsequent

lags are included in the model. Here *w* and *k* would be predetermined instead of *L.w* and *L2.w*. The output below implements this weaker definition for the [previous example](#).

```
. xtdpd L(0/2).n L(0/1).(w ys) L(0/2).k yr1980-yr1984 year,
> div(L(0/1).(ys) yr1980-yr1984 year) dgmmiv(n) dgmmiv(w k, lag(1 .))
> twostep noconstant vce(robust)

Dynamic panel-data estimation
Group variable: id
Time variable: year
Number of obs = 611
Number of groups = 140
Obs per group:
    min = 4
    avg = 4.364286
    max = 6
Number of instruments = 101
Wald chi2(15) = 879.53
Prob > chi2 = 0.0000
```

#### Two-step results

(Std. Err. adjusted for clustering on id)

n	WC-Robust					
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
n						
L1.	.6343155	.1221058	5.19	0.000	.3949925	.8736384
L2.	-.0871247	.0704816	-1.24	0.216	-.2252661	.0510168
w						
--.	-.720063	.1133359	-6.35	0.000	-.9421973	-.4979287
L1.	.238069	.1223186	1.95	0.052	-.0016712	.4778091
ys						
--.	.5999718	.1653036	3.63	0.000	.2759827	.923961
L1.	-.5674808	.1656411	-3.43	0.001	-.8921314	-.2428303
k						
--.	.3931997	.0986673	3.99	0.000	.1998153	.5865842
L1.	-.0019641	.0772814	-0.03	0.980	-.1534329	.1495047
L2.	-.0231165	.0487317	-0.47	0.635	-.1186288	.0723958
yr1980	-.006209	.0162138	-0.38	0.702	-.0379875	.0255694
yr1981	-.0398491	.0313794	-1.27	0.204	-.1013516	.0216535
yr1982	-.0525715	.0397346	-1.32	0.186	-.1304498	.0253068
yr1983	-.0451175	.0514118	-0.88	0.380	-.145895	.05566
yr1984	-.0437772	.0614391	-0.71	0.476	-.1641955	.0766412
year	.0173374	.0108665	1.60	0.111	-.0039605	.0386352

#### Instruments for differenced equation

GMM-type: L(2/.).n L(1/.).w L(1/.).k  
 Standard: D.ys LD.ys D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984  
 D.year

As expected, the output shows that the additional 18 instruments available under the weaker definition can affect the magnitudes of the estimates. Applying the stricter definition when the true model was generated by the weaker definition yielded consistent but inefficient results; there were some additional moment conditions that could have been included but were not. In contrast, applying the weaker definition when the true model was generated by the stricter definition yields inconsistent estimates. □

## ► Example 4: A system estimator of a dynamic panel-data model

Here we use **xtdpd** to reproduce [example 2](#) from [XT] **xtdpdsys** in which we used the system estimator to fit a model with predetermined variables.

. xtdpd L(0/1).n L(0/2).(w k) yr1980-yr1984 year, div(yr1980-yr1984 year)	> dgmmiv(n) dgmmiv(L2.(w k), lag(1 .)) lgmmiv(n L1.(w k)) vce(robust) hascons					
Dynamic panel-data estimation	Number of obs = 751					
Group variable: id	Number of groups = 140					
Time variable: year						
	Obs per group:					
	min = 5					
	avg = 5.364286					
	max = 7					
Number of instruments = 95	Wald chi2(13) = 7562.80					
	Prob > chi2 = 0.0000					
One-step results	(Std. Err. adjusted for clustering on id)					
n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]	
n L1.	.913278	.0460602	19.83	0.000	.8230017	1.003554
w --. L1. L2.	-.728159 .5602737 -.0523028	.1019044 .1939617 .1487653	-7.15 2.89 -0.35	0.000 0.004 0.725	-.9278879 .1801156 -.3438775	-.5284301 .9404317 .2392718
k --. L1. L2.	.4820097 -.2846944 -.1394181	.0760787 .0831902 .0405709	6.34 -3.42 -3.44	0.000 0.001 0.001	.3328983 -.4477442 -.2189356	.6311212 -.1216446 -.0599006
yr1980 yr1981 yr1982 yr1983 yr1984 year _cons	-.0325146 -.0726116 -.0477038 -.0396264 -.0810383 .0192741 -37.34972	.0216371 .0346482 .0451914 .0558734 .0736648 	-1.50 -2.10 -1.06 -0.71 -1.10 1.33 -1.30	0.133 0.036 0.291 0.478 0.271 0.185 0.194	-.0749226 -.1405207 -.1362772 -.1491362 -.2254186 -.0092092 -.93.75253	.0098935 -.0047024 .0408696 .0698835 .063342 .0477574 19.05308

Instruments for differenced equation

GMM-type: L(2/.).n L(1/.).L2.w L(1/.).L2.k

Standard: D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year

Instruments for level equation

GMM-type: LD.n L2D.w L2D.k

Standard: \_cons

The first lags of the variables included in **lgmmiv()** are used to create GMM-type instruments for the level equation. Only the first lags of the variables in **lgmmiv()** are used because the moment conditions using higher lags are redundant; see [Blundell and Bond \(1998\)](#) and [Blundell, Bond, and Windmeijer \(2000\)](#).



## ▷ Example 5: Allowing for MA(1) errors

All the previous examples have used moment conditions that are valid only if the idiosyncratic errors are i.i.d. This example shows how to use `xtdpd` to estimate the parameters of a model with first-order moving-average [MA(1)] errors using the Arellano–Bond estimator, the Arellano–Bover/Blundell–Bond system estimator, or any other consistent GMM estimator you want to specify. For simplicity, we assume that the independent variables are strictly exogenous. Also, to highlight the fact that we can specify the instrument list flexibly, we only include the levels and first lags of the exogenous variables in the instrument list. An Arellano–Bond estimator, for instance, would have included levels and first and second lags of the exogenous variables.

We begin by noting that the Sargan test rejects the null hypothesis that the overidentifying restrictions are valid in the model with i.i.d. errors.

```
. xtdpd L(0/1).n L(0/2).(w k) yr1980-yr1984 year,
> div(L(0/1).(w k) yr1980-yr1984 year) dgmmiv(n) hascons
  (output omitted)
. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
chi2(24)      =  49.70094
Prob > chi2   =    0.0015
```

Assuming that the idiosyncratic errors are MA(1) implies that only lags three or higher are valid instruments for the difference equation. (See the [technical note](#) below.)

. xtdpd L(0/1).n L(0/2).(w k) yr1980-yr1984 year,						
> div(L(0/1).(w k) yr1980-yr1984 year) dgmmiv(n, lag(3 .)) hascons						
Dynamic panel-data estimation					Number of obs =	751
Group variable: id					Number of groups =	140
Time variable: year						
					Obs per group:	
					min =	5
					avg =	5.364286
					max =	7
Number of instruments = 32					Wald chi2(13) =	1195.04
					Prob > chi2 =	0.0000
<b>One-step results</b>						
n	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
n L1.	.8696303	.2014473	4.32	0.000	.4748008	1.26446
w --. L1. L2.	-.5802971 .2918658 -.5903459	.0762659 .1543883 .2995123	-7.61 1.89 -1.97	0.000 0.059 0.049	-.7297756 -.0107296 -1.177379	-.4308187 .5944613 -.0033126
k --. L1. L2.	.3428139 -.1383918 -.0260956	.0447916 .0825823 .1535855	7.65 -1.68 -0.17	0.000 0.094 0.865	.2550239 -.3002502 -.3271177	.4306039 .0234665 .2749265
yr1980 yr1981 yr1982 yr1983 yr1984 year _cons	-.0036873 .00218 .0782939 .1734231 .2400685 -.0354681 73.13706	.0301587 .0592014 .0897622 .1308914 .1734456 .0309963 62.61443	-0.12 0.04 0.87 1.32 1.38 -1.14 1.17	0.903 0.971 0.383 0.185 0.166 0.253 0.243	-.0627973 -.1138526 -.0976367 -.0831193 -.0998787 -.0962198 -49.58496	.0554226 .1182125 .2542246 .4299655 .5800157 .0252836 195.8591

#### Instruments for differenced equation

GMM-type: L(3/.).n  
 Standard: D.w LD.w D.k LD.k D.yr1980 D.yr1981 D.yr1982 D.yr1983  
 D.yr1984 D.year

#### Instruments for level equation

Standard: \_cons

The results from `estat sargan` no longer reject the null hypothesis that the overidentifying restrictions are valid.

```
. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
chi2(18)      = 20.80081
Prob > chi2   = 0.2896
```

Moving on to the system estimator, we note that the Sargan test rejects the null hypothesis after fitting the model with i.i.d. errors.

```
. xtdpd L(0/1).n L(0/2).(w k) yr1980-yr1984 year,
> div(L(0/1).(w k) yr1980-yr1984 year) dgmmiv(n) lgmmiv(n) hascons
(output omitted)

. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
chi2(31)      =  59.22907
Prob > chi2   =  0.0017
```

Now we fit the model using the additional moment conditions constructed from the second lag of n as an instrument for the level equation.

```
. xtdpd L(0/1).n L(0/2).(w k) yr1980-yr1984 year,
> div(L(0/1).(w k) yr1980-yr1984 year) dgmmiv(n, lag(3 .)) lgmmiv(n, lag(2))
> hascons

Dynamic panel-data estimation                               Number of obs      =      751
Group variable: id                                     Number of groups   =      140
Time variable: year

Obs per group:
min =          5
avg =      5.364286
max =          7

Number of instruments =      38                           Wald chi2(13)     =    3680.01
                                                               Prob > chi2       =    0.0000
```

#### One-step results

n	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
n L1.	.9603675	.095608	10.04	0.000	.7729794 1.147756
w --. L1. L2.	-.5433987 .4356183 -.2785721	.068835 .0881727 .1115061	-7.89 4.94 -2.50	0.000 0.000 0.012	-.6783128 -.4084845 .262803 .6084336 -.4971201 -.0600241
k --. L1. L2.	.3139331 -.160103 -.1295766	.0419054 .0546915 .0507752	7.49 -2.93 -2.55	0.000 0.003 0.011	.2317999 .3960662 -.2672963 -.0529096 -.2290943 -.030059
yr1980 yr1981 yr1982 yr1983 yr1984 year _cons	-.0200704 -.0425838 .0048723 .0458978 .0633219 -.0075599 16.20856	.0248954 .0422155 .0600938 .0785687 .1026188 .019059 38.00619	-0.81 -1.01 0.08 0.58 0.62 -0.40 0.43	0.420 0.313 0.935 0.559 0.537 0.692 0.670	-.0688644 .0287236 -.1253246 .040157 .1129093 .122654 -.1080941 .1998897 -.1378074 .2644511 -.0449148 .029795 -58.28221 90.69932

#### Instruments for differenced equation

GMM-type: L(3/.).n  
Standard: D.w LD.w D.k LD.k D.yr1980 D.yr1981 D.yr1982 D.yr1983  
D.yr1984 D.year

#### Instruments for level equation

GMM-type: L2D.n  
Standard: \_cons

The estimate of the coefficient on L.n is now 0.96. Blundell, Bond, and Windmeijer (2000, 63–65) show that the moment conditions in the system estimator remain informative as the true coefficient on L.n approaches unity. Holtz-Eakin, Newey, and Rosen (1988) show that because the large-sample

distribution of the estimator is derived for fixed number of periods and a growing number of individuals there is no “unit-root” problem.

The results from `estat sargan` no longer reject the null hypothesis that the overidentifying restrictions are valid.

```
. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
chi2(24)      =  27.22585
Prob > chi2   =  0.2940
```

□

## □ Technical note

To find the valid moment conditions for the model with MA(1) errors, we begin by writing the model

$$n_{it} = \alpha n_{it-1} + \beta x_{it} + \nu_i + \epsilon_{it} + \gamma \epsilon_{it-1}$$

where the  $\epsilon_{it}$  are assumed to be i.i.d.

Because the composite error,  $\epsilon_{it} + \gamma \epsilon_{it-1}$ , is MA(1), only lags two or higher are valid instruments for the level equation, assuming the initial condition that  $E[\nu_i \Delta n_{i2}] = 0$ . The key to this point is that lagging the above equation two periods shows that  $\epsilon_{it-2}$  and  $\epsilon_{it-3}$  appear in the equation for  $n_{it-2}$ . Because the  $\epsilon_{it}$  are i.i.d.,  $n_{it-2}$  is a valid instrument for the level equation with errors  $\nu_i + \epsilon_{it} + \gamma \epsilon_{it-1}$ . ( $n_{it-2}$  will be correlated with  $n_{it-1}$  but uncorrelated with the errors  $\nu_i + \epsilon_{it} + \gamma \epsilon_{it-1}$ .) An analogous argument works for higher lags.

First-differencing the above equation yields

$$\Delta n_{it} = \alpha \Delta n_{it-1} + \beta \Delta x_{it} + \Delta \epsilon_{it} + \gamma \Delta \epsilon_{it-1}$$

Because  $\epsilon_{it-2}$  is the farthest lag of  $\epsilon_{it}$  that appears in the difference equation, lags three or higher are valid instruments for the differenced composite errors. (Lagging the level equation three periods shows that only  $\epsilon_{it-3}$  and  $\epsilon_{it-4}$  appear in the equation for  $n_{it-3}$ , which implies that  $n_{it-3}$  is a valid instrument for the current difference equation. An analogous argument works for higher lags.)

□

## Stored results

`xtdpd` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(t_min)</code>	minimum time in sample
<code>e(t_max)</code>	maximum time in sample
<code>e(chi2)</code>	$\chi^2$
<code>e(arm#)</code>	test for autocorrelation of order #
<code>e(artests)</code>	number of AR tests computed
<code>e(sig2)</code>	estimate of $\sigma_e^2$
<code>e(rss)</code>	sum of squared differenced residuals
<code>e(sargan)</code>	Sargan test statistic
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(zrank)</code>	rank of instrument matrix

Macros

<code>e(cmd)</code>	<code>xtdpd</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(twostep)</code>	<code>twostep</code> , if specified
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(vce)</code>	<i>vctype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(system)</code>	<code>system</code> , if system estimator
<code>e(transform)</code>	specified transform
<code>e(diffvars)</code>	already-differenced exogenous variables
<code>e(datasignature)</code>	checksum from <code>datasignature</code>
<code>e(datasignaturevars)</code>	variables used in calculation of checksum
<code>e(properties)</code>	<code>b V</code>
<code>e(estat_cmd)</code>	program used to implement <code>estat</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

Consider dynamic panel-data models of the form

$$y_{it} = \sum_{j=1}^p \alpha_j y_{i,t-j} + \mathbf{x}_{it}\boldsymbol{\beta}_1 + \mathbf{w}_{it}\boldsymbol{\beta}_2 + \nu_i + \epsilon_{it}$$

where the variables are as defined as in (1).

$\mathbf{x}$  and  $\mathbf{w}$  may contain lagged independent variables and time dummies.

Let  $\mathbf{X}_{it}^L = (y_{i,t-1}, y_{i,t-2}, \dots, y_{i,t-p}, \mathbf{x}_{it}, \mathbf{w}_{it})$  be the  $1 \times K$  vector of covariates for  $i$  at time  $t$ , where  $K = p + k_1 + k_2$ ,  $p$  is the number of included lags,  $k_1$  is the number of strictly exogenous variables in  $x_{it}$ , and  $k_2$  is the number of predetermined variables in  $w_{it}$ . (The superscript  $L$  stands for levels.)

Now rewrite this relationship as a set of  $T_i$  equations for each individual,

$$\mathbf{y}_i^L = \mathbf{X}_i^L \boldsymbol{\delta} + \nu_i \boldsymbol{\iota}_i + \boldsymbol{\epsilon}_i$$

where  $T_i$  is the number of observations available for individual  $i$ ;  $\mathbf{y}_i$ ,  $\boldsymbol{\iota}_i$ , and  $\boldsymbol{\epsilon}_i$  are  $T_i \times 1$ , whereas  $\mathbf{X}_i$  is  $T_i \times K$ .

The estimators use both the levels and a transform of the variables in the above equation. Denote the transformed variables by an  $*$ , so that  $\mathbf{y}_i^*$  is the transformed  $\mathbf{y}_i^L$  and  $\mathbf{X}_i^*$  is the transformed  $\mathbf{X}_i^L$ . The transform may be either the first difference or the forward-orthogonal deviations (FOD) transform. The  $(i, t)$ th observation of the FOD transform of a variable  $\mathbf{x}$  is given by

$$x_{it}^* = c_t \left\{ x_{it} - \frac{1}{T-t} (x_{it+1} + x_{it+2} + \dots + x_{iT}) \right\}$$

where  $c_t^2 = (T-t)/(T-t+1)$  and  $T$  is the number of observations on  $\mathbf{x}$ ; see [Arellano and Bover \(1995\)](#) and [Arellano \(2003\)](#).

Here we present the formulas for the Arellano–Bover/Blundell–Bond system estimator. The formulas for the Arellano–Bond estimator are obtained by setting the additional level matrices in the system estimator to null matrices.

Stacking the transformed and untransformed vectors of the dependent variable for a given  $i$  yields

$$\mathbf{y}_i = \begin{pmatrix} \mathbf{y}_i^* \\ \mathbf{y}_i^L \end{pmatrix}$$

Similarly, stacking the transformed and untransformed matrices of the covariates for a given  $i$  yields

$$\mathbf{X}_i = \begin{pmatrix} \mathbf{X}_i^* \\ \mathbf{X}_i^L \end{pmatrix}$$

$\mathbf{Z}_i$  is a matrix of instruments,

$$\mathbf{Z}_i = \begin{pmatrix} \mathbf{Z}_{di} & \mathbf{0} & \mathbf{D}_i & \mathbf{0} & \mathbf{I}_i^d \\ \mathbf{0} & \mathbf{Z}_{Li} & \mathbf{0} & \mathbf{L}_i & \mathbf{I}_i^L \end{pmatrix}$$

where  $\mathbf{Z}_{di}$  is the matrix of GMM-type instruments created from the `dgmmiv()` options,  $\mathbf{Z}_{Li}$  is the matrix of GMM-type instruments created from the `lgmmiv()` options,  $\mathbf{D}_i$  is the matrix of standard instruments created from the `div()` options,  $\mathbf{L}_i$  is the matrix of standard instruments created from the `liv()` options,  $\mathbf{I}_i^d$  is the matrix of standard instruments created from the `iv()` options for the differenced errors, and  $\mathbf{I}_i^L$  is the matrix of standard instruments created from the `iv()` options for the level errors.

`div()`, `liv()`, and `iv()` simply add columns to instrument matrix. The GMM-type instruments are more involved. Begin by considering a simple balanced-panel example in which our model is

$$y_{it} = \alpha_1 y_{i,t-1} + \alpha_2 y_{i,t-2} + \nu_i + \epsilon_{it}$$

We do not need to consider covariates because strictly exogenous variables are handled using `div()`, `iv()`, or `liv()`, and predetermined or endogenous variables are handled analogous to the dependent variable.

Assume that the data come from a balanced panel in which there are no missing values. After first-differencing the equation, we have

$$\Delta y_{it} = \alpha_1 \Delta y_{i,t-1} + \alpha_2 \Delta y_{i,t-2} + \Delta \epsilon_{it}$$

The first 3 observations are lost to lags and differencing. If we assume that the  $\epsilon_{it}$  are not autocorrelated, for each  $i$  at  $t = 4$ ,  $y_{i1}$  and  $y_{i2}$  are valid instruments for the differenced equation. Similarly, at  $t = 5$ ,  $y_{i1}$ ,  $y_{i2}$ , and  $y_{i3}$  are valid instruments. We specify `dgmmiv(y)` to obtain an instrument matrix with one row for each period that we are instrumenting:

$$\mathbf{Z}_{di} = \begin{pmatrix} y_{i1} & y_{i2} & 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & y_{i1} & y_{i2} & y_{i3} & \dots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & 0 & y_{i1} & \dots & y_{i,T-2} \end{pmatrix}$$

Because  $p = 2$ ,  $\mathbf{Z}_{di}$  has  $T - p - 1$  rows and  $\sum_{m=p}^{T-2} m$  columns.

Specifying `lgmmiv(y)` creates the instrument matrix

$$\mathbf{Z}_{Li} = \begin{pmatrix} \Delta.y_{i2} & 0 & 0 & \dots & 0 \\ 0 & \Delta.y_{i3} & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & 0 & \dots & \Delta.y_{i(T_i-1)} \end{pmatrix}$$

This extends to other lag structures with complete data. Unbalanced data and missing observations are handled by dropping the rows for which there are no data and filling in zeros in columns where missing data are required. Suppose that, for some  $i$ , the  $t = 1$  observation was missing but was not missing for some other panels. `dgmmiv(y)` would then create the instrument matrix

$$\mathbf{Z}_{di} = \begin{pmatrix} 0 & 0 & 0 & y_{i2} & y_{i3} & 0 & 0 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & y_{i2} & y_{i3} & 0 & \dots & 0 & 0 & 0 \\ \vdots & \ddots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \dots & 0 & y_{i2} & \dots & y_{iT-2} \end{pmatrix}$$

$\mathbf{Z}_{di}$  has  $T_i - p - 1$  rows and  $\sum_{m=p}^{\tau-2} m$  columns, where  $\tau = \max_i \tau_i$  and  $\tau_i$  is the number of nonmissing observations in panel  $i$ .

After defining

$$\mathbf{Q}_{xz} = \sum_i \mathbf{X}'_i \mathbf{Z}_i$$

$$\mathbf{Q}_{zy} = \sum_i \mathbf{Z}'_i \mathbf{y}_i$$

$$\mathbf{W}_1 = \mathbf{Q}_{xz} \mathbf{A}_1 \mathbf{Q}'_{xz}$$

$$\mathbf{A}_1 = \left( \sum_i \mathbf{Z}'_i \mathbf{H}_{1i} \mathbf{Z}_i \right)^{-1}$$

and

$$\mathbf{H}_{1i} = \begin{pmatrix} \mathbf{H}_{di} & \mathbf{0} \\ \mathbf{0} & \mathbf{H}_{Li} \end{pmatrix}$$

the one-step estimates are given by

$$\hat{\beta}_1 = \mathbf{W}_1^{-1} \mathbf{Q}_{xz} \mathbf{A}_1 \mathbf{Q}_{zy}$$

When using the first-difference transform  $\mathbf{H}_{di}$ , is given by

$$\mathbf{H}_{di} = \begin{pmatrix} 1 & -.5 & 0 & \dots & 0 & 0 \\ -.5 & 1 & -.5 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & 0 & \dots & 1 & -.5 \\ 0 & 0 & 0 & \dots & -.5 & 1 \end{pmatrix}$$

and  $\mathbf{H}_{Li}$  is given by 0.5 times the identity matrix. When using the FOD transform, both  $\mathbf{H}_{di}$  and  $\mathbf{H}_{Li}$  are equal to the identity matrix.

The transformed one-step residuals are given by

$$\hat{\epsilon}_{1i}^* = \mathbf{y}_i^* - \hat{\beta}_1 \mathbf{X}_i^*$$

which are used to compute

$$\hat{\sigma}_1^2 = \{1/(N - K)\} \sum_i \hat{\epsilon}_{1i}^{*'} \hat{\epsilon}_{1i}^*$$

The GMM one-step VCE is then given by

$$\hat{V}_{\text{GMM}}[\hat{\beta}_1] = \hat{\sigma}_1^2 \mathbf{W}_1^{-1}$$

The one-step level residuals are given by

$$\hat{\epsilon}_{1i}^L = \mathbf{y}_i^L - \hat{\beta}_1 \mathbf{X}_i^L$$

Stacking the residual vectors yields

$$\hat{\epsilon}_{1i} = \begin{pmatrix} \hat{\epsilon}_{1i}^* \\ \hat{\epsilon}_{1i}^L \end{pmatrix}$$

which is used to compute  $\mathbf{H}_{2i} = \hat{\epsilon}_{1i}' \hat{\epsilon}_{1i}$ , which is used in

$$\mathbf{A}_2 = \left( \sum_i \mathbf{Z}_i' \mathbf{H}_{2i} \mathbf{Z}_i \right)^{-1}$$

and the robust one-step VCE is given by

$$\hat{V}_{\text{robust}}[\hat{\beta}_1] = \mathbf{W}_1^{-1} \mathbf{Q}_{xz} \mathbf{A}_1 \mathbf{A}_2^{-1} \mathbf{A}_1 \mathbf{Q}_{xz}' \mathbf{W}_1^{-1}$$

$\hat{V}_{\text{robust}}[\hat{\beta}_1]$  is robust to heteroskedasticity in the errors.

After defining

$$\mathbf{W}_2 = \mathbf{Q}_{xz} \mathbf{A}_2 \mathbf{Q}_{xz}'$$

the two-step estimates are given by

$$\hat{\beta}_2 = \mathbf{W}_2^{-1} \mathbf{Q}_{xz} \mathbf{A}_2 \mathbf{Q}_{zy}$$

The GMM two-step VCE is then given by

$$\hat{V}_{\text{GMM}}[\hat{\beta}_2] = \mathbf{W}_2^{-1}$$

The GMM two-step VCE is known to be severely biased. Windmeijer (2005) derived the Windmeijer bias-corrected (WC) estimator for the robust VCE of two-step GMM estimators. xtdpd implements this WC-robust estimator of the VCE. The formulas for this method are involved; see Windmeijer (2005). The WC-robust estimator of the VCE is robust to heteroskedasticity in the errors.

## Acknowledgment

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## Also see

- [XT] **xtdpd postestimation** — Postestimation tools for *xtdpd*
- [XT] **xtabond** — Arellano–Bond linear dynamic panel-data estimation
- [XT] **xtdpdsys** — Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation
- [XT] **xtivreg** — Instrumental variables and two-stage least squares for panel-data models
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance
- [XT] **xtset** — Declare data to be panel data
- [R] **gmm** — Generalized method of moments estimation
- [U] **20 Estimation and postestimation commands**

**xtdpd postestimation** — Postestimation tools for xtdpd

[Postestimation commands](#)  
[Remarks and examples](#)

[predict](#)  
[Methods and formulas](#)

[margins](#)  
[Reference](#)

[estat](#)  
[Also see](#)

## Postestimation commands

The following postestimation commands are of special interest after `xtdpd`:

Command	Description
<code>estat abond</code>	test for autocorrelation
<code>estat sargan</code>	Sargan test of overidentifying restrictions

The following standard postestimation commands are also available:

Command	Description
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from <code>margins</code> (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

```
predict [type] newvar [if] [in] [, xb e stdp difference]
```

### Options for predict

---

Main

---

`xb`, the default, calculates the linear prediction.

`e` calculates the residual error.

`stdp` calculates the standard error of the prediction, which can be thought of as the standard error of the predicted expected value or mean for the observation's covariate pattern. The standard error of the prediction is also referred to as the standard error of the fitted value. `stdp` may not be combined with `difference`.

`difference` specifies that the statistic be calculated for the first differences instead of the levels, the default.

## margins

### Description for margins

`margins` estimates margins of responses for linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [ marginlist ] [ , options ]
margins [ marginlist ] , predict(statistic ...) [ options ]
```

<i>statistic</i>	Description
<code>xb</code>	linear prediction; the default
<code>e</code>	not allowed with <code>margins</code>
<code>stdp</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] **margins**.

## estat

### Description for estat

`estat abond` reports the Arellano–Bond test for serial correlation in the first-differenced residuals.

`estat sargan` reports the Sargan test of the overidentifying restrictions.

### Menu for estat

Statistics > Postestimation

### Syntax for estat

*Test for autocorrelation*

```
estat abond [ , artests(#) ]
```

*Sargan test of overidentifying restrictions*

```
estat sargan
```

## Option for **estat abond**

`artests(#)` specifies the highest order of serial correlation to be tested. By default, the tests computed during estimation are reported. The model will be refit when `artests(#)` specifies a higher order than that computed during the original estimation. The model can only be refit if the data have not changed.

## Remarks and examples

Remarks are presented under the following headings:

`estat abond`  
`estat sargan`

### estat abond

The moment conditions used by **xtdpd** are valid only if there is no serial correlation in the idiosyncratic errors. Testing for serial correlation in dynamic panel-data models is tricky because one needs to apply a transform to remove the panel-level effects, but the transformed errors have a more complicated error structure than the idiosyncratic errors. The Arellano–Bond test for serial correlation reported by `estat abond` tests for serial correlation in the first-differenced errors.

Because the first difference of independent and identically distributed idiosyncratic errors will be autocorrelated, rejecting the null hypothesis of no serial correlation at order one in the first-differenced errors does not imply that the model is misspecified. Rejecting the null hypothesis at higher orders implies that the moment conditions are not valid. See [example 5](#) in [\[XT\] xtdpd](#) for an alternative estimator that allows for idiosyncratic errors that follow a first-order moving average process.

After the one-step system estimator, the test can be computed only when `vce(robust)` has been specified.

### estat sargan

Like all GMM estimators, the estimator in **xtdpd** can produce consistent estimates only if the moment conditions used are valid. Although there is no method to test if the moment conditions from an exactly identified model are valid, one can test whether the overidentifying moment conditions are valid. `estat sargan` implements the Sargan test of overidentifying conditions discussed in [Arellano and Bond \(1991\)](#).

Only for a homoskedastic error term does the Sargan test have an asymptotic chi-squared distribution. In fact, [Arellano and Bond \(1991\)](#) show that the one-step Sargan test overrejects in the presence of heteroskedasticity. Because its asymptotic distribution is not known under the assumptions of the `vce(robust)` model, **xtdpd** does not compute it when `vce(robust)` is specified.

## Methods and formulas

The notation for  $\hat{\epsilon}_{1i}^*$ ,  $\hat{\epsilon}_{1i}$ ,  $\mathbf{H}_{1i}$ ,  $\mathbf{H}_{2i}$ ,  $\mathbf{X}_i$ ,  $\mathbf{Z}_i$ ,  $\mathbf{W}_1$ ,  $\mathbf{W}_2$ ,  $\widehat{\mathbf{V}}_*[\widehat{\beta}_*]$ ,  $\mathbf{A}_1$ ,  $\mathbf{A}_2$ ,  $\mathbf{Q}_{xz}$ , and  $\widehat{\sigma}_1^2$  has been defined in [Methods and formulas of \[XT\] xtdpd](#).

The Arellano–Bond test for zero  $m$ th-order autocorrelation in the first-differenced errors is given by

$$A(m) = \frac{s_0}{\sqrt{s_1 + s_2 + s_3}}$$

where the definitions of  $s_0$ ,  $s_1$ ,  $s_2$ , and  $s_3$  vary over the estimators and transforms.

We begin by defining  $\hat{\mathbf{u}}_{1i}^* = \mathbf{L}_m \hat{\boldsymbol{\epsilon}}_{1i}^*$ , with the missing values filled in with zeros. Letting  $j = 1$  for the one-step estimator,  $j = 2$  for the two-step estimator,  $c = \text{GMM}$  for the GMM VCE estimator, and  $c = \text{robust}$  for the robust VCE estimator, we can now define  $s_0$ ,  $s_1$ ,  $s_2$ , and  $s_3$ :

$$s_0 = \sum_i \hat{\mathbf{u}}_{ji}^{*'} \hat{\boldsymbol{\epsilon}}_{ji}^*$$

$$s_1 = \sum_i \hat{\mathbf{u}}_{ji}^{*'} \mathbf{H}_{ji} \hat{\mathbf{u}}_{ji}^*$$

$$s_2 = -2 \mathbf{q}_{ji} \mathbf{W}_j^{-1} \mathbf{Q}_{xz} \mathbf{A}_j \mathbf{Q}_{zu}$$

$$s_3 = \mathbf{q}_{jx} \hat{\mathbf{V}}_c [\hat{\boldsymbol{\beta}}_j] \mathbf{q}'_{jx}$$

where

$$\mathbf{q}_{jx} = \left( \sum_i \hat{\mathbf{u}}_{ji}^{*'} \mathbf{X}_i \right)$$

and  $\mathbf{Q}_{zu}$  varies over estimator and transform.

For the Arellano–Bond estimator with the first-differenced transform,

$$\mathbf{Q}_{zu} = \left( \sum_i \mathbf{Z}'_i \mathbf{H}_{ji} \hat{\mathbf{u}}_{ji}^* \right)$$

For the Arellano–Bond estimator with the FOD transform,

$$\mathbf{Q}_{zu} = \left( \sum_i \mathbf{Z}'_i \mathbf{Q}_{\text{fod}} \right)$$

where

$$\mathbf{Q}_{\text{fod}} = \begin{pmatrix} -\sqrt{\frac{T_i+1}{T_i}} & 0 & \cdots & 0 \\ \sqrt{\frac{T_i-1}{T_i}} & \sqrt{\frac{T_i}{T_i-1}} & \cdots & 0 \\ 0 & . & . & \vdots \\ 0 & \cdots & \sqrt{\frac{1}{2}} & -\sqrt{\frac{2}{1}} \end{pmatrix} \hat{\mathbf{u}}_{ji}^*$$

and \* implies the first-differenced transform instead of the FOD transform.

For the Arellano–Bover/Blundell–Bond system estimator with the first-differenced transform,

$$\mathbf{Q}_{zu} = \left( \sum_i \mathbf{Z}'_i \hat{\boldsymbol{\epsilon}}_{ji} \hat{\boldsymbol{\epsilon}}_{ji}' \hat{\mathbf{u}}_{ji}^* \right)$$

After a one-step estimator, the Sargan test is

$$S_1 = \frac{1}{\hat{\sigma}_1^2} \left( \sum_i \hat{\epsilon}'_{1i} \mathbf{Z}_i \right) \mathbf{A}_1 \left( \sum_i \mathbf{Z}'_i \hat{\epsilon}_{1i} \right)$$

The transformed two-step residuals are given by

$$\hat{\epsilon}_{2i}^* = \mathbf{y}_i^* - \hat{\beta}_2 \mathbf{X}_i^*$$

and the level two-step residuals are given by

$$\hat{\epsilon}_{2i}^L = \mathbf{y}_i^L - \hat{\beta}_2 \mathbf{X}_i^L$$

Stacking the residual vectors yields

$$\hat{\epsilon}_{2i} = \begin{pmatrix} \hat{\epsilon}_{2i}^* \\ \hat{\epsilon}_{2i}^L \end{pmatrix}$$

After a two-step estimator, the Sargan test is

$$S_2 = \left( \sum_i \hat{\epsilon}'_{2i} \mathbf{Z}_i \right) \mathbf{A}_2 \left( \sum_i \mathbf{Z}'_i \hat{\epsilon}_{2i} \right)$$

## Reference

Arellano, M., and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58: 277–297.

## Also see

[XT] **xtdpd** — Linear dynamic panel-data estimation

[U] **20 Estimation and postestimation commands**

Description  
Options  
Acknowledgment

Quick start  
Remarks and examples  
References

Menu  
Stored results  
Also see

Syntax  
Methods and formulas

## Description

`xtdpdsys` fits a linear dynamic panel-data model where the unobserved panel-level effects are correlated with the lags of the dependent variable. This model is an extension of the Arellano–Bond estimator that accommodates large autoregressive parameters and a large ratio of the variance of the panel-level effect to the variance of idiosyncratic error. This is known as the Arellano–Bover/Blundell–Bond system estimator. This estimator is designed for datasets with many panels and few periods. This method assumes that there is no autocorrelation in the idiosyncratic errors and requires that the panel-level effects be uncorrelated with the first difference of the first observation of the dependent variable.

## Quick start

Dynamic panel-data regression of *y* on *x* with default Arellano–Bond instruments and lagged difference of *y*

```
xtdpdsys y x
```

Add the lagged difference of *x* as an instrument

```
xtdpdsys y x, pre(x)
```

Set the maximum number of lags of the dependent variable used as instruments to 2

```
xtdpdsys y x, maxldep(2)
```

## Menu

Statistics > Longitudinal/panel data > Dynamic panel data (DPD) > Arellano–Bover/Blundell–Bond estimation

## Syntax

**xtdpdsys** *depvar* [*indepvars*] [*if*] [*in*] [, *options*]

<i>options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term
<u>lags(#)</u>	use # lags of dependent variable as covariates; default is <code>lags(1)</code>
<u>maxldep(#)</u>	maximum lags of dependent variable for use as instruments
<u>maxlags(#)</u>	maximum lags of predetermined and endogenous variables for use as instruments
<u>twostep</u>	compute the two-step estimator instead of the one-step estimator
<b>Predetermined</b>	
<u>pre(varlist)[...]</u>	predetermined variables; can be specified more than once
<b>Endogenous</b>	
<u>endogenous(varlist)[...]</u>	endogenous variables; can be specified more than once
<b>SE/Robust</b>	
<u>vce(vcetype)</u>	<i>vcetype</i> may be <code>gmm</code> or <code>robust</code>
<b>Reporting</b>	
<u>level(#)</u>	set confidence level; default is <code>level(95)</code>
<u>artests(#)</u>	use # as maximum order for AR tests; default is <code>artests(2)</code>
<u>display_options</u>	control spacing and line width
<u>coeflegend</u>	display legend instead of statistics

A panel variable and a time variable must be specified; use [XT] **xtset**.

*indepvars* and all *varlists*, except `pre(varlist[...])` and `endogenous(varlist[...])`, may contain time-series operators; see [U] 11.4.4 Time-series varlists. The specification of *depvar* may not contain time-series operators. *by*, *statsby*, and *xi* are allowed; see [U] 11.1.10 Prefix commands.

`coeflegend` does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

noconstant; see [R] **Estimation options**.

lags(#) sets *p*, the number of lags of the dependent variable to be included in the model. The default is *p* = 1.

maxldep(#) sets the maximum number of lags of the dependent variable that can be used as instruments. The default is to use all  $T_i - p - 2$  lags.

maxlags(#) sets the maximum number of lags of the predetermined and endogenous variables that can be used as instruments. For predetermined variables, the default is to use all  $T_i - p - 1$  lags. For endogenous variables, the default is to use all  $T_i - p - 2$  lags.

twostep specifies that the two-step estimator be calculated.

Predetermined

`pre(varlist [ , lagstruct(prelags, premaxlags) ])` specifies that a set of predetermined variables be included in the model. Optionally, you may specify that *prelags* lags of the specified variables also be included. The default for *prelags* is 0. Specifying *premaxlags* sets the maximum number of further lags of the predetermined variables that can be used as instruments. The default is to include  $T_i - p - 1$  lagged levels as instruments for predetermined variables. You may specify as many sets of predetermined variables as you need within the standard Stata limits on matrix size. Each set of predetermined variables may have its own number of *prelags* and *premaxlags*.

Endogenous

`endogenous(varlist [ , lagstruct(endlags, endmaxlags) ])` specifies that a set of endogenous variables be included in the model. Optionally, you may specify that *endlags* lags of the specified variables also be included. The default for *endlags* is 0. Specifying *endmaxlags* sets the maximum number of further lags of the endogenous variables that can be used as instruments. The default is to include  $T_i - p - 2$  lagged levels as instruments for endogenous variables. You may specify as many sets of endogenous variables as you need within the standard Stata limits on matrix size. Each set of endogenous variables may have its own number of *endlags* and *endmaxlags*.

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory and that are robust to some kinds of misspecification; see [Methods and formulas](#) in [XT] **xtdpd**.

`vce(gmm)`, the default, uses the conventionally derived variance estimator for generalized method of moments estimation.

`vce(robust)` uses the robust estimator. For the one-step estimator, this is the Arellano–Bond robust VCE estimator. For the two-step estimator, this is the [Windmeijer \(2005\)](#) WC-robust estimator.

Reporting

`level(#);` see [\[R\] Estimation options](#).

`artests(#)` specifies the maximum order of the autocorrelation test to be calculated. The tests are reported by `estat abond`; see [\[XT\] xtdpdsys postestimation](#). Specifying the order of the highest test at estimation time is more efficient than specifying it to `estat abond`, because `estat abond` must refit the model to obtain the test statistics. The maximum order must be less than or equal the number of periods in the longest panel. The default is `artests(2)`.

`display_options`: `vsquish` and `nolstretch`; see [\[R\] Estimation options](#).

The following option is available with `xtdpdsys` but is not shown in the dialog box:

`coeflegend`; see [\[R\] Estimation options](#).

## Remarks and examples

If you have not read [\[XT\] xtabond](#), you may want to do so before continuing.

Linear dynamic panel-data models include  $p$  lags of the dependent variable as covariates and contain unobserved panel-level effects, fixed or random

Consider the dynamic panel-data model

$$y_{it} = \sum_{j=1}^p \alpha_j y_{i,t-j} + \mathbf{x}_{it}\beta_1 + \mathbf{w}_{it}\beta_2 + \nu_i + \epsilon_{it} \quad i = 1, \dots, N \quad t = 1, \dots, T_i \quad (1)$$

where

- the  $\alpha_j$  are  $p$  parameters to be estimated,
- $\mathbf{x}_{it}$  is a  $1 \times k_1$  vector of strictly exogenous covariates,
- $\beta_1$  is a  $k_1 \times 1$  vector of parameters to be estimated,
- $\mathbf{w}_{it}$  is a  $1 \times k_2$  vector of predetermined or endogenous covariates,
- $\beta_2$  is a  $k_2 \times 1$  vector of parameters to be estimated,
- $\nu_i$  are the panel-level effects (which may be correlated with the covariates), and
- $\epsilon_{it}$  are i.i.d. over the whole sample with variance  $\sigma_\epsilon^2$ .

The  $\nu_i$  and the  $\epsilon_{it}$  are assumed to be independent for each  $i$  over all  $t$ .

By construction, the lagged dependent variables are correlated with the unobserved panel-level effects, making standard estimators inconsistent. [Arellano and Bond \(1991\)](#) derived a consistent generalized method of moments (GMM) estimator for this model. With many panels and few periods, the Arellano–Bond estimator is constructed by first-differencing to remove the panel-level effects and using instruments to form moment conditions.

[Blundell and Bond \(1998\)](#) show that the lagged-level instruments in the Arellano–Bond estimator become weak as the autoregressive process becomes too persistent or the ratio of the variance of the panel-level effects  $\nu_i$  to the variance of the idiosyncratic error  $\epsilon_{it}$  becomes too large. Building on the work of [Arellano and Bover \(1995\)](#), [Blundell and Bond \(1998\)](#) proposed a system estimator that uses moment conditions in which lagged differences are used as instruments for the level equation in addition to the moment conditions of lagged levels as instruments for the difference equation. The additional moment conditions are valid only if the initial condition  $E[\nu_i \Delta y_{i2}] = 0$  holds for all  $i$ ; see [Blundell and Bond \(1998\)](#) and [Blundell, Bond, and Windmeijer \(2000\)](#).

`xtdpdsys` fits dynamic panel-data estimators with the Arellano–Bover/Blundell–Bond system estimator. This estimator is designed for datasets with many panels and few periods. This method assumes that there is no autocorrelation in the idiosyncratic errors and requires the initial condition that the panel-level effects be uncorrelated with the first difference of the first observation of the dependent variable. Because `xtdpdsys` extends `xtabond`, [\[XT\] xtabond](#) provides useful background.

## ▷ Example 1: A dynamic panel model

In their article, [Arellano and Bond \(1991\)](#) apply their estimators and test statistics to a model of dynamic labor demand that had previously been considered by [Layard and Nickell \(1986\)](#), using data from an unbalanced panel of firms from the United Kingdom. All variables are indexed over the firm  $i$  and time  $t$ . In this dataset,  $n_{it}$  is the log of employment in firm  $i$  at time  $t$ ,  $w_{it}$  is the natural log of the real product wage,  $k_{it}$  is the natural log of the gross capital stock, and  $ys_{it}$  is the natural log of industry output. The model also includes time dummies `yr1980`, `yr1981`, `yr1982`, `yr1983`, and `yr1984`.

For comparison, we begin by using xtabond to fit a model to these data.

```
. use https://www.stata-press.com/data/r16/abdata
. xtabond n L(0/2).(w k) yr1980-yr1984 year, vce(robust)
Arellano-Bond dynamic panel-data estimation      Number of obs      =       611
Group variable: id                          Number of groups   =       140
Time variable: year
Obs per group:
min =           4
avg =        4.364286
max =           6
Number of instruments =      40          Wald chi2(13)     =    1318.68
                                         Prob > chi2      =     0.0000
One-step results
(Std. Err. adjusted for clustering on id)
```

n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]
n L1.	.6286618	.1161942	5.41	0.000	.4009254 .8563983
w --. L1. L2.	-.5104249 .2891446 -.0443653	.1904292 .140946 .0768135	-2.68 2.05 -0.58	0.007 0.040 0.564	-.8836592 -.1371906 .0128954 .5653937 -.194917 .1061865
k --. L1. L2.	.3556923 -.0457102 -.0619721	.0603274 .0699732 .0328589	5.90 -0.65 -1.89	0.000 0.514 0.059	.2374528 .4739318 -.1828552 .0914348 -.1263743 .0024301
yr1980 yr1981 yr1982 yr1983 yr1984 year _cons	-.0282422 -.0694052 -.0523678 -.0256599 -.0093229 .0019575 -2.543221	.0166363 .028961 .0423433 .0533747 .0696241 .0119481 23.97919	-1.70 -2.40 -1.24 -0.48 -0.13 0.16 -0.11	0.090 0.017 0.216 0.631 0.893 0.870 0.916	-.0608488 .0043643 -.1261677 -.0126426 -.1353591 .0306235 -.1302723 .0789525 -.1457837 .1271379 -.0214604 .0253754 -49.54158 44.45514

Instruments for differenced equation

GMM-type: L(2/.).n  
Standard: D.w LD.w L2D.w D.k LD.k L2D.k D.yr1980 D.yr1981 D.yr1982  
D.yr1983 D.yr1984 D.year

Instruments for level equation

Standard: \_cons

Now we fit the same model by using **xtdpdsys**:

```
. xtdpdsys n L(0/2).(w k) yr1980-yr1984 year, vce(robust)
System dynamic panel-data estimation          Number of obs      =      751
Group variable: id                          Number of groups   =      140
Time variable: year                         Obs per group:
                                                min =            5
                                                avg =      5.364286
                                                max =            7
Number of instruments =      47               Wald chi2(13)    =  2579.96
                                                               Prob > chi2     =  0.0000
```

#### One-step results

n	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]
n					
L1.	.8221535	.093387	8.80	0.000	.6391184 1.005189
w					
--.	-.5427935	.1881721	-2.88	0.004	-.911604 -.1739831
L1.	.3703602	.1656364	2.24	0.025	.0457189 .6950015
L2.	-.0726314	.0907148	-0.80	0.423	-.2504292 .1051664
k					
--.	.3638069	.0657524	5.53	0.000	.2349346 .4926792
L1.	-.1222996	.0701521	-1.74	0.081	-.2597951 .015196
L2.	-.0901355	.0344142	-2.62	0.009	-.1575862 -.0226849
yr1980	-.0308622	.016946	-1.82	0.069	-.0640757 .0023512
yr1981	-.0718417	.0293223	-2.45	0.014	-.1293123 -.014371
yr1982	-.0384806	.0373631	-1.03	0.303	-.1117111 .0347498
yr1983	-.0121768	.0498519	-0.24	0.807	-.1098847 .0855311
yr1984	-.0050903	.0655011	-0.08	0.938	-.1334701 .1232895
year	.0058631	.0119867	0.49	0.625	-.0176304 .0293566
_cons	-10.59198	23.92087	-0.44	0.658	-57.47602 36.29207

#### Instruments for differenced equation

GMM-type: L(2/.).n  
 Standard: D.w LD.w L2D.w D.k LD.k L2D.k D.yr1980 D.yr1981 D.yr1982  
 D.yr1983 D.yr1984 D.year

#### Instruments for level equation

GMM-type: LD.n  
 Standard: \_cons

If you are unfamiliar with the `L() .()` notation, see [U] 13.10 Time-series operators. That the system estimator produces a much higher estimate of the coefficient on lagged employment agrees with the results in Blundell and Bond (1998), who show that the system estimator does not have the downward bias that the Arellano–Bond estimator has when the true value is high.

Comparing the footers illustrates the difference between the two estimators; **xtdpdsys** includes lagged differences of `n` as instruments for the level equation, whereas **xtabond** does not. Comparing the headers shows that **xtdpdsys** has seven more instruments than **xtabond**. (As it should; there are 7 observations on `LD.n` available in the complete panels that run from 1976–1984, after accounting for the first two years that are lost because the model has two lags.) Only the first lags of the variables are used because the moment conditions using higher lags are redundant; see Blundell and Bond (1998) and Blundell, Bond, and Windmeijer (2000).

**estat abond** reports the Arellano–Bond test for serial correlation in the first-differenced errors. The moment conditions are valid only if there is no serial correlation in the idiosyncratic errors.

Because the first difference of independent and identically distributed idiosyncratic errors will be autocorrelated, rejecting the null hypothesis of no serial correlation at order one in the first-differenced errors does not imply that the model is misspecified. Rejecting the null hypothesis at higher orders implies that the moment conditions are not valid. See [XT] **xtdpd** for an alternative estimator in this case.

```
. estat abond
Arellano-Bond test for zero autocorrelation in first-differenced errors
```

Order	z	Prob > z
1	-4.6414	0.0000
2	-1.0572	0.2904

H0: no autocorrelation

The above output does not present evidence that the model is misspecified. ◇

## ▷ Example 2: Including predetermined covariates

Sometimes we cannot assume strict exogeneity. Recall that a variable  $x_{it}$  is said to be strictly exogenous if  $E[x_{it}\epsilon_{is}] = 0$  for all  $t$  and  $s$ . If  $E[x_{it}\epsilon_{is}] \neq 0$  for  $s < t$  but  $E[x_{it}\epsilon_{is}] = 0$  for all  $s \geq t$ , the variable is said to be predetermined. Intuitively, if the error term at time  $t$  has some feedback on the subsequent realizations of  $x_{it}$ ,  $x_{it}$  is a predetermined variable. Because unforecastable errors today might affect future changes in the real wage and in the capital stock, we might suspect that the log of the real product wage and the log of the gross capital stock are predetermined instead of strictly exogenous.

```
. xtdpdsys n yr1980-yr1984 year, pre(w k, lag(2, .)) vce(robust)
System dynamic panel-data estimation                               Number of obs      =       751
Group variable: id                                         Number of groups   =       140
Time variable: year                                         Obs per group:
                                                               min =          5
                                                               avg =    5.364286
                                                               max =          7
Number of instruments =      95                               Wald chi2(13)     =    7562.80
                                                               Prob > chi2      =     0.0000
```

## One-step results

	n	Robust				
		Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
n	L1.	.913278	.0460602	19.83	0.000	.8230017
w	--.	-.728159	.1019044	-7.15	0.000	-.9278879
	L1.	.5602737	.1939617	2.89	0.004	.1801156
	L2.	-.0523028	.1487653	-0.35	0.725	-.3438775
k	--.	.4820097	.0760787	6.34	0.000	.3328983
	L1.	-.2846944	.0831902	-3.42	0.001	-.4477442
	L2.	-.1394181	.0405709	-3.44	0.001	-.2189356
yr1980		-.0325146	.0216371	-1.50	0.133	-.0749226
yr1981		-.0726116	.0346482	-2.10	0.036	-.1405207
yr1982		-.0477038	.0451914	-1.06	0.291	-.1362772
yr1983		-.0396264	.0558734	-0.71	0.478	-.1491362
yr1984		-.0810383	.0736648	-1.10	0.271	-.2254186
year		.0192741	.0145326	1.33	0.185	-.0092092
_cons		-37.34972	28.77747	-1.30	0.194	93.75253
						19.05308

## Instruments for differenced equation

GMM-type: L(2/.).n L(1/.).L2.w L(1/.).L2.k

Standard: D.yr1980 D.yr1981 D.yr1982 D.yr1983 D.yr1984 D.year

## Instruments for level equation

GMM-type: LD.n L2D.w L2D.k

Standard: \_cons

The footer informs us that we are now including GMM-type instruments from the first lag of L.w on back and from the first lag of L2.k on back for the differenced errors and the second lags of the differences of w and k as instruments for the level errors.



## □ Technical note

The above example illustrates that **xtdpdsys** understands `pre(w k, lag(2, .))` to mean that L2.w and L2.k are predetermined variables. This is a stricter definition than the alternative that `pre(w k, lag(2, .))` means only that w k are predetermined but to include two lags of w and two lags of k in the model. If you prefer the weaker definition, **xtdpdsys** still gives you consistent estimates, but it is not using all possible instruments; see [XT] **xtdpd** for an example of how to include all possible instruments.



## Stored results

`xtdpdsys` stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(t_min)</code>	minimum time in sample
<code>e(t_max)</code>	maximum time in sample
<code>e(chi2)</code>	$\chi^2$
<code>e(arm#)</code>	test for autocorrelation of order #
<code>e(artests)</code>	number of AR tests computed
<code>e(sig2)</code>	estimate of $\sigma_\epsilon^2$
<code>e(rss)</code>	sum of squared differenced residuals
<code>e(sargan)</code>	Sargan test statistic
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(zrank)</code>	rank of instrument matrix

### Macros

<code>e(cmd)</code>	<code>xtdpdsys</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(twostep)</code>	<code>twostep</code> , if specified
<code>e(ivars)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(vce)</code>	<i>vctype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(system)</code>	<code>system</code> , if system estimator
<code>e(transform)</code>	specified transform
<code>e(diffvars)</code>	already-differenced exogenous variables
<code>e(datasignature)</code>	checksum from <code>datasignature</code>
<code>e(datasignaturevars)</code>	variables used in calculation of checksum
<code>e(properties)</code>	<code>b V</code>
<code>e(estat_cmd)</code>	program used to implement <code>estat</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>

### Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

`xtdpdsys` uses `xtdpd` to perform its computations, so the formulas are given in [Methods and formulas](#) of [XT] [xtdpd](#).

## Acknowledgment

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## Also see

- [XT] **xtdpdsys postestimation** — Postestimation tools for xtdpdsys
- [XT] **xtabond** — Arellano–Bond linear dynamic panel-data estimation
- [XT] **xtdpd** — Linear dynamic panel-data estimation
- [XT] **xtivreg** — Instrumental variables and two-stage least squares for panel-data models
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance

[XT] **xtset** — Declare data to be panel data

[U] **20 Estimation and postestimation commands**

**xtdpdsys postestimation** — Postestimation tools for xtdpdsys

Postestimation commands  
Remarks and examples

[predict](#)  
[Methods and formulas](#)

[margins](#)  
[Reference](#)

[estat](#)  
[Also see](#)

## Postestimation commands

The following postestimation commands are of special interest after `xtdpdsys`:

Command	Description
<code>estat abond</code>	test for autocorrelation
<code>estat sargan</code>	Sargan test of overidentifying restrictions

The following standard postestimation commands are also available:

Command	Description
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

```
predict [type] newvar [if] [in] [, xb e stdp difference]
```

### Options for predict

Main

`xb`, the default, calculates the linear prediction.

`e` calculates the residual error.

`stdp` calculates the standard error of the prediction, which can be thought of as the standard error of the predicted expected value or mean for the observation's covariate pattern. The standard error of the prediction is also referred to as the standard error of the fitted value. `stdp` may not be combined with `difference`.

`difference` specifies that the statistic be calculated for the first differences instead of the levels, the default.

## margins

### Description for margins

`margins` estimates margins of responses for linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [ marginlist ] [ , options ]
margins [ marginlist ] , predict(statistic ...) [ options ]
```

<i>statistic</i>	Description
xb	linear prediction; the default
e	not allowed with <code>margins</code>
stdp	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] **margins**.

## estat

### Description for estat

`estat abond` reports the Arellano–Bond test for serial correlation in the first-differenced residuals.

`estat sargan` reports the Sargan test of the overidentifying restrictions.

### Menu for estat

Statistics > Postestimation

### Syntax for estat

*Test for autocorrelation*

```
estat abond [ , artests(#) ]
```

*Sargan test of overidentifying restrictions*

```
estat sargan
```

## Option for `estat abond`

`artests(#)` specifies the highest order of serial correlation to be tested. By default, the tests computed during estimation are reported. The model will be refit when `artests(#)` specifies a higher order than that computed during the original estimation. The model can only be refit if the data have not changed.

## Remarks and examples

Remarks are presented under the following headings:

*estat abond*  
*estat sargan*

### `estat abond`

The moment conditions used by `xtdpdsys` are valid only if there is no serial correlation in the idiosyncratic errors. Testing for serial correlation in dynamic panel-data models is tricky because one needs to apply a transform to remove the panel-level effects, but the transformed errors have a more complicated error structure than the idiosyncratic errors. The Arellano–Bond test for serial correlation reported by `estat abond` tests for serial correlation in the first-differenced errors.

Because the first difference of independent and identically distributed idiosyncratic errors will be serially correlated, rejecting the null hypothesis of no serial correlation in the first-differenced errors at order one does not imply that the model is misspecified. Rejecting the null hypothesis at higher orders implies that the moment conditions are not valid. See [example 5](#) in [XT] `xtdpd` for an alternative estimator that allows for idiosyncratic errors that follow a first-order moving average process.

After the one-step system estimator, the test can be computed only when `vce(robust)` has been specified.

### `estat sargan`

Like all GMM estimators, the estimator in `xtdpdsys` can produce consistent estimates only if the moment conditions used are valid. Although there is no method to test if the moment conditions from an exactly identified model are valid, one can test whether the overidentifying moment conditions are valid. `estat sargan` implements the Sargan test of overidentifying conditions discussed in [Arellano and Bond \(1991\)](#).

Only for a homoskedastic error term does the Sargan test have an asymptotic chi-squared distribution. In fact, [Arellano and Bond \(1991\)](#) show that the one-step Sargan test overrejects in the presence of heteroskedasticity. Because its asymptotic distribution is not known under the assumptions of the `vce(robust)` model, `xtdpdsys` does not compute it when `vce(robust)` is specified. See [XT] `xtdpd` for an [example](#) in which the null hypothesis of the Sargan test is not rejected.

```
. use https://www.stata-press.com/data/r16/abdata
. xtdpdsys n L(0/2).(w k) yr1980-yr1984 year
  (output omitted)
. estat sargan
Sargan test of overidentifying restrictions
H0: overidentifying restrictions are valid
chi2(33)      =  63.63911
Prob > chi2   =  0.0011
```

The output above presents strong evidence against the null hypothesis that the overidentifying restrictions are valid. Rejecting this null hypothesis implies that we need to reconsider our model or our instruments, unless we attribute the rejection to heteroskedasticity in the data-generating process. Although performing the Sargan test after the two-step estimator is an alternative, [Arellano and Bond \(1991\)](#) found a tendency for this test to underreject in the presence of heteroskedasticity.

## Methods and formulas

The formulas are given in [Methods and formulas](#) of **[XT] xtdpd postestimation**.

## Reference

Arellano, M., and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58: 277–297.

## Also see

[\[XT\] xtdpdsys](#) — Arellano–Bover/Blundell–Bond linear dynamic panel-data estimation

[\[U\] 20 Estimation and postestimation commands](#)

## Description

**xteintreg** fits a random-effects interval-data regression model that accommodates any combination of endogenous covariates, nonrandom treatment assignment, and endogenous sample selection and also accounts for correlation of observations within panels or within groups.

The dependent variable may be measured as point data, interval data, left-censored data, or right-censored data. Continuous, binary, and ordinal endogenous covariates are allowed. Treatment assignment may be endogenous or exogenous. A probit or tobit model may be used to account for endogenous sample selection.

**xteintreg** fits extended regression models for panel data in the same way that **eintreg** does for cross-sectional data. See [ERM] **eintreg** to learn about these models and how to fit them using **xteintreg**.

## Quick start

All *Quick start* examples use an interval-measured dependent variable with the interval's lower bound recorded in variable *y\_l* and its upper bound recorded in *y\_u*.

Random-effects regression of [*y\_l*, *y\_u*] on *x* with continuous endogenous covariate *y2* modeled by *x* and *z* using **xtset** data

```
xteintreg y_l y_u x, endogenous(y2 = x z)
```

As above, but with binary endogenous covariate *d* modeled by *x* and *z*

```
xteintreg y_l y_u x, endogenous(d = x z, probit)
```

Random-effects regression of [*y\_l*, *y\_u*] on *x* with endogenous treatment *trtvar* modeled by *x* and *z*

```
xteintreg y_l y_u x, entreat(trtvar = x z)
```

As above, but only the equation for [*y\_l*, *y\_u*] has a random effect

```
xteintreg y_l y_u x, entreat(trtvar = x z, nore)
```

Random-effects regression of [*y\_l*, *y\_u*] on *x* with endogenous sample-selection indicator *selvar* modeled by *x* and *z*

```
xteintreg y_l y_u x, select(selvar = x z)
```

As above, but adding endogenous covariate *y2* modeled by *x* and *z2*

```
xteintreg y_l y_u x, select(selvar = x z) endogenous(y2 = x z2)
```

## Menu

Statistics > Longitudinal/panel data > Endogenous covariates > Models adding selection and treatment > Interval regression (RE)

## Syntax

For syntax, methods, and all other information on **xteintreg**, see [ERM] **eintreg**.

## Description

`xteoprobit` fits a random-effects ordered probit regression model that accommodates any combination of endogenous covariates, nonrandom treatment assignment, and endogenous sample selection and also accounts for correlation of observations within panels or within groups.

Continuous, binary, and ordinal endogenous covariates are allowed. Treatment assignment may be endogenous or exogenous. A probit or tobit model may be used to account for endogenous sample selection.

`xteoprobit` fits ordered probit extended regression models for panel data in the same way that `eoprobit` does for cross-sectional data. See [ERM] **eoprobit** to learn about these models and how to fit them using `xteoprobit`.

## Quick start

Random-effects ordered probit regression of `y` on `x` with continuous endogenous covariate `y2` modeled by `x` and `z` using `xtset` data

```
xteoprobit y x, endogenous(y2 = x z)
```

As above, but with binary endogenous covariate `d` modeled by `x` and `z`

```
xteoprobit y x, endogenous(d = x z, probit)
```

Random-effects ordered probit regression of `y` on `x` with endogenous treatment `trtvar` modeled by `x` and `z`

```
xteoprobit y x, entreat(trtvar = x z)
```

As above, but only the equation for `y` has a random effect

```
xteoprobit y x, entreat(trtvar = x z, nore)
```

Random-effects ordered probit regression of `y` on `x` with endogenous sample-selection indicator `selvar` modeled by `x` and `z`

```
xteoprobit y x, select(selvar = x z)
```

As above, but adding endogenous covariate `y2` modeled by `x` and `z2`

```
xteoprobit y x, select(selvar = x z) endogenous(y2 = x z2)
```

## Menu

Statistics > Longitudinal/panel data > Endogenous covariates > Models adding selection and treatment > Ordered probit regression (RE)

## Syntax

For syntax, methods, and all other information on **xteoprobit**, see [ERM] **eoprobit**.

## Description

**xteprobit** fits a random-effects probit model that accommodates any combination of endogenous covariates, nonrandom treatment assignment, and endogenous sample selection and also accounts for correlation of observations within panels or within groups.

Continuous, binary, and ordinal endogenous covariates are allowed. Treatment assignment may be endogenous or exogenous. A probit or tobit model may be used to account for endogenous sample selection.

**xteprobit** fits probit extended regression models for panel data in the same way that **eprobit** does for cross-sectional data. See [[ERM](#)] **eprobit** to learn about these models and how to fit them using **xteprobit**.

## Quick start

Random-effects probit regression of *y* on *x* with continuous endogenous covariate *y2* modeled by *x* and *z* using **xtset** data

```
xteprobit y x, endogenous(y2 = x z)
```

As above, but with binary endogenous covariate *d* modeled by *x* and *z*

```
xteprobit y x, endogenous(d = x z, probit)
```

Random-effects probit regression of *y* on *x* with endogenous treatment *trtvar* modeled by *x* and *z*

```
xteprobit y x, entreat(trtvar = x z)
```

As above, but only the equation for *y* has a random effect

```
xteprobit x, entreat(trtvar = x z, nore)
```

Random-effects probit regression of *y* on *x* with endogenous sample-selection indicator *selvar* modeled by *x* and *z*

```
xteprobit y x, select(selvar = x z)
```

As above, but adding endogenous covariate *y2* modeled by *x* and *z2*

```
xteprobit y x, select(selvar = x z) endogenous(y2 = x z2)
```

## Menu

Statistics > Longitudinal/panel data > Endogenous covariates > Models adding selection and treatment > Probit regression (RE)

## Syntax

For syntax, methods, and all other information on **xtpoprobit**, see [ER] **eprobit**.

## Description

**xteregress** fits a random-effects linear regression model that accommodates any combination of endogenous covariates, nonrandom treatment assignment, and endogenous sample selection and also accounts for correlation of observations within panels or within groups.

Continuous, binary, and ordinal endogenous covariates are allowed. Treatment assignment may be endogenous or exogenous. A probit or tobit model may be used to account for endogenous sample selection.

**xteregress** fits linear extended regression models for panel data in the same way that **eregress** does for cross-sectional data. See [**ERM**] **eregress** to learn about these models and how to fit them using **xteregress**.

## Quick start

Random-effects linear regression of *y* on *x* with continuous endogenous covariate *y2* modeled by *x* and *z* using **xtset** data

```
xteregress y x, endogenous(y2 = x z)
```

As above, but with binary endogenous covariate *d* modeled by *x* and *z*

```
xteregress y x, endogenous(d = x z, probit)
```

Random-effects regression of *y* on *x* with endogenous treatment *trtvar* modeled by *x* and *z*

```
xteregress y x, entreat(trtvar = x z)
```

As above, but only the equation for *y* has a random effect

```
xteregress y x, entreat(trtvar = x z, nore)
```

Random-effects regression of *y* on *x* with endogenous sample-selection indicator *selvar* modeled by *x* and *z*

```
xteregress y x, select(selvar = x z)
```

As above, but adding endogenous covariate *y2* modeled by *x* and *z2*

```
xteregress y x, select(selvar = x z) endogenous(y2 = x z2)
```

## Menu

Statistics > Longitudinal/panel data > Endogenous covariates > Models adding selection and treatment > Linear regression (RE)

## Syntax

For syntax, methods, and all other information on **xteregress**, see [ER] **eregress**.

**xtfrontier** — Stochastic frontier models for panel data

Description	Quick start
Menu	Syntax
Options for time-invariant model	Options for time-varying decay model
Remarks and examples	Stored results
Methods and formulas	References
Also see	

## Description

**xtfrontier** fits stochastic production or cost frontier models for panel data where the disturbance term is a mixture of an inefficiency term and the idiosyncratic error. **xtfrontier** can fit a time-invariant model, in which the inefficiency term is assumed to have a truncated-normal distribution, or a time-varying decay model, in which the inefficiency term is modeled as a truncated-normal random variable multiplied by a function of time.

**xtfrontier** expects that the dependent variable and independent variables are on the natural logarithm scale; this transformation must be performed before estimation takes place.

## Quick start

Stochastic production frontier regression of `lny` on `lnx1` and `lnx2` with time-invariant inefficiency using `xtset` data

```
xtfrontier lny lnx1 lnx2, ti
```

Stochastic cost frontier regression of `lny` on `lnx1` and `lnx2` with time-invariant inefficiency

```
xtfrontier lny lnx1 lnx2, ti cost
```

Time-varying decay model for production

```
xtfrontier lny lnx1 lnx2, tvd
```

## Menu

Statistics > Longitudinal/panel data > Frontier models

## Syntax

*Time-invariant model*

`xtfrontier depvar [indepvars] [if] [in] [weight], ti [ti_options]`

*Time-varying decay model*

`xtfrontier depvar [indepvars] [if] [in] [weight], tvd [tvd_options]`

<i>ti_options</i>	Description
<hr/>	
Model	
<u>noconstant</u>	suppress constant term
<u>ti</u>	use time-invariant model
<u>cost</u>	fit cost frontier model
<u>constraints</u> ( <i>constraints</i> )	apply specified linear constraints
SE	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be <u>oim</u> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

---

<i>tvd_options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term
tvd	use time-varying decay model
cost	fit cost frontier model
<u>constraints</u> ( <i>constraints</i> )	apply specified linear constraints
<b>SE</b>	
vce( <i>vcetype</i> )	<i>vcetype</i> may be oim, bootstrap, or jackknife
<b>Reporting</b>	
<u>level</u> (#)	set confidence level; default is level(95)
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Maximization</b>	
<u>maximize_options</u>	control the maximization process; seldom used
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

A panel variable must be specified. For `xtfrontier`, `tvd`, a time variable must also be specified. Use `xtset`; see [XT] `xtset`.

`indepvars` may contain factor variables; see [U] 11.4.3 Factor variables.

`depvar` and `indepvars` may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by`, `fp`, and `statsby` are allowed; see [U] 11.1.10 Prefix commands.

`fweights` and `iweights` are allowed; see [U] 11.1.6 weight. Weights must be constant within panel.

`collinear` and `coeflegend` do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options for time-invariant model

### Model

`noconstant`; see [R] Estimation options.

`ti` specifies that the parameters of the time-invariant technical inefficiency model be estimated.

`cost` specifies that the frontier model be fit in terms of a cost function instead of a production function. By default, `xtfrontier` fits a production frontier model.

`constraints`(*constraints*); see [R] Estimation options.

### SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (oim) and that use bootstrap or jackknife methods (bootstrap, jackknife); see [XT] `vce_options`.

**Reporting**

`level(#)`; see [R] **Estimation options**.

`nocnsreport`; see [R] **Estimation options**.

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] **Estimation options**.

**Maximization**

`maximize_options`: `difficult`, `technique(algorithm_spec)` `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] **Maximize**. These options are seldom used.

The following options are available with `xtfrontier` but are not shown in the dialog box:  
`collinear`, `coeflegend`; see [R] **Estimation options**.

## Options for time-varying decay model

**Model**

`noconstant`; see [R] **Estimation options**.

`tvd` specifies that the parameters of the time-varying decay model be estimated.

`cost` specifies that the frontier model be fit in terms of a cost function instead of a production function. By default, `xtfrontier` fits a production frontier model.

`constraints(constraints)`; see [R] **Estimation options**.

**SE**

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] **vce\_options**.

**Reporting**

`level(#)`; see [R] **Estimation options**.

`nocnsreport`; see [R] **Estimation options**.

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] **Estimation options**.

**Maximization**

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] **Maximize**. These options are seldom used.

The following options are available with `xtfrontier` but are not shown in the dialog box: `collinear`, `coeflegend`; see [R] **Estimation options**.

## Remarks and examples

Remarks are presented under the following headings:

- Introduction*
- Time-invariant model*
- Time-varying decay model*

## Introduction

Stochastic production frontier models were introduced by Aigner, Lovell, and Schmidt (1977) and Meeusen and van den Broeck (1977). Since then, stochastic frontier models have become a popular subfield in econometrics; see Kumbhakar and Lovell (2000) for an introduction. `xtfrontier` fits two stochastic frontier models with distinct specifications of the inefficiency term and can fit both production- and cost-frontier models.

Let's review the nature of the stochastic frontier problem. Suppose that a producer has a production function  $f(\mathbf{z}_{it}, \boldsymbol{\beta})$ . In a world without error or inefficiency, in time  $t$ , the  $i$ th firm would produce

$$q_{it} = f(\mathbf{z}_{it}, \boldsymbol{\beta})$$

A fundamental element of stochastic frontier analysis is that each firm potentially produces less than it might because of a degree of inefficiency. Specifically,

$$q_{it} = f(\mathbf{z}_{it}, \boldsymbol{\beta})\xi_{it}$$

where  $\xi_{it}$  is the level of efficiency for firm  $i$  at time  $t$ ;  $\xi_i$  must be in the interval  $(0, 1]$ . If  $\xi_{it} = 1$ , the firm is achieving the optimal output with the technology embodied in the production function  $f(\mathbf{z}_{it}, \boldsymbol{\beta})$ . When  $\xi_{it} < 1$ , the firm is not making the most of the inputs  $\mathbf{z}_{it}$  given the technology embodied in the production function  $f(\mathbf{z}_{it}, \boldsymbol{\beta})$ . Because the output is assumed to be strictly positive (that is,  $q_{it} > 0$ ), the degree of technical efficiency is assumed to be strictly positive (that is,  $\xi_{it} > 0$ ).

Output is also assumed to be subject to random shocks, implying that

$$q_{it} = f(\mathbf{z}_{it}, \boldsymbol{\beta})\xi_{it}\exp(v_{it})$$

Taking the natural log of both sides yields

$$\ln(q_{it}) = \ln\{f(\mathbf{z}_{it}, \boldsymbol{\beta})\} + \ln(\xi_{it}) + v_{it}$$

Assuming that there are  $k$  inputs and that the production function is linear in logs, defining  $u_{it} = -\ln(\xi_{it})$  yields

$$\ln(q_{it}) = \beta_0 + \sum_{j=1}^k \beta_j \ln(z_{j, it}) + v_{it} - u_{it} \quad (1)$$

Because  $u_{it}$  is subtracted from  $\ln(q_{it})$ , restricting  $u_{it} \geq 0$  implies that  $0 < \xi_{it} \leq 1$ , as specified above.

Kumbhakar and Lovell (2000) provide a detailed version of this derivation, and they show that performing an analogous derivation in the dual cost function problem allows us to specify the problem as

$$\ln(c_{it}) = \beta_0 + \beta_q \ln(q_{it}) + \sum_{j=1}^k \beta_j \ln(p_{jit}) + v_{it} - su_{it} \quad (2)$$

where  $q_{it}$  is output, the  $z_{ jit}$  are input quantities,  $c_{it}$  is cost, the  $p_{ jit}$  are input prices, and

$$s = \begin{cases} 1, & \text{for production functions} \\ -1, & \text{for cost functions} \end{cases}$$

Intuitively, the inefficiency effect is required to lower output or raise expenditure, depending on the specification.

## □ Technical note

The model that **xtfrontier** actually fits has the form

$$y_{it} = \beta_0 + \sum_{j=1}^k \beta_j x_{ jit} + v_{it} - su_{it}$$

so in the context of the discussion above,  $y_{it} = \ln(q_{it})$  and  $x_{ jit} = \ln(z_{ jit})$  for a production function; for a cost function,  $y_{it} = \ln(c_{it})$ , the  $x_{ jit}$  are the  $\ln(p_{ jit})$ , and  $\ln(q_{it})$ . You must perform the natural logarithm transformation of the data before estimation to interpret the estimation results correctly for a stochastic frontier production or cost model. **xtfrontier** does not perform any transformations on the data.

□

As shown above, the disturbance term in a stochastic frontier model is assumed to have two components. One component is assumed to have a strictly nonnegative distribution, and the other component is assumed to have a symmetric distribution. In the econometrics literature, the nonnegative component is often referred to as the *inefficiency term*, and the component with the symmetric distribution as the *idiosyncratic error*.

Equation (2) is a variant of a panel-data model in which  $v_{it}$  is the idiosyncratic error and  $u_{it}$  is a time-varying panel-level effect. Much of the literature on this model has focused on deriving estimators for different specifications of the  $u_{it}$  term. Kumbhakar and Lovell (2000) provide a survey of this literature.

**xtfrontier** provides estimators for two different specifications of  $u_{it}$ . To facilitate the discussion, let  $N^+(\mu, \sigma^2)$  denote the truncated-normal distribution, which is truncated at zero with mean  $\mu$  and variance  $\sigma^2$ , and let  $\stackrel{\text{iid}}{\sim}$  stand for independent and identically distributed.

Consider the simplest specification in which the inefficiency term  $u_{it}$  is a time-invariant truncated-normal random variable. In the time-invariant model,  $u_{it} = u_i$ ,  $u_i \stackrel{\text{iid}}{\sim} N^+(\mu, \sigma_u^2)$ ,  $v_{it} \stackrel{\text{iid}}{\sim} N(0, \sigma_v^2)$ , and  $u_i$  and  $v_{it}$  are distributed independently of each other and the covariates in the model. Specifying the `ti` option causes **xtfrontier** to estimate the parameters of this model.

In the Battese–Coelli (1992) parameterization of time effects, the inefficiency term is modeled as a truncated-normal random variable multiplied by a specific function of time. In the time-varying decay specification,

$$u_{it} = \exp\{-\eta(t - T_i)\} u_i$$

where  $T_i$  is the last period in the  $i$ th panel,  $\eta$  is the decay parameter,  $u_i \stackrel{\text{iid}}{\sim} N^+(\mu, \sigma_u^2)$ ,  $v_{it} \stackrel{\text{iid}}{\sim} N(0, \sigma_v^2)$ , and  $u_i$  and  $v_{it}$  are distributed independently of each other and the covariates in the model. Specifying the `tvd` option causes `xtfrontier` to estimate the parameters of this model.

## Time-invariant model

### ▷ Example 1

`xtfrontier`, `ti` provides maximum likelihood estimates for the parameters of the time-invariant decay model. In this model, the inefficiency effects are modeled as  $u_{it} = u_i$ ,  $u_i \stackrel{\text{iid}}{\sim} N^+(\mu, \sigma_u^2)$ ,  $v_{it} \stackrel{\text{iid}}{\sim} N(0, \sigma_v^2)$ , and  $u_i$  and  $v_{it}$  are distributed independently of each other and the covariates in the model. In this example, firms produce a product called a widget, using a constant-returns-to-scale technology. We have 948 observations—91 firms, with 6–14 observations per firm. Our dataset contains variables representing the quantity of widgets produced, the number of machine hours used in production, the number of labor hours used in production, and three additional variables that are the natural logarithm transformations of the three aforementioned variables.

We fit a time-invariant model using the transformed variables:

```
. use https://www.stata-press.com/data/r16/xtfrontier1
. xtfrontier lnwidgets lnmachines lnworkers, ti

Iteration 0: log likelihood = -1473.8703
Iteration 1: log likelihood = -1473.0565
Iteration 2: log likelihood = -1472.6155
Iteration 3: log likelihood = -1472.607
Iteration 4: log likelihood = -1472.6069

Time-invariant inefficiency model
Number of obs      =         948
Group variable: id
Number of groups   =          91
Obs per group:
min =             6
avg =            10.4
max =            14
Wald chi2(2)      =       661.76
Prob > chi2       =     0.0000
Log likelihood    = -1472.6069
```

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
lnwidgets	.2904551	.0164219	17.69	0.000	.2582688 .3226415
lnmachines	.2943333	.0154352	19.07	0.000	.2640808 .3245858
lnworkers	3.030983	.1441022	21.03	0.000	2.748548 3.313418
_cons					
/mu	1.125667	.6479217	1.74	0.082	-.144236 2.39557
/lnsigma2	1.421979	.2672745	5.32	0.000	.898131 1.945828
/lgtgamma	1.138685	.3562642	3.20	0.001	.4404204 1.83695
sigma2	4.145318	1.107938			2.455011 6.999424
gamma	.7574382	.0654548			.6083592 .8625876
sigma_u2	3.139822	1.107235			.9696821 5.309962
sigma_v2	1.005496	.0484143			.9106055 1.100386

In addition to the coefficients, the output reports estimates for the parameters `sigma_v2`, `sigma_u2`, `gamma`, `sigma2`, `lgtgamma`, `lnsigma2`, and `mu`. `sigma_v2` is the estimate of  $\sigma_v^2$ . `sigma_u2` is the estimate of  $\sigma_u^2$ . `gamma` is the estimate of  $\gamma = \sigma_u^2/\sigma_S^2$ . `sigma2` is the estimate of  $\sigma_S^2 = \sigma_v^2 + \sigma_u^2$ . Because  $\gamma$  must be between 0 and 1, the optimization is parameterized in terms of the logit of  $\gamma$ , and

this estimate is reported as `lgtgamma`. Because  $\sigma_S^2$  must be positive, the optimization is parameterized in terms of  $\ln(\sigma_S^2)$ , and this estimate is reported as `lnsigma2`. Finally, `mu` is the estimate of  $\mu$ .  $\square$

## □ Technical note

Our simulation results indicate that this estimator requires relatively large samples to achieve any reasonable degree of precision in the estimates of  $\mu$  and  $\sigma_u^2$ .  $\square$

## Time-varying decay model

`xtfrontier`, `tvd` provides maximum likelihood estimates for the parameters of the time-varying decay model. In this model, the inefficiency effects are modeled as

$$u_{it} = \exp\{-\eta(t - T_i)\} u_i$$

where  $u_i \stackrel{\text{iid}}{\sim} N^+(\mu, \sigma_u^2)$ .

When  $\eta > 0$ , the degree of inefficiency decreases over time; when  $\eta < 0$ , the degree of inefficiency increases over time. Because  $t = T_i$  in the last period, the last period for firm  $i$  contains the base level of inefficiency for that firm. If  $\eta > 0$ , the level of inefficiency decays toward the base level. If  $\eta < 0$ , the level of inefficiency increases to the base level.

## ▷ Example 2

When  $\eta = 0$ , the time-varying decay model reduces to the time-invariant model. The following example illustrates this property and demonstrates how to specify constraints and starting values in these models.

Let's begin by fitting the time-varying decay model on the same data that were used in the previous example for the time-invariant model.

```
. xtfrontier lnwidgets lnmachines lnworkers, tvd
Iteration 0: log likelihood = -1551.3798 (not concave)
Iteration 1: log likelihood = -1502.2637
Iteration 2: log likelihood = -1476.3093 (not concave)
Iteration 3: log likelihood = -1472.9845
Iteration 4: log likelihood = -1472.5365
Iteration 5: log likelihood = -1472.529
Iteration 6: log likelihood = -1472.5289

Time-varying decay inefficiency model
Number of obs      =      948
Group variable: id      Number of groups =       91
Time variable: t      Obs per group:
                                         min =          6
                                         avg =      10.4
                                         max =      14
                                         Wald chi2(2) =     661.93
Log likelihood = -1472.5289      Prob > chi2 =    0.0000
```

lnwidgets	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
lnmachines	.2907555	.0164376	17.69	0.000	.2585384 .3229725
lnworkers	.2942412	.0154373	19.06	0.000	.2639846 .3244978
_cons	3.028939	.1436046	21.09	0.000	2.74748 3.310399
/mu	1.110831	.6452809	1.72	0.085	-.1538967 2.375558
/eta	.0016764	.00425	0.39	0.693	-.0066535 .0100064
/lnsigma2	1.410723	.2679485	5.26	0.000	.885554 1.935893
/lgtgamma	1.123982	.3584243	3.14	0.002	.4214828 1.82648
sigma2	4.098919	1.098299			2.424327 6.930228
gamma	.7547265	.0663495			.603838 .8613419
sigma_u2	3.093563	1.097606			.9422943 5.244832
sigma_v2	1.005356	.0484079			.9104785 1.100234

The estimate of  $\eta$  is close to zero, and the other estimates are not too far from those of the time-invariant model.

We can use `constraint` to constrain  $\eta = 0$  and obtain the same results produced by the time-invariant model. Although there is only one statistical equation to be estimated in this model, the model fits five of Stata's [R] `ml` equations; see [R] `ml` or Gould, Pitblado, and Poi (2010). The equation names can be seen by listing the matrix of estimated coefficients.

```
. matrix list e(b)
e(b)[1,7]
  lnwidgets:  lnwidgets:  lnwidgets:  lnsigma2:  lgtgamma:           mu:
  lnmachines   lnworkers      _cons      _cons      _cons      _cons
y1   .29075546   .2942412   3.0289395   1.4107233   1.1239816   1.1108307
      eta:
      _cons
y1   .00167642
```

To constrain a parameter to a particular value in any equation, except the first equation, you must specify both the equation name and the parameter name by using the syntax

`constraint # [eqname]_b[varname] = value`      or

`constraint # [eqname]coefficient = value`

where *eqname* is the equation name, *varname* is the name of the variable in a linear equation, and *coefficient* refers to any parameter that has been estimated. More elaborate specifications with

expressions are possible; see the example with constant returns to scale below, and see [R] constraint for general reference.

Suppose that we impose the constraint  $\eta = 0$ ; we get the same results as those reported above for the time-invariant model, except for some minute differences attributable to an alternate convergence path in the optimization.

```
. constraint 1 [eta]_cons = 0
. xtfrontier lnwidgets lnmachines lnworkers, tvd constraints(1)
Iteration 0: log likelihood = -1540.7124 (not concave)
Iteration 1: log likelihood = -1515.7726
Iteration 2: log likelihood = -1473.0162
Iteration 3: log likelihood = -1472.9223
Iteration 4: log likelihood = -1472.6254
Iteration 5: log likelihood = -1472.607
Iteration 6: log likelihood = -1472.6069

Time-varying decay inefficiency model
Group variable: id
Time variable: t

Number of obs      =      948
Number of groups   =       91
Obs per group:
               min =        6
                  avg =     10.4
                     max =     14

Wald chi2(2)      =     661.76
Prob > chi2       =     0.0000

Log likelihood   = -1472.6069
```

( 1) [eta]\_cons = 0

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
lnwidgets	.2904551	.0164219	17.69	0.000	.2582688 .3226414
lnmachines	.2943332	.0154352	19.07	0.000	.2640807 .3245857
_cons	3.030963	.1440995	21.03	0.000	2.748534 3.313393
/mu	1.125507	.6480444	1.74	0.082	-.1446369 2.39565
/eta	0	(omitted)			
/lnsigma2	1.422039	.2673128	5.32	0.000	.8981155 1.945962
/lgtgamma	1.138764	.3563076	3.20	0.001	.4404135 1.837114
sigma2	4.145565	1.108162			2.454972 7.000366
gamma	.7574526	.0654602			.6083575 .862607
sigma_u2	3.140068	1.107459			.9694878 5.310649
sigma_v2	1.005496	.0484143			.9106057 1.100386



## Stored results

`xtfrontier` stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(g_min)</code>	minimum number of observations per group
<code>e(g_avg)</code>	average number of observations per group
<code>e(g_max)</code>	maximum number of observations per group
<code>e(sigma2)</code>	$\sigma^2$
<code>e(gamma)</code>	$\gamma$
<code>e(Tcon)</code>	1 if panels balanced, 0 otherwise
<code>e(sigma_u)</code>	standard deviation of technical inefficiency
<code>e(sigma_v)</code>	standard deviation of random error
<code>e(chi2)</code>	$\chi^2$
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

### Macros

<code>e(cmd)</code>	<code>xtfrontier</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(function)</code>	production or cost
<code>e(model)</code>	ti, after time-invariant model; tvd, after time-varying decay model
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(chi2type)</code>	Wald; type of model $\chi^2$ test
<code>e(vce)</code>	<code>vctype</code> specified in <code>vce()</code>
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(asbalanced)</code>	factor variables fvset as asbalanced
<code>e(asobserved)</code>	factor variables fvset as asobserved

### Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log (up to 20 iterations)
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimators

### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

**xtfrontier** fits stochastic frontier models for panel data that can be expressed as

$$y_{it} = \beta_0 + \sum_{j=1}^k \beta_j x_{jit} + v_{it} - s u_{it}$$

where  $y_{it}$  is the natural logarithm of output, the  $x_{ jit}$  are the natural logarithm of the input quantities for the production efficiency problem,  $y_{it}$  is the natural logarithm of costs, the  $x_{it}$  are the natural logarithm of input prices for the cost efficiency problem, and

$$s = \begin{cases} 1, & \text{for production functions} \\ -1, & \text{for cost functions} \end{cases}$$

For the time-varying decay model, the log-likelihood function is derived as

$$\begin{aligned} \ln L = & -\frac{1}{2} \left( \sum_{i=1}^N T_i \right) \{ \ln(2\pi) + \ln(\sigma_S^2) \} - \frac{1}{2} \sum_{i=1}^N (T_i - 1) \ln(1 - \gamma) \\ & - \frac{1}{2} \sum_{i=1}^N \ln \left\{ 1 + \left( \sum_{t=1}^{T_i} \eta_{it}^2 - 1 \right) \gamma \right\} - N \ln \{ 1 - \Phi(-\tilde{z}) \} - \frac{1}{2} N \tilde{z}^2 \\ & + \sum_{i=1}^N \ln \{ 1 - \Phi(-z_i^*) \} + \frac{1}{2} \sum_{i=1}^N z_i^{*2} - \frac{1}{2} \sum_{i=1}^N \sum_{t=1}^{T_i} \frac{\epsilon_{it}^2}{(1 - \gamma) \sigma_S^2} \end{aligned}$$

where  $\sigma_S = (\sigma_u^2 + \sigma_v^2)^{1/2}$ ,  $\gamma = \sigma_u^2 / \sigma_S^2$ ,  $\epsilon_{it} = y_{it} - \mathbf{x}_{it}\beta$ ,  $\eta_{it} = \exp\{-\eta(t - T_i)\}$ ,  $\tilde{z} = \mu / (\gamma \sigma_S^2)^{1/2}$ ,  $\Phi()$  is the cumulative distribution function of the standard normal distribution, and

$$z_i^* = \frac{\mu(1 - \gamma) - s\gamma \sum_{t=1}^{T_i} \eta_{it} \epsilon_{it}}{\left[ \gamma(1 - \gamma) \sigma_S^2 \left\{ 1 + \left( \sum_{t=1}^{T_i} \eta_{it}^2 - 1 \right) \gamma \right\} \right]^{1/2}}$$

Maximizing the above log likelihood estimates the coefficients  $\eta$ ,  $\mu$ ,  $\sigma_v$ , and  $\sigma_u$ .

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## Also see

- [XT] **xtfrontier postestimation** — Postestimation tools for xtfrontier
- [XT] **xtset** — Declare data to be panel data
- [R] **frontier** — Stochastic frontier models
- [U] **20 Estimation and postestimation commands**

Postestimation commands  
Methods and formulas

[predict](#)  
[Also see](#)

[margins](#)

Remarks and examples

## Postestimation commands

The following postestimation commands are available after `xtfrontier`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions, standard errors, and technical efficiencies.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

`predict [type] newvar [if] [in] [, statistic]`

<i>statistic</i>	Description
<b>Main</b>	
<code>xb</code>	linear prediction; the default
<code>stdp</code>	standard error of the linear prediction
<code>u</code>	minus the natural log of the technical efficiency via $E(u_{it}   \epsilon_{it})$
<code>m</code>	minus the natural log of the technical efficiency via $M(u_{it}   \epsilon_{it})$
<code>te</code>	the technical efficiency via $E\{\exp(-su_{it})   \epsilon_{it}\}$

where

$$s = \begin{cases} 1, & \text{for production functions} \\ -1, & \text{for cost functions} \end{cases}$$

### Options for predict

#### Main

`xb`, the default, calculates the linear prediction.

`stdp` calculates the standard error of the linear prediction.

`u` produces estimates of minus the natural log of the technical efficiency via  $E(u_{it} | \epsilon_{it})$ .

`m` produces estimates of minus the natural log of the technical efficiency via the mode,  $M(u_{it} | \epsilon_{it})$ .

`te` produces estimates of the technical efficiency via  $E\{\exp(-su_{it}) | \epsilon_{it}\}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist], predict(statistic ...) [options]
```

<i>statistic</i>	Description
<code>xb</code>	linear prediction; the default
<code>stdp</code>	not allowed with <code>margins</code>
<code>u</code>	not allowed with <code>margins</code>
<code>m</code>	not allowed with <code>margins</code>
<code>te</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

## Remarks and examples

### ▷ Example 1

A production function exhibits *constant returns to scale* if doubling the amount of each input results in a doubling in the quantity produced. When the production function is linear in logs, constant returns to scale implies that the sum of the coefficients on the inputs is one. In [example 2 of \[XT\] xfrontier](#), we fit a time-varying decay model. Here we test whether the estimated production function exhibits constant returns:

```
. use https://www.stata-press.com/data/r16/xtfrontier1
. xfrontier lnwidgets lnmachines lnworkers, tvd
  (output omitted)
. test lnmachines + lnworkers = 1
( 1)  [lnwidgets]lnmachines + [lnwidgets]lnworkers = 1
           chi2( 1) =   331.55
           Prob > chi2 =      0.0000
```

The test statistic is highly significant, so we reject the null hypothesis and conclude that this production function does not exhibit constant returns to scale.

The previous Wald  $\chi^2$  test indicated that the sum of the coefficients does not equal one. An alternative is to use `lincom` to compute the sum explicitly:

```
. lincom lnmachines + lnworkers
( 1) [lnwidgets]lnmachines + [lnwidgets]lnworkers = 0
```

lnwidgets	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
(1)	.5849967	.0227918	25.67	0.000	.5403256 .6296677

The sum of the coefficients is significantly less than one, so this production function exhibits *decreasing returns to scale*. If we doubled the number of machines and workers, we would obtain less than twice as much output.



## Methods and formulas

Continuing from the [Methods and formulas](#) section of [XT] **xtfrontier**, estimates for  $u_{it}$  can be obtained from the mean or the mode of the conditional distribution  $f(u|\epsilon)$ .

$$E(u_{it} | \epsilon_{it}) = \tilde{\mu}_i + \tilde{\sigma}_i \left\{ \frac{\phi(-\tilde{\mu}_i/\tilde{\sigma}_i)}{1 - \Phi(-\tilde{\mu}_i/\tilde{\sigma}_i)} \right\}$$

$$M(u_{it} | \epsilon_{it}) = \begin{cases} -\tilde{\mu}_i, & \text{if } \tilde{\mu}_i \geq 0 \\ 0, & \text{otherwise} \end{cases}$$

where

$$\tilde{\mu}_i = \frac{\mu\sigma_v^2 - s \sum_{t=1}^{T_i} \eta_{it}\epsilon_{it}\sigma_u^2}{\sigma_v^2 + \sum_{t=1}^{T_i} \eta_{it}^2\sigma_u^2}$$

$$\tilde{\sigma}_i^2 = \frac{\sigma_v^2\sigma_u^2}{\sigma_v^2 + \sum_{t=1}^{T_i} \eta_{it}^2\sigma_u^2}$$

These estimates can be obtained from `predict newvar, u` and `predict newvar, m`, respectively, and are calculated by plugging in the estimated parameters.

`predict newvar, te` produces estimates of the technical-efficiency term. These estimates are obtained from

$$E \{ \exp(-su_{it}) | \epsilon_{it} \} = \left[ \frac{1 - \Phi \{ s\eta_{it}\tilde{\sigma}_i - (\tilde{\mu}_i/\tilde{\sigma}_i) \}}{1 - \Phi(-\tilde{\mu}_i/\tilde{\sigma}_i)} \right] \exp \left( -s\eta_{it}\tilde{\mu}_i + \frac{1}{2}\eta_{it}^2\tilde{\sigma}_i^2 \right)$$

Replacing  $\eta_{it} = 1$  and  $\eta = 0$  in these formulas produces the formulas for the time-invariant models.

## Also see

[XT] **xtfrontier** — Stochastic frontier models for panel data

[U] **20 Estimation and postestimation commands**

**xtgee** — Fit population-averaged panel-data models by using GEE

Description  
Options  
References

Quick start  
Remarks and examples  
Also see

Menu  
Stored results

Syntax  
Methods and formulas

## Description

`xtgee` fits population-averaged panel-data models. In particular, `xtgee` fits generalized linear models and allows you to specify the within-group correlation structure for the panels.

## Quick start

Population-averaged linear regression of `y` on `x1` and `x2`

```
xtgee y x1 x2
```

As above, but estimate time-varying intragroup correlations

```
xtgee y x1 x2, corr(unstructured)
```

As above, but estimate a common second-order autoregression structure for the within-panel correlation

```
xtgee y x1 x2, corr(ar 2)
```

Population-averaged negative binomial regression of `y2` on `x3` and `x4` equivalent to `xtnbreg`, pa

```
xtgee y2 x3 x4, family(nbinomial 1)
```

Population-averaged logistic regression of `y3` on `x5` and `x6` when `y3` is the number of events out of 10 trials

```
xtgee y3 x5 x6, family(binomial 10)
```

## Menu

Statistics > Longitudinal/panel data > Generalized estimating equations (GEE) > Generalized estimating equations (GEE)

## Syntax

`xtgee depvar [indepvars] [if] [in] [weight] [, options]`

<i>options</i>	Description
<hr/>	
Model	
<code>family(family)</code>	distribution of <i>depvar</i>
<code>link(link)</code>	link function
Model 2	
<code>exposure(varname)</code>	include $\ln(\text{varname})$ in model with coefficient constrained to 1
<code>offset(varname)</code>	include <i>varname</i> in model with coefficient constrained to 1
<code>noconstant</code>	suppress constant term
<code>asis</code>	retain perfect predictor variables
<code>force</code>	estimate even if observations unequally spaced in time
Correlation	
<code>corr(correlation)</code>	within-group correlation structure
SE/Robust	
<code>vce(vcetype)</code>	<i>vcetype</i> may be conventional, robust, bootstrap, or jackknife
<code>nmp</code>	use divisor $N - P$ instead of the default $N$
<code>rgf</code>	multiply the robust variance estimate by $(N - 1)/(N - P)$
<code>scale(parm)</code>	overrides the default scale parameter; <i>parm</i> may be x2, dev, phi, or #
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>eform</code>	report exponentiated coefficients
<code>display_options</code>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<code>optimize_options</code>	control the optimization process; seldom used
<code>nodisplay</code>	suppress display of header and coefficients
<code>coeflegend</code>	display legend instead of statistics

A panel variable must be specified. Correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] `xtset`.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

*depvar* and *indepvars* may contain time-series operators; see [U] 11.4 varname and varlists.

`by`, `mfp`, `mi estimate`, and `statsby` are allowed; see [U] 11.1.10 Prefix commands.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] `mi estimate`.

`iweights`, `fweights`, and `pweights` are allowed; see [U] 11.1.6 weight. Weights must be constant within panel.

`nodisplay` and `coeflegend` do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

<i>family</i>	Description
<u>gaussian</u>	Gaussian (normal); <code>family(normal)</code> is a synonym
<u>igaussian</u>	inverse Gaussian
<u>binomial</u> [#  <i>varname</i> ]	Bernoulli/binomial
<u>poisson</u>	Poisson
<u>nbinomial</u> [#]	negative binomial
<u>gamma</u>	gamma

<i>link</i>	Link function/definition
<u>identity</u>	identity; $y = y$
<u>log</u>	log; $\ln(y)$
<u>logit</u>	logit; $\ln\{y/(1 - y)\}$ , natural log of the odds
<u>probit</u>	probit; $\Phi^{-1}(y)$ , where $\Phi()$ is the normal cumulative distribution
<u>cloglog</u>	clog-log; $\ln\{-\ln(1 - y)\}$
<u>power</u> [#]	power; $y^k$ with $k = \#$ ; $\# = 1$ if not specified
<u>opower</u> [#]	odds power; $\{\{y/(1 - y)\}^k - 1\}/k$ with $k = \#$ ; $\# = 1$ if not specified
<u>nbinomial</u>	negative binomial; $\ln\{y/(y + \alpha)\}$
<u>reciprocal</u>	reciprocal; $1/y$

<i>correlation</i>	Description
<u>exchangeable</u>	exchangeable
<u>independent</u>	independent
<u>unstructured</u>	unstructured
<u>fixed</u> <i>matname</i>	user-specified
<u>ar</u> #	autoregressive of order #
<u>stationary</u> #	stationary of order #
<u>nonstationary</u> #	nonstationary of order #

## Options

### Model

`family(family)` specifies the distribution of *depvar*; `family(gaussian)` is the default.

`link(link)` specifies the link function; the default is the canonical link for the `family()` specified (except for `family(nbinomial)`).

### Model 2

`exposure(varname)` and `offset(varname)` are different ways of specifying the same thing. `exposure()` specifies a variable that reflects the amount of exposure over which the *depvar* events were observed for each observation; `ln(varname)` with coefficient constrained to be 1 is entered into the regression equation. `offset()` specifies a variable that is to be entered directly into the log-link function with its coefficient constrained to be 1; thus, exposure is assumed to be  $e^{varname}$ . If you were fitting a Poisson regression model, `family(poisson)` `link(log)`, for instance, you would account for exposure time by specifying `offset()` containing the log of exposure time.

**noconstant** specifies that the linear predictor has no intercept term, thus forcing it through the origin on the scale defined by the link function.

**asis** forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] **probit**. This option is only allowed with option **family(binomial)** with a denominator of 1.

**force** specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify **force**, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

#### Correlation

**corr(correlation)** specifies the within-group correlation structure; the default corresponds to the equal-correlation model, **corr(exchangeable)**.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, **corr(ar 1)** or **corr(ar1)**.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word **fixed**, for example, **corr(fixed myr)**.

#### SE/Robust

**vce(vcetype)** specifies the type of standard error reported, which includes types that are derived from asymptotic theory (**conventional**), that are robust to some kinds of misspecification (**robust**), and that use bootstrap or jackknife methods (**bootstrap**, **jackknife**); see [XT] **vce\_options**.

**vce(conventional)**, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

**vce(robust)** specifies that the Huber/White/sandwich estimator of variance is to be used in place of the default conventional variance estimator (see **Methods and formulas** below). Use of this option causes **xtgee** to produce valid standard errors even if the correlations within group are not as hypothesized by the specified correlation structure. Under a noncanonical link, it does, however, require that the model correctly specifies the mean. The resulting standard errors are thus labeled "semirobust" instead of "robust" in this case. Although there is no **vce(cluster clustvar)** option, results are as if this option were included and you specified clustering on the panel variable.

**nmp**; see [XT] **vce\_options**.

**rgf** specifies that the robust variance estimate is multiplied by  $(N - 1)/(N - P)$ , where  $N$  is the total number of observations and  $P$  is the number of coefficients estimated. This option can be used only with **family(gaussian)** when **vce(robust)** is either specified or implied by the use of **pweights**. Using this option implies that the robust variance estimate is not invariant to the scale of any weights used.

**scale(x2 | dev | phi | #)**; see [XT] **vce\_options**.

#### Reporting

**level(#)**; see [R] **Estimation options**.

`eform` displays the exponentiated coefficients and corresponding standard errors and confidence intervals as described in [R] **Maximize**. For `family(binomial)` `link(logit)` (that is, logistic regression), exponentiation results in odds ratios; for `family(poisson)` `link(log)` (that is, Poisson regression), exponentiated coefficients are incidence-rate ratios.

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] **Estimation options**.

#### Optimization

`optimize_options` control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`log` and `nolog` specify whether to display the iteration log. The iteration log is displayed by default unless you used `set iterlog off` to suppress it; see `set iterlog` in [R] **set iter**.

`trace` specifies that the current estimates be printed at each iteration.

The following options are available with `xtgee` but are not shown in the dialog box:

`nodisplay` is for programmers. It suppresses display of the header and coefficients.

`coeflegend`; see [R] **Estimation options**.

## Remarks and examples

For a thorough introduction to GEE in the estimation of GLM, see Hardin and Hilbe (2013). More information on linear models is presented in Nelder and Wedderburn (1972). Finally, there have been several illuminating articles on various applications of GEE in Zeger, Liang, and Albert (1988); Zeger and Liang (1986), and Liang (1987). Pendergast et al. (1996) surveys the current methods for analyzing clustered data in regard to binary response data. Our implementation follows that of Liang and Zeger (1986).

`xtgee` fits generalized linear models of  $y_{it}$  with covariates  $\mathbf{x}_{it}$

$$g\{E(y_{it})\} = \mathbf{x}_{it}\boldsymbol{\beta}, \quad y \sim F \text{ with parameters } \theta_{it}$$

for  $i = 1, \dots, m$  and  $t = 1, \dots, n_i$ , where there are  $n_i$  observations for each group identifier  $i$ .  $g()$  is called the link function, and  $F$  is the distributional family. Substituting various definitions for  $g()$  and  $F$  results in a wide array of models. For instance, if  $y_{it}$  is distributed Gaussian (normal) and  $g()$  is the identity function, we have

$$E(y_{it}) = \mathbf{x}_{it}\boldsymbol{\beta}, \quad y \sim N()$$

yielding linear regression, random-effects regression, or other regression-related models, depending on what we assume for the correlation structure.

If  $g()$  is the logit function and  $y_{it}$  is distributed Bernoulli (binomial), we have

$$\text{logit}\{E(y_{it})\} = \mathbf{x}_{it}\boldsymbol{\beta}, \quad y \sim \text{Bernoulli}$$

or logistic regression. If  $g(\cdot)$  is the natural log function and  $y_{it}$  is distributed Poisson, we have

$$\ln\{E(y_{it})\} = \mathbf{x}_{it}\boldsymbol{\beta}, \quad y \sim \text{Poisson}$$

or Poisson regression, also known as the log-linear model. Other combinations are possible.

You specify the link function with the `link()` option, the distributional family with `family()`, and the assumed within-group correlation structure with `corr()`.

The binomial distribution can be specified as case 1 `family(binomial)`, case 2 `family(binomial #)`, or case 3 `family(binomial varname)`. In case 2, `#` is the value of the binomial denominator  $N$ , the number of trials. Specifying `family(binomial 1)` is the same as specifying `family(binomial)`; both mean that  $y$  has the Bernoulli distribution with values 0 and 1 only. In case 3, `varname` is the variable containing the binomial denominator, thus allowing the number of trials to vary across observations.

The negative binomial distribution must be specified as `family(nbinomial #)`, where `#` denotes the value of the parameter  $\alpha$  in the negative binomial distribution. The results will be conditional on this value.

You do not have to specify both `family()` and `link()`; the default `link()` is the canonical link for the specified `family()` (excluding `family(nbinomial)`):

Family	Default link
<code>family(binomial)</code>	<code>link(logit)</code>
<code>family(gamma)</code>	<code>link(reciprocal)</code>
<code>family(gaussian)</code>	<code>link(identity)</code>
<code>family(igaussian)</code>	<code>link(power -2)</code>
<code>family(nbinomial)</code>	<code>link(log)</code>
<code>family(poison)</code>	<code>link(log)</code>

The canonical link for the negative binomial family is obtained by specifying `link(nbinomial)`. If you specify both `family()` and `link()`, not all combinations make sense. You may choose among the following combinations:

	Gaussian	Inverse Gaussian	Binomial	Poisson	Negative Binomial	Gamma
Identity	x	x	x	x	x	x
Log	x	x	x	x	x	x
Logit			x			
Probit			x			
C. log-log			x			
Power	x	x	x	x	x	x
Odds Power			x			
Neg. binom.					x	
Reciprocal	x		x	x		x

You specify the assumed within-group correlation structure with the `corr()` option.

For example, call  $\mathbf{R}$  the working correlation matrix for modeling the within-group correlation, a square  $\max\{n_i\} \times \max\{n_i\}$  matrix. `corr()` specifies the structure of  $\mathbf{R}$ . Let  $\mathbf{R}_{t,s}$  denote the  $t, s$  element.

The `independent` structure is defined as

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ 0 & \text{otherwise} \end{cases}$$

The `corr(exchangeable)` structure (corresponding to equal-correlation models) is defined as

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ \rho & \text{otherwise} \end{cases}$$

The `corr(ar g)` structure is defined as the usual correlation matrix for an AR( $g$ ) model. This is sometimes called multiplicative correlation. For example, an AR(1) model is given by

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ \rho^{|t-s|} & \text{otherwise} \end{cases}$$

The `corr(stationary g)` structure is a stationary( $g$ ) model. For example, a stationary(1) model is given by

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ \rho & \text{if } |t - s| = 1 \\ 0 & \text{otherwise} \end{cases}$$

The `corr(nonstationary g)` structure is a nonstationary( $g$ ) model that imposes only the constraints that the elements of the working correlation matrix along the diagonal be 1 and the elements outside the  $g$ th band be zero,

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ \rho_{ts} & \text{if } 0 < |t - s| \leq g, \rho_{ts} = \rho_{st} \\ 0 & \text{otherwise} \end{cases}$$

`corr(unstructured)` imposes only the constraint that the diagonal elements of the working correlation matrix be 1.

$$\mathbf{R}_{t,s} = \begin{cases} 1 & \text{if } t = s \\ \rho_{ts} & \text{otherwise, } \rho_{ts} = \rho_{st} \end{cases}$$

The `corr(fixed matname)` specification is taken from the user-supplied matrix, such that

$$\mathbf{R} = \text{matname}$$

Here the correlations are not estimated from the data. The user-supplied matrix must be a valid correlation matrix with 1s on the diagonal.

Full formulas for all the correlation structures are provided in the *Methods and formulas* below.

## □ Technical note

Some `family()`, `link()`, and `corr()` combinations result in models already fit by Stata:

<code>family()</code>	<code>link()</code>	<code>corr()</code>	Other Stata estimation command
gaussian	identity	independent	<code>regress</code>
gaussian	identity	exchangeable	<code>xtreg, re</code>
gaussian	identity	exchangeable	<code>xtreg, pa</code>
binomial	cloglog	independent	<code>cloglog</code> (see note 1)
binomial	cloglog	exchangeable	<code>xtcloglog, pa</code>
binomial	logit	independent	<code>logit</code> or <code>logistic</code>
binomial	logit	exchangeable	<code>xtlogit, pa</code>
binomial	probit	independent	<code>probit</code> (see note 2)
binomial	probit	exchangeable	<code>xtprobit, pa</code>
nbinomial	log	independent	<code>nbreg</code> (see note 3)
poisson	log	independent	<code>Poisson</code>
poisson	log	exchangeable	<code>xtpoisson, pa</code>
gamma	log	independent	<code>streg, dist(exp) nohr</code> (see note 4)
family	link	independent	<code>glm, irls</code> (see note 5)

Notes:

1. For clog-log estimation, `xtgee` with `corr(independent)` and `cloglog` (see [R] `cloglog`) will produce the same coefficients, but the standard errors will be only asymptotically equivalent because clog-log is not the canonical link for the binomial family.
  2. For probit estimation, `xtgee` with `corr(independent)` and `probit` will produce the same coefficients, but the standard errors will be only asymptotically equivalent because probit is not the canonical link for the binomial family. If the binomial denominator is not 1, the equivalent maximum-likelihood command is `glm` with options `family(binomial #)` or `family(binomial varname)` and `link(probit)`; see [R] `probit` and [R] `glm`.
  3. Fitting a negative binomial model by using `xtgee` (or using `glm`) will yield results conditional on the specified value of  $\alpha$ . The `nbreg` command, however, estimates that parameter and provides unconditional estimates; see [R] `nbreg`.
  4. `xtgee` with `corr(independent)` can be used to fit exponential regressions, but this requires specifying `scale(1)`. As with probit, the `xtgee`-reported standard errors will be only asymptotically equivalent to those produced by `streg`, `dist(exp) nohr` (see [ST] `streg`) because log is not the canonical link for the gamma family. `xtgee` cannot be used to fit exponential regressions on censored data.
- Using the `independent` correlation structure, the `xtgee` command will fit the same model fit with the `glm`, `irls` command if the family–link combination is the same.
5. If the `xtgee` command is equivalent to another command, using `corr(independent)` and the `vce(robust)` option with `xtgee` corresponds to using the `vce(cluster clustvar)` option in the equivalent command, where `clustvar` corresponds to the panel variable. □

`xtgee` is a generalization of the `glm`, `irls` command and gives the same output when the same family and link are specified together with an independent correlation structure. What makes `xtgee` useful is

- the number of statistical models that it generalizes for use with panel data, many of which are not otherwise available in Stata;
- the richer correlation structure `xtgee` allows, even when models are available through other `xt` commands; and
- the availability of robust standard errors (see [U] 20.22 Obtaining robust variance estimates), even when the model and correlation structure are available through other `xt` commands.

In the following examples, we illustrate the relationships of `xtgee` with other Stata estimation commands. Remember that, although `xtgee` generalizes many other commands, the computational algorithm is different; therefore, the answers you obtain will not be identical. The dataset we are using is a subset of the `nlswork` data (see [XT] `xt`); we are looking at observations before 1980.

## ▷ Example 1

We can use **xtgee** to perform ordinary least squares by **regress**:

```
. use https://www.stata-press.com/data/r16/nlswork2
(National Longitudinal Survey. Young Women 14–26 years of age in 1968)
. regress ln_w grade age c.age#c.age
```

Source	SS	df	MS	Number of obs	=	16,085
Model	597.54468	3	199.18156	F(3, 16081)	=	1413.68
Residual	2265.74584	16,081	.14089583	Prob > F	=	0.0000
Total	2863.29052	16,084	.178021047	R-squared	=	0.2087
				Adj R-squared	=	0.2085
				Root MSE	=	.37536

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
grade	.0724483	.0014229	50.91	0.000	.0696592 .0752374
age	.1064874	.0083644	12.73	0.000	.0900922 .1228825
c.age#c.age	-.0016931	.0001655	-10.23	0.000	-.0020174 -.0013688
_cons	-.8681487	.1024896	-8.47	0.000	-1.06904 -.6672577

```
. xtgee ln_w grade age c.age#c.age, corr(indep) nmp
```

Iteration 1: tolerance = 8.634e-13

GEE population-averaged model	Number of obs	=	16,085	
Group variable:	idcode	Number of groups	=	3,913
Link:	identity	Obs per group:		
Family:	Gaussian	min =	1	
Correlation:	independent	avg =	4.1	
		max =	9	
		Wald chi2(3)	=	4241.04
Scale parameter:	.1408958	Prob > chi2	=	0.0000
Pearson chi2(16081):	2265.75	Deviance	=	2265.75
Dispersion (Pearson):	.1408958	Dispersion	=	.1408958

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
grade	.0724483	.0014229	50.91	0.000	.0696594 .0752372
age	.1064874	.0083644	12.73	0.000	.0900935 .1228812
c.age#c.age	-.0016931	.0001655	-10.23	0.000	-.0020174 -.0013688
_cons	-.8681487	.1024896	-8.47	0.000	-1.069025 -.6672728

When **nmp** is specified, the coefficients and the standard errors produced by the estimators are the same. Moreover, the scale parameter estimate from the **xtgee** command equals the MSE calculation from **regress**; both are estimates of the variance of the residuals.



## ▷ Example 2

The identity link and Gaussian family produce regression-type models. With the independent correlation structure, we reproduce ordinary least squares. With the exchangeable correlation structure, we produce an equal-correlation linear regression estimator.

`xtgee`, `fam(gauss)` `link(ident)` `corr(exch)` is asymptotically equivalent to the weighted-GLS estimator provided by `xtreg`, `re` and to the full maximum-likelihood estimator provided by `xtreg`, `mle`. In balanced data, `xtgee`, `fam(gauss)` `link(ident)` `corr(exch)` and `xtreg`, `mle` produce the same results. With unbalanced data, the results are close but differ because the two estimators handle unbalanced data differently. For both balanced and unbalanced data, the results produced by `xtgee`, `fam(gauss)` `link(ident)` `corr(exch)` and `xtreg`, `mle` differ from those produced by `xtreg`, `re`. Below we demonstrate the use of the three estimators with unbalanced data. We begin with `xtgee`; show the maximum likelihood estimator `xtreg`, `mle`; show the GLS estimator `xtreg`, `re`; and finally show `xtgee` with the `vce(robust)` option.

```
. xtgee ln_w grade age c.age#c.age, nolog
GEE population-averaged model
Group variable: idcode          Number of obs      = 16,085
Link:           identity        Number of groups   = 3,913
Family:         Gaussian       Obs per group:
Correlation:   exchangeable    min =           1
                           avg =         4.1
                           max =         9
Scale parameter: .1416586     Wald chi2(3)    = 2918.26
                           Prob > chi2   = 0.0000
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
grade	.0717731	.00211	34.02	0.000	.0676377 .0759086
age	.1077645	.006885	15.65	0.000	.0942701 .1212589
c.age#c.age	-.0016381	.0001362	-12.03	0.000	-.001905 -.0013712
_cons	-.9480449	.0869277	-10.91	0.000	-1.11842 -.7776698

```
. xtreg ln_w grade age c.age#c.age, mle
Fitting constant-only model:
Iteration 0: log likelihood = -5868.3483
Iteration 1: log likelihood = -5858.8833
Iteration 2: log likelihood = -5858.8244
Fitting full model:
Iteration 0: log likelihood = -4591.9241
Iteration 1: log likelihood = -4562.4406
Iteration 2: log likelihood = -4562.3526
Iteration 3: log likelihood = -4562.3525
Random-effects ML regression
Number of obs      =     16,085
Group variable: idcode
Number of groups   =      3,913
Random effects u_i ~ Gaussian
Obs per group:
    min =           1
    avg =        4.1
    max =         9
LR chi2(3)          =     2592.94
Prob > chi2        =     0.0000
Log likelihood     = -4562.3525
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
grade	.0717747	.002142	33.51	0.000	.0675765 .075973
age	.1077899	.0068266	15.79	0.000	.0944101 .1211697
c.age#c.age	-.0016364	.000135	-12.12	0.000	-.0019011 -.0013718
_cons	-.9500833	.086384	-11.00	0.000	-1.119393 -.7807737
/sigma_u	.2689639	.0040854			.2610748 .2770915
/sigma_e	.2669944	.0017113			.2636613 .2703696
rho	.5036748	.0086449			.4867329 .52061

LR test of sigma\_u=0: chibar2(01) = 4996.22      Prob >= chibar2 = 0.000

```
. xtreg ln_w grade age c.age#c.age, re
Random-effects GLS regression
Group variable: idcode
R-sq:
    within = 0.0983
    between = 0.2946
    overall = 0.2076
corr(u_i, X) = 0 (assumed)

Number of obs      = 16,085
Number of groups  = 3,913
Obs per group:
    min = 1
    avg = 4.1
    max = 9
Wald chi2(3)      = 2875.02
Prob > chi2        = 0.0000
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
grade	.0717757	.0021666	33.13	0.000	.0675294 .0760221
age	.1078042	.0068125	15.82	0.000	.0944519 .1211566
c.age#c.age	-.0016355	.0001347	-12.14	0.000	-.0018996 -.0013714
_cons	-.9512118	.0863139	-11.02	0.000	-1.120384 -.7820397
sigma_u	.27383747				
sigma_e	.26624266				
rho	.51405959				(fraction of variance due to u_i)

```
. xtgee ln_w grade age c.age#c.age, vce(robust) nolog
GEE population-averaged model
Group variable: idcode
Link: identity
Family: Gaussian
Correlation: exchangeable
Number of obs      = 16,085
Number of groups  = 3,913
Obs per group:
    min = 1
    avg = 4.1
    max = 9
Wald chi2(3)      = 2031.28
Prob > chi2        = 0.0000
Scale parameter: .1416586
(Std. Err. adjusted for clustering on idcode)
```

ln_wage	Coef.	Robust Std. Err.	z	P> z	[95% Conf. Interval]
grade	.0717731	.0023341	30.75	0.000	.0671983 .0763479
age	.1077645	.0098097	10.99	0.000	.0885379 .1269911
c.age#c.age	-.0016381	.0001964	-8.34	0.000	-.002023 -.0012532
_cons	-.9480449	.1195009	-7.93	0.000	-1.182262 -.7138274

In [R] `regress`, `regress`, `vce(cluster clustvar)` may produce inefficient coefficient estimates with valid standard errors for random-effects models. These standard errors are robust to model misspecification. The `vce(robust)` option of `xtgee`, on the other hand, requires that the model correctly specify the mean and the link function when the noncanonical link is used.



## Stored results

**xtgee** stores the following in **e()**:

### Scalars

<b>e(N)</b>	number of observations
<b>e(N_g)</b>	number of groups
<b>e(df_m)</b>	model degrees of freedom
<b>e(chi2)</b>	$\chi^2$
<b>e(p)</b>	<i>p</i> -value for model test
<b>e(df_pear)</b>	degrees of freedom for Pearson $\chi^2$
<b>e(chi2_dev)</b>	$\chi^2$ test of deviance
<b>e(chi2_dis)</b>	$\chi^2$ test of deviance dispersion
<b>e(deviance)</b>	deviance
<b>e(dispers)</b>	deviance dispersion
<b>e(phi)</b>	scale parameter
<b>e(g_min)</b>	smallest group size
<b>e(g_avg)</b>	average group size
<b>e(g_max)</b>	largest group size
<b>e(tol)</b>	target tolerance
<b>e(dif)</b>	achieved tolerance
<b>e(rank)</b>	rank of <b>e(V)</b>
<b>e(rc)</b>	return code

### Macros

<b>e(cmd)</b>	<b>xtgee</b>
<b>e(cmdline)</b>	command as typed
<b>e(depyvar)</b>	name of dependent variable
<b>e(ivars)</b>	variable denoting groups
<b>e(tvars)</b>	variable denoting time within groups
<b>e(model)</b>	pa
<b>e(family)</b>	distribution family
<b>e(link)</b>	link function
<b>e(corr)</b>	correlation structure
<b>e(scale)</b>	x2, dev, phi, or #; scale parameter
<b>e(wtype)</b>	weight type
<b>e(wexp)</b>	weight expression
<b>e(offset)</b>	linear offset variable
<b>e(chi2type)</b>	Wald; type of model $\chi^2$ test
<b>e(vce)</b>	<i>vctype</i> specified in <b>vce()</b>
<b>e(vcetype)</b>	title used to label Std. Err.
<b>e(nmp)</b>	nmp, if specified
<b>e(properties)</b>	b V
<b>e(estat_cmd)</b>	program used to implement <b>estat</b>
<b>e(predict)</b>	program used to implement <b>predict</b>
<b>e(marginsnotok)</b>	predictions disallowed by <b>margins</b>
<b>e(asbalanced)</b>	factor variables <b>fvset</b> as <b>asbalanced</b>
<b>e(asobserved)</b>	factor variables <b>fvset</b> as <b>asobserved</b>

### Matrices

<b>e(b)</b>	coefficient vector
<b>e(R)</b>	estimated working correlation matrix
<b>e(V)</b>	variance–covariance matrix of the estimators
<b>e(V_modelbased)</b>	model-based variance

### Functions

<b>e(sample)</b>	marks estimation sample
------------------	-------------------------

## Methods and formulas

Methods and formulas are presented under the following headings:

- [Introduction](#)
- [Calculating GEE for GLM](#)
- [Correlation structures](#)
- [Nonstationary and unstructured](#)

### Introduction

xtgee fits generalized linear models for panel data with the GEE approach described in Liang and Zeger (1986). A related method, referred to as GEE2, is described in Zhao and Prentice (1990) and Prentice and Zhao (1991). The GEE2 method attempts to gain efficiency in the estimation of  $\beta$  by specifying a parametric model for  $\alpha$  and then assumes that the models for both the mean and dependency parameters are correct. Thus there is a tradeoff in robustness for efficiency. The preliminary work of Liang, Zeger, and Qaqish (1992), however, indicates that there is little efficiency gained with this alternative approach.

In the GLM approach (see McCullagh and Nelder [1989]), we assume that

$$\begin{aligned} h(\mu_{i,j}) &= x_{i,j}^T \beta \\ \text{Var}(y_{i,j}) &= g(\mu_{i,j})\phi \\ \mu_i &= E(\mathbf{y}_i) = \{h^{-1}(x_{i,1}^T \beta), \dots, h^{-1}(x_{i,n_i}^T \beta)\}^T \\ \mathbf{A}_i &= \text{diag}\{g(\mu_{i,1}), \dots, g(\mu_{i,n_i})\} \\ \text{Cov}(\mathbf{y}_i) &= \phi \mathbf{A}_i \quad \text{for independent observations.} \end{aligned}$$

In the absence of a convenient likelihood function with which to work, we can rely on a multivariate analog of the quasimle function introduced by Wedderburn (1974):

$$\mathbf{S}_\beta(\beta, \alpha) = \sum_{i=1}^m \left( \frac{\partial \mu_i}{\partial \beta} \right)^T \text{Var}(\mathbf{y}_i)^{-1} (\mathbf{y}_i - \mu_i) = 0$$

We can solve for correlation parameters  $\alpha$  by simultaneously solving

$$\mathbf{S}_\alpha(\beta, \alpha) = \sum_{i=1}^m \left( \frac{\partial \eta_i}{\partial \alpha} \right)^T \mathbf{H}_i^{-1} (\mathbf{W}_i - \eta_i) = 0$$

In the GEE approach to GLM, we let  $\mathbf{R}_i(\alpha)$  be a “working” correlation matrix depending on the parameters in  $\alpha$  (see the [Correlation structures](#) section for the number of parameters), and we estimate  $\beta$  by solving the GEE,

$$\mathbf{U}(\beta) = \sum_{i=1}^m \left( \frac{\partial \mu_i}{\partial \beta} \right)^T \mathbf{V}_i^{-1}(\alpha) (\mathbf{y}_i - \mu_i) = 0$$

where  $\mathbf{V}_i(\alpha) = \mathbf{A}_i^{1/2} \mathbf{R}_i(\alpha) \mathbf{A}_i^{1/2}$

To solve this equation, we need only a crude approximation of the variance matrix, which we can obtain from a Taylor series expansion, where

$$\text{Cov}(\mathbf{y}_i) = \mathbf{L}_i \mathbf{Z}_i \mathbf{D}_i \mathbf{Z}_i^T \mathbf{L}_i + \phi \mathbf{A}_i = \tilde{\mathbf{V}}_i$$

$$\mathbf{L}_i = \text{diag}\{\partial h^{-1}(u)/\partial u, u = x_{i,j}^T \boldsymbol{\beta}, j = 1, \dots, n_i\}$$

which allows that

$$\hat{\mathbf{D}}_i \approx (\mathbf{Z}_i^T \mathbf{Z}_i)^{-1} \mathbf{Z}_i \hat{\mathbf{L}}_i^{-1} \left\{ (\mathbf{y}_i - \hat{\boldsymbol{\mu}}_i)(\mathbf{y}_i - \hat{\boldsymbol{\mu}}_i)^T - \hat{\boldsymbol{\phi}} \hat{\mathbf{A}}_i \right\} \hat{\mathbf{L}}_i^{-1} \mathbf{Z}_i^T (\mathbf{Z}_i' \mathbf{Z}_i)^{-1}$$

$$\hat{\boldsymbol{\phi}} = \sum_{i=1}^m \sum_{j=1}^{n_i} \frac{(y_{i,j} - \hat{\mu}_{i,j})^2 - (\hat{\mathbf{L}}_{i,j})^2 \mathbf{Z}_{i,j}^T \hat{\mathbf{D}}_i \mathbf{Z}_{i,j}}{g(\hat{\mu}_{i,j})}$$

## Calculating GEE for GLM

Using the notation from [Liang and Zeger \(1986\)](#), let  $\mathbf{y}_i = (y_{i,1}, \dots, y_{i,n_i})^T$  be the  $n_i \times 1$  vector of outcome values, and let  $\mathbf{X}_i = (x_{i,1}, \dots, x_{i,n_i})^T$  be the  $n_i \times p$  matrix of covariate values for the  $i$ th subject  $i = 1, \dots, m$ . We assume that the marginal density for  $y_{i,j}$  may be written in exponential family notation as

$$f(y_{i,j}) = \exp [ \{y_{i,j} \theta_{i,j} - a(\theta_{i,j}) + b(y_{i,j})\} \phi]$$

where  $\theta_{i,j} = h(\eta_{i,j})$ ,  $\eta_{i,j} = x_{i,j} \boldsymbol{\beta}$ . Under this formulation, the first two moments are given by

$$E(y_{i,j}) = a'(\theta_{i,j}), \quad \text{Var}(y_{i,j}) = a''(\theta_{i,j})/\phi$$

In what follows, we let  $n_i = n$  without loss of generality. We define the quantities, assuming that we have an  $n \times n$  working correlation matrix  $\mathbf{R}(\boldsymbol{\alpha})$ ,

$$\begin{aligned} \Delta_i &= \text{diag}(d\theta_{i,j}/d\eta_{i,j}) && n \times n \text{ matrix} \\ \mathbf{A}_i &= \text{diag}\{a''(\theta_{i,j})\} && n \times n \text{ matrix} \\ \mathbf{S}_i &= \mathbf{y}_i - a'(\boldsymbol{\theta}_i) && n \times 1 \text{ matrix} \\ \mathbf{D}_i &= \mathbf{A}_i \Delta_i \mathbf{X}_i && n \times p \text{ matrix} \\ \mathbf{V}_i &= \mathbf{A}_i^{1/2} \mathbf{R}(\boldsymbol{\alpha}) \mathbf{A}_i^{1/2} && n \times n \text{ matrix} \end{aligned}$$

such that the GEE becomes

$$\sum_{i=1}^m \mathbf{D}_i^T \mathbf{V}_i^{-1} \mathbf{S}_i = 0$$

We then have that

$$\hat{\boldsymbol{\beta}}_{j+1} = \hat{\boldsymbol{\beta}}_j - \left\{ \sum_{i=1}^m \mathbf{D}_i^T (\hat{\boldsymbol{\beta}}_j) \tilde{\mathbf{V}}_i^{-1} (\hat{\boldsymbol{\beta}}_j) \mathbf{D}_i (\hat{\boldsymbol{\beta}}_j) \right\}^{-1} \left\{ \sum_{i=1}^m \mathbf{D}_i^T (\hat{\boldsymbol{\beta}}_j) \tilde{\mathbf{V}}_i^{-1} (\hat{\boldsymbol{\beta}}_j) \mathbf{S}_i (\hat{\boldsymbol{\beta}}_j) \right\}$$

where the term

$$\left\{ \sum_{i=1}^m \mathbf{D}_i^T (\hat{\boldsymbol{\beta}}_j) \tilde{\mathbf{V}}_i^{-1} (\hat{\boldsymbol{\beta}}_j) \mathbf{D}_i (\hat{\boldsymbol{\beta}}_j) \right\}^{-1}$$

is what we call the conventional variance estimate. It is used to calculate the standard errors if the `vce(robust)` option is not specified. This command supports the clustered version of the Huber/White/sandwich estimator of the variance with panels treated as clusters when `vce(robust)` is specified. See [P] `_robust`, particularly *Maximum likelihood estimators* and *Methods and formulas*. Liang and Zeger (1986) also discuss the calculation of the robust variance estimator.

Define the following:

$$\mathbf{D} = (\mathbf{D}_1^T, \dots, \mathbf{D}_m^T)$$

$$\mathbf{S} = (\mathbf{S}_1^T, \dots, \mathbf{S}_m^T)^T$$

$\tilde{\mathbf{V}} = nm \times nm$  block diagonal matrix with  $\tilde{\mathbf{V}}_i$

$$\mathbf{Z} = \mathbf{D}\boldsymbol{\beta} - \mathbf{S}$$

At a given iteration, the correlation parameters  $\boldsymbol{\alpha}$  and scale parameter  $\phi$  can be estimated from the current Pearson residuals, defined by

$$\hat{r}_{i,j} = \{y_{i,j} - a'(\hat{\theta}_{i,j})\}/\{a''(\hat{\theta}_{i,j})\}^{1/2}$$

where  $\hat{\theta}_{i,j}$  depends on the current value for  $\hat{\boldsymbol{\beta}}$ . We can then estimate  $\phi$  by

$$\hat{\phi}^{-1} = \sum_{i=1}^m \sum_{j=1}^{n_i} \hat{r}_{i,j}^2 / (N - p)$$

As this general derivation is complicated, let's follow the derivation of the Gaussian family with the identity link (regression) to illustrate the generalization. After making appropriate substitutions, we will see a familiar updating equation. First, we rewrite the updating equation for  $\boldsymbol{\beta}$  as

$$\hat{\boldsymbol{\beta}}_{j+1} = \hat{\boldsymbol{\beta}}_j - \mathbf{Z}_1^{-1} \mathbf{Z}_2$$

and then derive  $\mathbf{Z}_1$  and  $\mathbf{Z}_2$ .

$$\begin{aligned} \mathbf{Z}_1 &= \sum_{i=1}^m \mathbf{D}_i^T (\hat{\boldsymbol{\beta}}_j) \tilde{\mathbf{V}}_i^{-1} (\hat{\boldsymbol{\beta}}_j) \mathbf{D}_i (\hat{\boldsymbol{\beta}}_j) = \sum_{i=1}^m \mathbf{X}_i^T \boldsymbol{\Delta}_i^T \mathbf{A}_i^T \{ \mathbf{A}_i^{1/2} \mathbf{R}(\boldsymbol{\alpha}) \mathbf{A}_i^{1/2} \}^{-1} \mathbf{A}_i \boldsymbol{\Delta}_i \mathbf{X}_i \\ &= \sum_{i=1}^m \mathbf{X}_i^T \text{diag} \left\{ \frac{\partial \theta_{i,j}}{\partial (\mathbf{X} \boldsymbol{\beta})} \right\} \text{diag} \{a''(\theta_{i,j})\} \left[ \text{diag} \{a''(\theta_{i,j})\}^{1/2} \mathbf{R}(\boldsymbol{\alpha}) \text{diag} \{a''(\theta_{i,j})\}^{1/2} \right]^{-1} \\ &\quad \text{diag} \{a''(\theta_{i,j})\} \text{diag} \left\{ \frac{\partial \theta_{i,j}}{\partial (\mathbf{X} \boldsymbol{\beta})} \right\} \mathbf{X}_i \\ &= \sum_{i=1}^m \mathbf{X}_i^T \mathbf{I} \mathbf{I} (\mathbf{I} \mathbf{I})^{-1} \mathbf{I} \mathbf{I} \mathbf{X}_i = \sum_{i=1}^m \mathbf{X}_i^T \mathbf{X}_i = \mathbf{X}^T \mathbf{X} \end{aligned}$$

$$\begin{aligned}
\mathbf{Z}_2 &= \sum_{i=1}^m \mathbf{D}_i^T(\widehat{\boldsymbol{\beta}}_j) \widetilde{\mathbf{V}}_i^{-1}(\widehat{\boldsymbol{\beta}}_j) \mathbf{S}_i(\widehat{\boldsymbol{\beta}}_j) = \sum_{i=1}^m \mathbf{X}_i^T \Delta_i^T \mathbf{A}_i^T \{ \mathbf{A}_i^{1/2} \mathbf{R}(\boldsymbol{\alpha}) \mathbf{A}_i^{1/2} \}^{-1} (\mathbf{y}_i - \mathbf{X}_i \widehat{\boldsymbol{\beta}}_j) \\
&= \sum_{i=1}^m \mathbf{X}_i^T \operatorname{diag} \left\{ \frac{\partial \theta_{i,j}}{\partial (\mathbf{X} \boldsymbol{\beta})} \right\} \operatorname{diag} \{ a''(\theta_{i,j}) \} \left[ \operatorname{diag} \{ a''(\theta_{i,j}) \}^{1/2} \mathbf{R}(\boldsymbol{\alpha}) \operatorname{diag} \{ a''(\theta_{i,j}) \}^{1/2} \right]^{-1} \\
&\quad (\mathbf{y}_i - \mathbf{X}_i \widehat{\boldsymbol{\beta}}_j) \\
&= \sum_{i=1}^m \mathbf{X}_i^T \mathbf{II}(\mathbf{III})^{-1} (\mathbf{y}_i - \mathbf{X}_i \widehat{\boldsymbol{\beta}}_j) = \sum_{i=1}^m \mathbf{X}_i^T (\mathbf{y}_i - \mathbf{X}_i \widehat{\boldsymbol{\beta}}_j) = \mathbf{X}^T \widehat{s}_j
\end{aligned}$$

So, we may write the update formula as

$$\widehat{\boldsymbol{\beta}}_{j+1} = \widehat{\boldsymbol{\beta}}_j - (\mathbf{X}^T \mathbf{X})^{-1} \mathbf{X}^T \widehat{s}_j$$

which is the same formula for GLS in regression.

## Correlation structures

The working correlation matrix  $\mathbf{R}$  is a function of  $\boldsymbol{\alpha}$  and is more accurately written as  $\mathbf{R}(\boldsymbol{\alpha})$ . Depending on the assumed correlation structure,  $\boldsymbol{\alpha}$  might be

Independent	no parameters to estimate
Exchangeable	$\boldsymbol{\alpha}$ is a scalar
Autoregressive	$\boldsymbol{\alpha}$ is a vector
Stationary	$\boldsymbol{\alpha}$ is a vector
Nonstationary	$\boldsymbol{\alpha}$ is a matrix
Unstructured	$\boldsymbol{\alpha}$ is a matrix

Also, throughout the estimation of a general unbalanced panel, it is more proper to discuss  $\mathbf{R}_i$ , which is the upper left  $n_i \times n_i$  submatrix of the ultimately stored matrix in  $\mathbf{e}(\mathbf{R})$ ,  $\max\{n_i\} \times \max\{n_i\}$ .

The only panels that enter into the estimation for a lag-dependent correlation structure are those with  $n_i > g$  (assuming a lag of  $g$ ). **xtgee** drops panels with too few observations (and mentions when it does so).

### Independent

The working correlation matrix  $\mathbf{R}$  is an identity matrix.

### Exchangeable

$$\boldsymbol{\alpha} = \frac{\sum_{i=1}^m \left( \sum_{j=1}^{n_i} \sum_{k=1}^{n_i} \widehat{r}_{i,j} \widehat{r}_{i,k} - \sum_{j=1}^{n_i} \widehat{r}_{i,j}^2 \right)}{\sum_{i=1}^m \{n_i(n_i - 1)\}} \Bigg/ \frac{\sum_{i=1}^m \left( \sum_{j=1}^{n_i} \widehat{r}_{i,j}^2 \right)}{\sum_{i=1}^m n_i}$$

and the working correlation matrix is given by

$$\mathbf{R}_{s,t} = \begin{cases} 1 & s = t \\ \alpha & \text{otherwise} \end{cases}$$

## Autoregressive and stationary

These two structures require  $g$  parameters to be estimated so that  $\alpha$  is a vector of length  $g + 1$  (the first element of  $\alpha$  is 1).

$$\alpha = \sum_{i=1}^m \left( \frac{\sum_{j=1}^{n_i} \hat{r}_{i,j}^2}{n_i}, \frac{\sum_{j=1}^{n_i-1} \hat{r}_{i,j} \hat{r}_{i,j+1}}{n_i}, \dots, \frac{\sum_{j=1}^{n_i-g} \hat{r}_{i,j} \hat{r}_{i,j+g}}{n_i} \right) \Bigg/ \left( \sum_{i=1}^m \frac{\sum_{j=1}^{n_i} \hat{r}_{i,j}^2}{n_i} \right)$$

The working correlation matrix for the AR model is calculated as a function of Toeplitz matrices formed from the  $\alpha$  vector; see [Newton \(1988\)](#). The working correlation matrix for the stationary model is given by

$$\mathbf{R}_{s,t} = \begin{cases} \alpha_{1,|s-t|} & \text{if } |s-t| \leq g \\ 0 & \text{otherwise} \end{cases}$$

## Nonstationary and unstructured

These two correlation structures require a matrix of parameters.  $\alpha$  is estimated (where we replace  $\hat{r}_{i,j} = 0$  whenever  $i > n_i$  or  $j > n_i$ ) as

$$\alpha = \sum_{i=1}^m m \begin{pmatrix} N_{1,1}^{-1} \hat{r}_{i,1}^2 & N_{1,2}^{-1} \hat{r}_{i,1} \hat{r}_{i,2} & \cdots & N_{1,n}^{-1} \hat{r}_{i,1} \hat{r}_{i,n} \\ N_{2,1}^{-1} \hat{r}_{i,2} \hat{r}_{i,1} & N_{2,2}^{-1} \hat{r}_{i,2}^2 & \cdots & N_{2,n}^{-1} \hat{r}_{i,2} \hat{r}_{i,n} \\ \vdots & \vdots & \ddots & \vdots \\ N_{n,1}^{-1} \hat{r}_{i,n} \hat{r}_{i,1} & N_{n,2}^{-1} \hat{r}_{i,n} \hat{r}_{i,2} & \cdots & N_{n,n}^{-1} \hat{r}_{i,n}^2 \end{pmatrix} \Bigg/ \left( \sum_{i=1}^m \frac{\sum_{j=1}^{n_i} \hat{r}_{i,j}^2}{n_i} \right)$$

where  $N_{p,q} = \sum_{i=1}^m I(i, p, q)$  and

$$I(i, p, q) = \begin{cases} 1 & \text{if panel } i \text{ has valid observations at times } p \text{ and } q \\ 0 & \text{otherwise} \end{cases}$$

where  $N_{i,j} = \min(N_i, N_j)$ ,  $N_i =$  number of panels observed at time  $i$ , and  $n = \max(n_1, n_2, \dots, n_m)$ .

The working correlation matrix for the nonstationary model is given by

$$\mathbf{R}_{s,t} = \begin{cases} 1 & \text{if } s = t \\ \alpha_{s,t} & \text{if } 0 < |s - t| \leq g \\ 0 & \text{otherwise} \end{cases}$$

The working correlation matrix for the unstructured model is given by

$$\mathbf{R}_{s,t} = \begin{cases} 1 & \text{if } s = t \\ \alpha_{s,t} & \text{otherwise} \end{cases}$$

such that the unstructured model is equal to the nonstationary model at lag  $g = n - 1$ , where the panels are balanced with  $n_i = n$  for all  $i$ .

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## Also see

- [XT] **xtgee postestimation** — Postestimation tools for xtgee
- [XT] **xtcloglog** — Random-effects and population-averaged cloglog models
- [XT] **xtlogit** — Fixed-effects, random-effects, and population-averaged logit models
- [XT] **xtnbreg** — Fixed-effects, random-effects, & population-averaged negative binomial models
- [XT] **xtpoisson** — Fixed-effects, random-effects, and population-averaged Poisson models
- [XT] **xtprobit** — Random-effects and population-averaged probit models
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance
- [XT] **xtset** — Declare data to be panel data
- [MI] **Estimation** — Estimation commands for use with mi estimate
- [R] **glm** — Generalized linear models
- [R] **logistic** — Logistic regression, reporting odds ratios
- [R] **regress** — Linear regression
- [U] **20 Estimation and postestimation commands**

**xtgee postestimation** — Postestimation tools for xtgee

Postestimation commands	predict	margins
Remarks and examples	Also see	estat

## Postestimation commands

The following postestimation command is of special interest after `xtgee`:

Command	Description
<code>estat wcorrelation</code>	estimated matrix of the within-group correlations

The following standard postestimation commands are also available:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>* forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from <code>margins</code> (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

\* `forecast` is not appropriate with `mi` estimation results.

## predict

### Description for predict

`predict` creates a new variable containing predictions such as predicted values, probabilities, linear predictions, standard errors, and equation-level scores.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

```
predict [type] newvar [if] [in] [, statistic nooffset]
```

statistic	Description
<hr/>	
Main	
<code>mu</code>	predicted value of <code>depvar</code> ; considers the <code>offset()</code> or <code>exposure()</code> ; the default
<code>rate</code>	predicted value of <code>depvar</code>
<code>pr(n)</code>	probability $\Pr(y_{it} = n)$ for <code>family(poisson)</code> <code>link(log)</code>
<code>pr(a,b)</code>	probability $\Pr(a \leq y_{it} \leq b)$ for <code>family(poisson)</code> <code>link(log)</code>
<code>xb</code>	linear prediction
<code>stdp</code>	standard error of the linear prediction
<code>score</code>	first derivative of the log likelihood with respect to $x_{it}\beta$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

### Options for predict

#### Main

---

`mu`, the default, and `rate` calculate the predicted value of `depvar`. `mu` takes into account the `offset()` or `exposure()` together with the denominator if the family is binomial; `rate` ignores those adjustments. `mu` and `rate` are equivalent if you did not specify `offset()` or `exposure()` when you fit the `xtgee` model and you did not specify `family(binomial #)` or `family(binomial varname)`, meaning the binomial family and a denominator not equal to one.

Thus `mu` and `rate` are the same for `family(gaussian)` `link(identity)`.

`mu` and `rate` are not equivalent for `family(binomial pop)` `link(logit)`. Then `mu` would predict the number of positive outcomes and `rate` would predict the probability of a positive outcome.

`mu` and `rate` are not equivalent for `family(poisson)` `link(log)` `exposure(time)`. Then `mu` would predict the number of events given exposure time and `rate` would calculate the incidence rate—the number of events given an exposure time of 1.

`pr(n)` calculates the probability  $\Pr(y_{it} = n)$  for `family(poisson)` `link(log)`, where  $n$  is a nonnegative integer that may be specified as a number or a variable.

`pr(a,b)` calculates the probability  $\Pr(a \leq y_{it} \leq b)$  for `family(poisson)` `link(log)`, where  $a$  and  $b$  are nonnegative integers that may be specified as numbers or variables;

$b$  missing ( $b \geq .$ ) means  $+\infty$ ;

`pr(20,.)` calculates  $\Pr(y_{it} \geq 20)$ ;

`pr(20,b)` calculates  $\Pr(y_{it} \geq 20)$  in observations for which  $b \geq .$  and calculates  $\Pr(20 \leq y_{it} \leq b)$  elsewhere.

`pr(.,b)` produces a syntax error. A missing value in an observation of the variable  $a$  causes a missing value in that observation for `pr(a,b)`.

`xb` calculates the linear prediction.

`stdp` calculates the standard error of the linear prediction.

`score` calculates the equation-level score,  $u_{it} = \partial \ln L(\mathbf{x}_{it}\beta) / \partial (\mathbf{x}_{it}\beta)$ .

`nooffset` is relevant only if you specified `offset(varname)`, `exposure(varname)`, `family(binomial #)`, or `family(binomial varname)` when you fit the model. It modifies the calculations made by `predict` so that they ignore the offset or exposure variable and the binomial denominator. Thus `predict ... , mu nooffset` produces the same results as `predict ... , rate`.

## margins

### Description for margins

`margins` estimates margins of response for predicted values, probabilities, and linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist] , predict(statistic ...) [predict(statistic ...) ...] [options]
```

statistic	Description
<code>mu</code>	predicted value of <code>depvar</code> ; considers the <code>offset()</code> or <code>exposure()</code> ; the default
<code>rate</code>	predicted value of <code>depvar</code>
<code>pr(n)</code>	probability $\Pr(y_{it} = n)$ for <code>family(poisson)</code> <code>link(log)</code>
<code>pr(a,b)</code>	probability $\Pr(a \leq y_{it} \leq b)$ for <code>family(poisson)</code> <code>link(log)</code>
<code>xb</code>	linear prediction
<code>stdp</code>	not allowed with <code>margins</code>
<code>score</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

## estat

### Description for estat

estat wcorrelation displays the estimated matrix of the within-group correlations.

### Menu for estat

Statistics > Postestimation

### Syntax for estat

```
estat wcorrelation [ , compact format(%fmt) ]
```

### Options for estat

compact specifies that only the parameters (alpha) of the estimated matrix of within-group correlations be displayed rather than the entire matrix.

format(%fmt) overrides the display format; see [D] format.

## Remarks and examples

### ▷ Example 1

xtgee can estimate rich correlation structures. In example 2 of [XT] xtgee, we fit the model

```
. use https://www.stata-press.com/data/r16/nlswork2
(National Longitudinal Survey. Young Women 14–26 years of age in 1968)
. xtgee ln_w grade age c.age#c.age
(output omitted)
```

After estimation, estat wcorrelation reports the working correlation matrix R:

```
. estat wcorrelation
Estimated within-idcode correlation matrix R:
```

	c1	c2	c3	c4	c5	c6
r1	1					
r2	.4851356	1				
r3	.4851356	.4851356	1			
r4	.4851356	.4851356	.4851356	1		
r5	.4851356	.4851356	.4851356	.4851356	1	
r6	.4851356	.4851356	.4851356	.4851356	.4851356	1
r7	.4851356	.4851356	.4851356	.4851356	.4851356	.4851356
r8	.4851356	.4851356	.4851356	.4851356	.4851356	.4851356
r9	.4851356	.4851356	.4851356	.4851356	.4851356	.4851356
	c7	c8	c9			
r7	1					
r8	.4851356	1				
r9	.4851356	.4851356	1			

The equal-correlation model corresponds to an exchangeable correlation structure, meaning that the correlation of observations within person is a constant. The working correlation estimated by `xtgee` is 0.4851. (`xtreg`, `re`, by comparison, reports 0.5141; see the `xtreg` command in example 2 of [XT] `xtgee`.) We constrained the model to have this simple correlation structure. What if we relaxed the constraint? To go to the other extreme, let's place no constraints on the matrix (other than its being symmetric). We do this by specifying `correlation(unstructured)`, although we can abbreviate the option.

. xtgee ln_w grade age c.age#c.age, corr(unstr) nolog						
GEE population-averaged model			Number of obs	=	16,085	
Group and time vars:	idcode year		Number of groups	=	3,913	
Link:	identity		Obs per group:			
Family:	Gaussian		min =	1		
Correlation:	unstructured		avg =	4.1		
			max =	9		
			Wald chi2(3)	=	2405.20	
Scale parameter:	.1418513		Prob > chi2	=	0.0000	
<hr/>						
ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0720684	.002151	33.50	0.000	.0678525	.0762843
age	.1008095	.0081471	12.37	0.000	.0848416	.1167775
c.age#c.age	-.0015104	.0001617	-9.34	0.000	-.0018272	-.0011936
_cons	-.8645484	.1009488	-8.56	0.000	-1.062404	-.6666923

. estat wcorrelation

Estimated within-idcode correlation matrix R:

	c1	c2	c3	c4	c5	c6
r1	1					
r2	.4354838	1				
r3	.4280248	.5597329	1			
r4	.3772342	.5012129	.5475113	1		
r5	.4031433	.5301403	.502668	.6216227	1	
r6	.3663686	.4519138	.4783186	.5685009	.7306005	1
r7	.2819915	.3605743	.3918118	.4012104	.4642561	.50219
r8	.3162028	.3445668	.4285424	.4389241	.4696792	.5222537
r9	.2148737	.3078491	.3337292	.3584013	.4865802	.4613128
	c7	c8	c9			
r7	1					
r8	.6475654	1				
r9	.5791417	.7386595	1			

This correlation matrix looks different from the previously constrained one and shows, in particular, that the serial correlation of the residuals diminishes as the lag increases, although residuals separated by small lags are more correlated than, say, AR(1) would imply.



## ▷ Example 2

In example 1 of [XT] `xtprobit`, we showed a random-effects model of unionization using the `union` data described in [XT] `xt`. We performed the estimation using `xtprobit` but said that we could have used `xtgee` as well. Here we fit a population-averaged (equal correlation) model for comparison:

```
. use https://www.stata-press.com/data/r16/union
(NLS Women 14-24 in 1968)

. xtgee union age grade i.not_smsa south##c.year, family(binomial) link(probit)
Iteration 1: tolerance = .12544249
Iteration 2: tolerance = .0034686
Iteration 3: tolerance = .00017448
Iteration 4: tolerance = 8.382e-06
Iteration 5: tolerance = 3.997e-07

GEE population-averaged model
Number of obs      =    26,200
Group variable: idcode      Number of groups =     4,434
Link:             probit      Obs per group:
Family:           binomial      min =          1
Correlation:      exchangeable avg =         5.9
                                         max =        12
                                         Wald chi2(6) =   242.57
Scale parameter: 1      Prob > chi2 = 0.0000
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
age	.0089699	.0053208	1.69	0.092	-.0014586 .0193985
grade	.0333174	.0062352	5.34	0.000	.0210966 .0455382
1.not_smsa	-.0715717	.027543	-2.60	0.009	-.1255551 -.0175884
1.south	-1.017368	.207931	-4.89	0.000	-1.424905 -.6098308
year	-.0062708	.0055314	-1.13	0.257	-.0171122 .0045706
south##c.year					
1	.0086294	.00258	3.34	0.001	.0035727 .013686
_cons	-.8670997	.294771	-2.94	0.003	-1.44484 -.2893592

Let's look at the correlation structure and then relax it:

```
. estat wcorrelation, format(%8.4f)
Estimated within-idcode correlation matrix R:
```

	c1	c2	c3	c4	c5	c6	c7
r1	1.0000						
r2	0.4615	1.0000					
r3	0.4615	0.4615	1.0000				
r4	0.4615	0.4615	0.4615	1.0000			
r5	0.4615	0.4615	0.4615	0.4615	1.0000		
r6	0.4615	0.4615	0.4615	0.4615	0.4615	1.0000	
r7	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	1.0000
r8	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615
r9	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615
r10	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615
r11	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615
r12	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615	0.4615
	c8	c9	c10	c11	c12		
r8	1.0000						
r9	0.4615	1.0000					
r10	0.4615	0.4615	1.0000				
r11	0.4615	0.4615	0.4615	1.0000			
r12	0.4615	0.4615	0.4615	0.4615	1.0000		

We estimate the fixed correlation between observations within person to be 0.4615. We have many data (an average of 5.9 observations on 4,434 women), so estimating the full correlation matrix is feasible. Let's do that and then examine the results:

```
. xtgee union age grade i.not_smsa south##c.year, family(binomial) link(probit)
> corr(unstr) nolog
```

GEE population-averaged model  
 Group and time vars: idcode year Number of obs = 26,200  
 Link: probit Number of groups = 4,434  
 Family: binomial Obs per group:  
 Correlation: unstructured min = 1  
 Scale parameter: 1 avg = 5.9  
 Wald chi2(6) max = 12  
 Prob > chi2 = 198.45  
 0.0000

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
age	.0096612	.0053366	1.81	0.070	-.0007984 .0201208
grade	.0352762	.0065621	5.38	0.000	.0224148 .0481377
1.not_smsa	-.093073	.0291971	-3.19	0.001	-.1502983 -.0358478
1.south	-1.028526	.278802	-3.69	0.000	-1.574968 -.4820839
year	-.0088187	.005719	-1.54	0.123	-.0200278 .0023904
south##c.year					
1	.0089824	.0034865	2.58	0.010	.002149 .0158158
_cons	-.7306192	.316757	-2.31	0.021	-1.351451 -.109787

```
. estat wcorrelation, format(%8.4f)
```

Estimated within-idcode correlation matrix R:

	c1	c2	c3	c4	c5	c6	c7
r1	1.0000						
r2	0.6667	1.0000					
r3	0.6151	0.6523	1.0000				
r4	0.5268	0.5717	0.6101	1.0000			
r5	0.3309	0.3669	0.4005	0.4783	1.0000		
r6	0.3000	0.3706	0.4237	0.4562	0.6426	1.0000	
r7	0.2995	0.3568	0.3851	0.4279	0.4931	0.6384	1.0000
r8	0.2759	0.3021	0.3225	0.3751	0.4682	0.5597	0.7009
r9	0.2989	0.2981	0.3021	0.3806	0.4605	0.5068	0.6090
r10	0.2285	0.2597	0.2748	0.3637	0.3981	0.4909	0.5889
r11	0.2325	0.2289	0.2696	0.3246	0.3551	0.4426	0.5103
r12	0.2359	0.2351	0.2544	0.3134	0.3474	0.3822	0.4788
	c8	c9	c10	c11	c12		
r8	1.0000						
r9	0.6714	1.0000					
r10	0.5973	0.6325	1.0000				
r11	0.5625	0.5756	0.5738	1.0000			
r12	0.4999	0.5412	0.5329	0.6428	1.0000		

As before, we find that the correlation of residuals decreases as the lag increases, but more slowly than an AR(1) process.



## ▷ Example 3

In this example, we examine injury incidents among 20 airlines in each of 4 years. The data are fictional, and, as a matter of fact, are really from a random-effects model.

. use https://www.stata-press.com/data/r16/airacc						
. generate lnpm = ln(pmiles)						
. xtgee i_cnt inprog, family(poisson) eform offset(lnpm) nolog						
GEE population-averaged model			Number of obs	=	80	
Group variable:	airline		Number of groups	=	20	
Link:	log		Obs per group:			
Family:	Poisson		min	=	4	
Correlation:	exchangeable		avg	=	4.0	
			max	=	4	
			Wald chi2(1)	=	5.27	
Scale parameter:	1		Prob > chi2	=	0.0217	
i_cnt	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
inprog	.9059936	.0389528	-2.30	0.022	.8327758	.9856487
_cons	.0080065	.0002912	-132.71	0.000	.0074555	.0085981
lnpm	1	(offset)				

Note: \_cons estimates baseline incidence rate (conditional on zero random effects).

. estat wcorrelation

Estimated within-airline correlation matrix R:

	c1	c2	c3	c4
r1	1			
r2	.4606406	1		
r3	.4606406	.4606406	1	
r4	.4606406	.4606406	.4606406	1

Now there are not really enough data here to reliably estimate the correlation without any constraints of structure, but here is what happens if we try:

. xtgee i_cnt inprog, family(poisson) eform offset(lnpm) corr(unstr) nolog						
GEE population-averaged model			Number of obs	=	80	
Group and time vars:	airline time		Number of groups	=	20	
Link:	log		Obs per group:			
Family:	Poisson		min	=	4	
Correlation:	unstructured		avg	=	4.0	
			max	=	4	
			Wald chi2(1)	=	0.36	
Scale parameter:	1		Prob > chi2	=	0.5496	
i_cnt	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
inprog	.9791082	.0345486	-0.60	0.550	.9136826	1.049219
_cons	.0078716	.0002787	-136.82	0.000	.0073439	.0084373
lnpm	1	(offset)				

Note: \_cons estimates baseline incidence rate (conditional on zero random effects).

	c1	c2	c3	c4
r1	1			
r2	.5700298	1		
r3	.716356	.4192126	1	
r4	.2383264	.3839863	.3521287	1

There is no sensible pattern to the correlations.

We created this dataset from a random-effects Poisson model. We reran our data-creation program and this time had it create 400 airlines rather than 20, still with 4 years of data each. Here are the equal-correlation model and estimated correlation structure:

GEE population-averaged model				Number of obs	=	1,600	
Group variable:		airline		Number of groups	=	400	
Link:		log		Obs per group:			
Family:		Poisson		min =		4	
Correlation:		exchangeable		avg =		4.0	
				max =		4	
				Wald chi2(1)	=	111.80	
Scale parameter:			1	Prob > chi2	=	0.0000	
i_cnt		IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
inprog		.8915304	.0096807	-10.57	0.000	.8727571	.9107076
_cons		.0071357	.0000629	-560.57	0.000	.0070134	.0072601
lnpm		1	(offset)				

Note: \_cons estimates baseline incidence rate (conditional on zero random effects).

. estat wcorrelation  
Estimated within-airline correlation matrix R:

	c1	c2	c3	c4
r1	1			
r2	.5291707	1		
r3	.5291707	.5291707	1	
r4	.5291707	.5291707	.5291707	1

The following estimation results assume unstructured correlation:

. xtgee i_cnt inprog, family(poisson) corr(unstr) eform offset(lnpm) nolog	
GEE population-averaged model	Number of obs = 1,600
Group and time vars: airline time	Number of groups = 400
Link: log	Obs per group:
Family: Poisson	min = 4
Correlation: unstructured	avg = 4.0
	max = 4
	Wald chi2(1) = 113.43
Scale parameter: 1	Prob > chi2 = 0.0000
<hr/>	
i_cnt	IRR Std. Err. z P> z  [95% Conf. Interval]
inprog	.8914155 .0096208 -10.65 0.000 .8727572 .9104728
_cons	.0071402 .0000628 -561.50 0.000 .0070181 .0072645
lnpm	1 (offset)

Note: \_cons estimates baseline incidence rate (conditional on zero random effects).

. estat wcorrelation

Estimated within-airline correlation matrix R:

	c1	c2	c3	c4
r1	1			
r2	.4733189	1		
r3	.5240576	.5748868	1	
r4	.5139748	.5048895	.5840707	1

The equal-correlation model estimated a fixed correlation of 0.5292, and above we have correlations ranging between 0.4733 and 0.5841 with little pattern in their structure.



## Also see

[XT] **xtgee** — Fit population-averaged panel-data models by using GEE

[U] **20 Estimation and postestimation commands**

**xtgls** — Fit panel-data models by using GLS

Description  
Options  
References

Quick start  
Remarks and examples  
Also see

Menu  
Stored results

Syntax  
Methods and formulas

## Description

**xtgls** fits panel-data linear models by using feasible generalized least squares. This command allows estimation in the presence of AR(1) autocorrelation within panels and cross-sectional correlation and heteroskedasticity across panels.

## Quick start

GLS regression of *y* on *x1*, *x2*, and *indicators* for levels of categorical variable *a* using **xtset** data

```
xtgls y x1 x2 i.a
```

With heteroskedastic but uncorrelated errors across panels

```
xtgls y x1 x2 i.a, panels(heteroskedastic)
```

With heteroskedastic and correlated errors across panels

```
xtgls y x1 x2 i.a, panels(correlated)
```

Three-stage GLS with a common first-order autocorrelation within panels

```
xtgls y x1 x2 i.a, panels(correlated) corr(ar1)
```

As above, but let autocorrelation structure be panel-specific

```
xtgls y x1 x2 i.a, panels(correlated) corr(psar1)
```

As above, but estimate by iterated GLS

```
xtgls y x1 x2 i.a, panels(correlated) corr(psar1) igls
```

## Menu

Statistics > Longitudinal/panel data > Contemporaneous correlation > GLS regression with correlated disturbances

## Syntax

`xtgls depvar [indepvars] [if] [in] [weight] [, options]`

<i>options</i>	Description
<b>Model</b>	
<code>noconstant</code>	suppress constant term
<code>panels(iid)</code>	use i.i.d. error structure
<code>panels(heteroskedastic)</code>	use heteroskedastic but uncorrelated error structure
<code>panels(correlated)</code>	use heteroskedastic and correlated error structure
<code>corr(independent)</code>	use independent autocorrelation structure
<code>corr(ar1)</code>	use AR1 autocorrelation structure
<code>corr(psar1)</code>	use panel-specific AR1 autocorrelation structure
<code>rhototype(calc)</code>	specify method to compute autocorrelation parameter; see <i>Options</i> for details; seldom used
<code>igls</code>	use iterated GLS estimator instead of two-step GLS estimator
<code>force</code>	estimate even if observations unequally spaced in time
<b>SE</b>	
<code>nmk</code>	normalize standard error by $N - k$ instead of $N$
<b>Reporting</b>	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>display_options</code>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Optimization</b>	
<code>optimize_options</code>	control the optimization process; seldom used
<code>coeflegend</code>	display legend instead of statistics

A panel variable must be specified. For correlation structures other than `independent`, a time variable must be specified. A time variable must also be specified if `panels(correlated)` is specified. Use `xtset`; see [XT] `xtset`.

`indepvars` may contain factor variables; see [U] 11.4.3 Factor variables.

`depvar` and `indepvars` may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by` and `statsby` are allowed; see [U] 11.1.10 Prefix commands.

`aweights` are allowed; see [U] 11.1.6 weight.

`coeflegend` does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

`noconstant`; see [R] Estimation options.

`panels(pdist)` specifies the error structure across panels.

`panels(iid)` specifies a homoskedastic error structure with no cross-sectional correlation. This is the default.

`panels(heteroskedastic)` specifies a heteroskedastic error structure with no cross-sectional correlation.

`panels(correlated)` specifies a heteroskedastic error structure with cross-sectional correlation. If `p(c)` is specified, you must also specify a time variable (use `xtset`). The results will be based on a generalized inverse of a singular matrix unless  $T \geq m$  (the number of periods is greater than or equal to the number of panels).

`corr(corr)` specifies the assumed autocorrelation within panels.

`corr(independent)` specifies that there is no autocorrelation. This is the default.

`corr(ar1)` specifies that, within panels, there is AR(1) autocorrelation and that the coefficient of the AR(1) process is common to all the panels. If `c(ar1)` is specified, you must also specify a time variable (use `xtset`).

`corr(psar1)` specifies that, within panels, there is AR(1) autocorrelation and that the coefficient of the AR(1) process is specific to each panel. `psar1` stands for panel-specific AR(1). If `c(psar1)` is specified, a time variable must also be specified; use `xtset`.

`rhototype(calc)` specifies the method to be used to calculate the autocorrelation parameter:

<code>regress</code>	regression using lags; the default
<code>dw</code>	Durbin–Watson calculation
<code>freg</code>	regression using leads
<code>nagar</code>	Nagar calculation
<code>theil</code>	Theil calculation
<code>tscorr</code>	time-series autocorrelation calculation

All the calculations are asymptotically equivalent and consistent; this is a rarely used option.

`igls` requests an iterated GLS estimator instead of the two-step GLS estimator for a nonautocorrelated model or instead of the three-step GLS estimator for an autocorrelated model. The iterated GLS estimator converges to the MLE for the `corr(independent)` models but does not for the other `corr()` models.

`force` specifies that estimation be forced even though the time variable is not equally spaced. This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

### SE

`nmk` specifies that standard errors be normalized by  $N - k$ , where  $k$  is the number of parameters estimated, rather than  $N$ , the number of observations. Different authors have used one or the other normalization. Greene (2018, 313) remarks that whether a degree-of-freedom correction improves the small-sample properties is an open question.

### Reporting

`level(#); see [R] Estimation options.`

`display_options`: `noci`, `nocvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see `[R] Estimation options`.

### Optimization

*optimize\_options* control the iterative optimization process. These options are seldom used.

**iterate(#)** specifies the maximum number of iterations. When the number of iterations equals #, the optimization stops and presents the current results, even if convergence has not been reached. The default is **iterate(100)**.

**tolerance(#)** specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to #, the optimization process is stopped. **tolerance(1e-7)** is the default.

**log** and **nolog** specify whether to display the iteration log. The iteration log is displayed by default unless you used **set iterlog off** to suppress it; see **set iterlog** in [R] **set iter**.

The following option is available with **xtgls** but is not shown in the dialog box:

**coeflegend**; see [R] **Estimation options**.

## Remarks and examples

Remarks are presented under the following headings:

- Introduction*
- Heteroskedasticity across panels*
- Correlation across panels (cross-sectional correlation)*
- Autocorrelation within panels*

## Introduction

Information on GLS can be found in Greene (2018), Maddala and Lahiri (2006), Davidson and MacKinnon (1993), and Judge et al. (1985).

If you have many panels relative to periods, see [XT] **xtreg** and [XT] **xtgee**. **xtgee**, in particular, provides capabilities similar to those of **xtgls** but does not allow cross-sectional correlation. On the other hand, **xtgee** allows a richer description of the correlation within panels as long as the same correlations apply to all panels. **xtgls** provides two unique features:

1. Cross-sectional correlation may be modeled (**panels(correlated)**).
2. Within panels, the AR(1) correlation coefficient may be unique (**corr(psar1)**).

**xtgls** allows models with heteroskedasticity and no cross-sectional correlation, but, strictly speaking, **xtgee** does not. **xtgee** with the **vce(robust)** option relaxes the assumption of equal variances, at least as far as the standard error calculation is concerned.

Also, **xtgls, panels(iid) corr(independent) nmk** is equivalent to **regress**.

The **nmk** option uses  $n - k$  rather than  $n$  to normalize the variance calculation.

To fit a model with autocorrelated errors (**corr(ar1)** or **corr(psar1)**), the data must be equally spaced in time. To fit a model with cross-sectional correlation (**panels(correlated)**), panels must have the same number of observations (be balanced).

The equation from which the models are developed is given by

$$y_{it} = \mathbf{x}_{it}\beta + \epsilon_{it}$$

where  $i = 1, \dots, m$  is the number of units (or panels) and  $t = 1, \dots, T_i$  is the number of observations for panel  $i$ . This model can equally be written as

$$\begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_m \end{bmatrix} = \begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_m \end{bmatrix} \boldsymbol{\beta} + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_m \end{bmatrix}$$

The variance matrix of the disturbance terms can be written as

$$E[\boldsymbol{\epsilon}\boldsymbol{\epsilon}'] = \boldsymbol{\Omega} = \begin{bmatrix} \sigma_{1,1}\boldsymbol{\Omega}_{1,1} & \sigma_{1,2}\boldsymbol{\Omega}_{1,2} & \cdots & \sigma_{1,m}\boldsymbol{\Omega}_{1,m} \\ \sigma_{2,1}\boldsymbol{\Omega}_{2,1} & \sigma_{2,2}\boldsymbol{\Omega}_{2,2} & \cdots & \sigma_{2,m}\boldsymbol{\Omega}_{2,m} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{m,1}\boldsymbol{\Omega}_{m,1} & \sigma_{m,2}\boldsymbol{\Omega}_{m,2} & \cdots & \sigma_{m,m}\boldsymbol{\Omega}_{m,m} \end{bmatrix}$$

For the  $\boldsymbol{\Omega}_{i,j}$  matrices to be parameterized to model cross-sectional correlation, they must be square (balanced panels).

In these models, we assume that the coefficient vector  $\boldsymbol{\beta}$  is the same for all panels and consider a variety of models by changing the assumptions on the structure of  $\boldsymbol{\Omega}$ .

For the classic OLS regression model, we have

$$\begin{aligned} E[\epsilon_{i,t}] &= 0 \\ \text{Var}[\epsilon_{i,t}] &= \sigma^2 \\ \text{Cov}[\epsilon_{i,t}, \epsilon_{j,s}] &= 0 \quad \text{if } t \neq s \text{ or } i \neq j \end{aligned}$$

This amounts to assuming that  $\boldsymbol{\Omega}$  has the structure given by

$$\boldsymbol{\Omega} = \begin{bmatrix} \sigma^2\mathbf{I} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \sigma^2\mathbf{I} & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \sigma^2\mathbf{I} \end{bmatrix}$$

whether or not the panels are balanced (the **0** matrices may be rectangular). The classic OLS assumptions are the default `panels(iid)` and `corr(independent)` options for this command.

## Heteroskedasticity across panels

In many cross-sectional datasets, the variance for each of the panels differs. It is common to have data on countries, states, or other units that have variation of scale. The heteroskedastic model is specified by including the `panels(heteroskedastic)` option, which assumes that

$$\boldsymbol{\Omega} = \begin{bmatrix} \sigma_1^2\mathbf{I} & \mathbf{0} & \cdots & \mathbf{0} \\ \mathbf{0} & \sigma_2^2\mathbf{I} & \cdots & \mathbf{0} \\ \vdots & \vdots & \ddots & \vdots \\ \mathbf{0} & \mathbf{0} & \cdots & \sigma_m^2\mathbf{I} \end{bmatrix}$$

## ▷ Example 1

Greene (2012, 1112) reprints data in a classic study of investment demand by Grunfeld and Griliches (1960). Below we allow the variances to differ for each of the five companies.

```
. use https://www.stata-press.com/data/r16/invest2
. xtgls invest market stock, panels(hetero)
Cross-sectional time-series FGLS regression
Coefficients: generalized least squares
Panels: heteroskedastic
Correlation: no autocorrelation
Estimated covariances      =      5          Number of obs      =      100
Estimated autocorrelations =      0          Number of groups   =        5
Estimated coefficients     =      3          Time periods      =       20
                                         Wald chi2(2)      =    865.38
                                         Prob > chi2       =    0.0000
```

	invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
market	.0949905	.007409	12.82	0.000	.0804692	.1095118
stock	.3378129	.0302254	11.18	0.000	.2785722	.3970535
_cons	-36.2537	6.124363	-5.92	0.000	-48.25723	-24.25017



## Correlation across panels (cross-sectional correlation)

We may wish to assume that the error terms of panels are correlated, in addition to having different scale variances. The variance structure is specified by including the `panels(correlated)` option and is given by

$$\Omega = \begin{bmatrix} \sigma_1^2 \mathbf{I} & \sigma_{1,2} \mathbf{I} & \cdots & \sigma_{1,m} \mathbf{I} \\ \sigma_{2,1} \mathbf{I} & \sigma_2^2 \mathbf{I} & \cdots & \sigma_{2,m} \mathbf{I} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{m,1} \mathbf{I} & \sigma_{m,2} \mathbf{I} & \cdots & \sigma_m^2 \mathbf{I} \end{bmatrix}$$

Because we must estimate cross-sectional correlation in this model, the panels must be balanced (and  $T \geq m$  for valid results). A time variable must also be specified so that `xtgls` knows how the observations within panels are ordered. `xtset` shows us that this is true.

## ► Example 2

```
. xtset
    panel variable: company (strongly balanced)
    time variable: time, 1 to 20
        delta: 1 unit

. xtgls invest market stock, panels(correlated)
Cross-sectional time-series FGLS regression
Coefficients: generalized least squares
Panels: heteroskedastic with cross-sectional correlation
Correlation: no autocorrelation

Estimated covariances      =      15      Number of obs      =      100
Estimated autocorrelations =      0      Number of groups   =       5
Estimated coefficients     =      3      Time periods     =      20
                                         Wald chi2(2)     =    1285.19
                                         Prob > chi2     =      0.0000
```

	invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
market	.0961894	.0054752	17.57	0.000	.0854583	.1069206
stock	.3095321	.0179851	17.21	0.000	.2742819	.3447822
_cons	-38.36128	5.344871	-7.18	0.000	-48.83703	-27.88552

The estimated cross-sectional covariances are stored in e(Sigma).

```
. matrix list e(Sigma)
symmetric e(Sigma)[5,5]
      _ee      _ee2      _ee3      _ee4      _ee5
_ee  9410.9061
_ee2 -168.04631  755.85077
_ee3 -1915.9538 -4163.3434  34288.49
_ee4 -1129.2896 -80.381742  2259.3242  633.42367
_ee5  258.50132  4035.872 -27898.235 -1170.6801  33455.511
```



## ▷ Example 3

We can obtain the MLE results by specifying the `igls` option, which iterates the GLS estimation technique to convergence:

```
. xtgls invest market stock, panels(correlated) igls
Iteration 1: tolerance = .2127384
Iteration 2: tolerance = .22817
(output omitted)
Iteration 1046: tolerance = 1.000e-07

Cross-sectional time-series FGLS regression
Coefficients: generalized least squares
Panels: heteroskedastic with cross-sectional correlation
Correlation: no autocorrelation

Estimated covariances      =      15          Number of obs     =      100
Estimated autocorrelations =      0          Number of groups  =        5
Estimated coefficients     =      3          Time periods    =      20
                                         Wald chi2(2)    =     558.51
Log likelihood             = -515.4222    Prob > chi2     =     0.0000


```

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
invest	.023631	.004291	5.51	0.000	.0152207 .0320413
market	.1709472	.0152526	11.21	0.000	.1410526 .2008417
stock					
_cons	-2.216508	1.958845	-1.13	0.258	-6.055774 1.622759

Here the log likelihood is reported in the header of the output.



## Autocorrelation within panels

The individual identity matrices along the diagonal of  $\Omega$  may be replaced with more general structures to allow for serial correlation. `xtgls` allows three options so that you may assume a structure with `corr(independent)` (no autocorrelation); `corr(ar1)` (serial correlation where the correlation parameter is common for all panels); or `corr(psar1)` (serial correlation where the correlation parameter is unique for each panel).

The restriction of a common autocorrelation parameter is reasonable when the individual correlations are nearly equal and the time series are short.

If the restriction of a common autocorrelation parameter is reasonable, this allows us to use more information in estimating the autocorrelation parameter to produce a more reasonable estimate of the regression coefficients.

When you specify `corr(ar1)` or `corr(psar1)`, the iterated GLS estimator does not converge to the MLE.

## ▷ Example 4

If `corr(ar1)` is specified, each group is assumed to have errors that follow the same AR(1) process; that is, the autocorrelation parameter is the same for all groups.

```
. xtgls invest market stock, panels(hetero) corr(ar1)
Cross-sectional time-series FGLS regression
Coefficients: generalized least squares
Panels: heteroskedastic
Correlation: common AR(1) coefficient for all panels (0.8651)

Estimated covariances      =      5          Number of obs      =      100
Estimated autocorrelations =      1          Number of groups   =       5
Estimated coefficients     =      3          Time periods     =      20
                                         Wald chi2(2)    =     119.69
                                         Prob > chi2    =     0.0000
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
market	.0744315	.0097937	7.60	0.000	.0552362 .0936268
stock	.2874294	.0475391	6.05	0.000	.1942545 .3806043
_cons	-18.96238	17.64943	-1.07	0.283	-53.55464 15.62987



## ▷ Example 5

If `corr(psar1)` is specified, each group is assumed to have errors that follow a different AR(1) process.

```
. xtgls invest market stock, panels(iid) corr(psar1)
Cross-sectional time-series FGLS regression
Coefficients: generalized least squares
Panels: homoskedastic
Correlation: panel-specific AR(1)

Estimated covariances      =      1          Number of obs      =      100
Estimated autocorrelations =      5          Number of groups   =       5
Estimated coefficients     =      3          Time periods     =      20
                                         Wald chi2(2)    =     252.93
                                         Prob > chi2    =     0.0000
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
market	.0934343	.0097783	9.56	0.000	.0742693 .1125993
stock	.3838814	.0416775	9.21	0.000	.302195 .4655677
_cons	-10.1246	34.06675	-0.30	0.766	-76.8942 56.64499



## Stored results

`xtgls` stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_ic)</code>	number of observations used to compute information criteria
<code>e(N_g)</code>	number of groups
<code>e(N_t)</code>	number of periods
<code>e(N_miss)</code>	number of missing observations
<code>e(n_cf)</code>	number of estimated coefficients
<code>e(n_cv)</code>	number of estimated covariances
<code>e(n_cr)</code>	number of estimated correlations
<code>e(df)</code>	degrees of freedom
<code>e(df_pear)</code>	degrees of freedom for Pearson $\chi^2$
<code>e(df_ic)</code>	degrees of freedom for information criteria
<code>e(l1)</code>	log likelihood
<code>e(chi2)</code>	$\chi^2$
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rc)</code>	return code

### Macros

<code>e(cmd)</code>	<code>xtgls</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(tvars)</code>	variable denoting time within groups
<code>e(coefftype)</code>	estimation scheme
<code>e(corr)</code>	correlation structure
<code>e(vt)</code>	panel option
<code>e(rhotype)</code>	type of estimated correlation
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(chi2type)</code>	Wald; type of model $\chi^2$ test
<code>e(rho)</code>	$\rho$
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

### Matrices

<code>e(b)</code>	coefficient vector
<code>e(Sigma)</code>	$\widehat{\Sigma}$ matrix
<code>e(V)</code>	variance–covariance matrix of the estimators

### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

The GLS results are given by

$$\widehat{\beta}_{\text{GLS}} = (\mathbf{X}' \widehat{\boldsymbol{\Omega}}^{-1} \mathbf{X})^{-1} \mathbf{X}' \widehat{\boldsymbol{\Omega}}^{-1} \mathbf{y}$$

$$\widehat{\text{Var}}(\widehat{\beta}_{\text{GLS}}) = (\mathbf{X}' \widehat{\boldsymbol{\Omega}}^{-1} \mathbf{X})^{-1}$$

For all our models, the  $\boldsymbol{\Omega}$  matrix may be written in terms of the Kronecker product:

$$\boldsymbol{\Omega} = \boldsymbol{\Sigma}_{m \times m} \otimes \mathbf{I}_{T_i \times T_i}$$

The estimated variance matrix is obtained by substituting the estimator  $\widehat{\Sigma}$  for  $\Sigma$ , where

$$\widehat{\Sigma}_{i,j} = \frac{\widehat{\epsilon}_i' \widehat{\epsilon}_j}{T}$$

The residuals used in estimating  $\Sigma$  are first obtained from OLS regression. If the estimation is iterated, residuals are obtained from the last fitted model.

Maximum likelihood estimates may be obtained by iterating the FGLS estimates to convergence for models with no autocorrelation, `corr(independent)`.

The GLS estimates and their associated standard errors are calculated using  $\widehat{\Sigma}^{-1}$ . As Beck and Katz (1995) point out, the  $\Sigma$  matrix is of rank at most  $\min(T, m)$  when you use the `panels(correlated)` option. For the GLS results to be valid (not based on a generalized inverse),  $T$  must be at least as large as  $m$ , as you need at least as many period observations as there are panels.

Beck and Katz (1995) suggest using OLS parameter estimates with asymptotic standard errors that are corrected for correlation between the panels. This estimation can be performed with the `xtpcse` command; see [XT] `xtpcse`.

## References

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## Also see

- [XT] `xtgls postestimation` — Postestimation tools for `xtgls`
- [XT] `xtpcse` — Linear regression with panel-corrected standard errors
- [XT] `xtreg` — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] `xtregar` — Fixed- and random-effects linear models with an AR(1) disturbance
- [XT] `xtset` — Declare data to be panel data
- [R] `regress` — Linear regression
- [TS] `newey` — Regression with Newey–West standard errors
- [TS] `prais` — Prais–Winsten and Cochrane–Orcutt regression
- [U] **20 Estimation and postestimation commands**

## Postestimation commands

The following postestimation commands are available after `xtgls`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
* <code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
* <code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

\* `estat ic` and `lrtest` are available only if `igls` and `corr(independent)` were specified at estimation.

## **predict**

### **Description for predict**

`predict` creates a new variable containing predictions such as linear predictions and standard errors.

### **Menu for predict**

Statistics > Postestimation

### **Syntax for predict**

```
predict [type] newvar [if] [in] [, xb stdp]
```

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

### **Options for predict**

Main

`xb`, the default, calculates the linear prediction.

`stdp` calculates the standard error of the linear prediction.

## margins

### Description for margins

`margins` estimates margins of response for linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist] , predict(statistic ...) [options]
```

<i>statistic</i>	Description
<code>xb</code>	linear prediction; the default
<code>stdp</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] **margins**.

### Also see

[XT] **xtgls** — Fit panel-data models by using GLS

[U] 20 Estimation and postestimation commands

**xheckman** — Random-effects regression with sample selection

Description	Quick start	Menu	Syntax
Options	Remarks and examples	Stored results	Methods and formulas
References	Also see		

## Description

`xheckman` fits a random-effects linear regression model with endogenous sample selection.

## Quick start

Random-effects model of `y` on `x1` using `xtset` data, with selection indicated by binary variable `selected` and predicted by `v1` and `x1`

```
xheckman y x1, select(selected = v1 x1)
```

As above, but constraining random effects to be independent

```
xheckman y x1, select(selected = v1 x1) norecorrelation
```

As above, but omit random effects from selection model

```
xheckman y x1, select(selected = v1 x1, nore)
```

## Menu

Statistics > Longitudinal/panel data > Sample-selection models > Linear regression with sample selection (RE)

## Syntax

`xheckman depvar [indepvars] [if] [in],  
select(depvars = varlists [ , sel_options] ) [options]`

<i>options</i>	Description
<b>Model</b>	
<code>* <u>select</u>()</code>	specify selection equation: dependent and independent variables; whether to have constant term and offset variable or include random effect
<code><u>noconstant</u></code>	suppress constant term
<code><u>norecorrelation</u></code>	constrain the random effects to be independent
<code><u>offset</u>(<i>varname<sub>o</sub></i>)</code>	include <i>varname<sub>o</sub></i> in model with coefficient constrained to 1
<code><u>constraints</u>(<i>numlist</i>)</code>	apply specified linear constraints
<b>SE/Robust</b>	
<code>vce(vcetype)</code>	<i>vcetype</i> may be <code>oim</code> , <code>robust</code> , <code>cluster</code> <i>clustvar</i> , <code>opg</code> , <code>bootstrap</code> , or <code>jackknife</code>
<b>Reporting</b>	
<code><u>level</u>(#)</code>	set confidence level; default is <code>level(95)</code>
<code><u>nocnsreport</u></code>	do not display constraints
<code><u>display_options</u></code>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Integration</b>	
<code><u>intmethod</u>(<i>intmethod</i>)</code>	integration method for random effects; <i>intmethod</i> may be <code>mvaghermite</code> (the default) or <code>ghermite</code>
<code><u>intpoints</u>(#)</code>	set the number of integration (quadrature) points for random-effects integration; default is <code>intpoints(7)</code>
<b>Maximization</b>	
<code><u>maximize_options</u></code>	control the maximization process; seldom used
<code><u>collinear</u></code>	keep collinear variables
<code><u>coeflegend</u></code>	display legend instead of statistics

<i>sel_options</i>	Description
<b>Model</b>	
<code><u>noconstant</u></code>	suppress constant term
<code><u>nore</u></code>	do not include random effects in selection model
<code><u>offset</u>(<i>varname<sub>o</sub></i>)</code>	include <i>varname<sub>o</sub></i> in model with coefficient constrained to 1

\*`select()` is required.

*indepvars* and *varlist<sub>s</sub>* may contain factor variables; see [U] 11.4.3 Factor variables.

*depvar*, *indepvars*, *depvar<sub>s</sub>*, and *varlist<sub>s</sub>* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`bootstrap`, `by`, `jackknife`, and `statsby` are allowed. See [U] 11.1.10 Prefix commands.

`collinear` and `coeflegend` do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

`select(depvars = varlists [ , sel_options ])` specifies a random-effects probit model for sample selection with `varlists` as the covariates for the selection model. When `depvars = 1`, the model's dependent variable is treated as observed (selected); when `depvars = 0`, it is treated as unobserved (not selected). `select()` is required.

`sel_options` are the following:

`noconstant` suppresses the constant term (intercept) in the selection model.

`nore` specifies that a random effect not be included in the selection equation.

`offset(varnameo)` specifies that `varnameo` be included in the selection model with the coefficient constrained to 1.

`noconstant`; see [\[R\] Estimation options](#).

`norecorrelation` constrains the random effects in the outcome and selection equations to be independent.

`offset(varnameo)`, `constraints(numlist)`; see [\[R\] Estimation options](#).

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`, `opg`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [\[XT\] vce\\_options](#).

### Reporting

`level(#)`, `nocnsreport`; see [\[R\] Estimation options](#).

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwwrap(#)`, `fvrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [\[R\] Estimation options](#).

### Integration

`intmethod(intmethod)` and `intpoints(#)` control how the integration of random effects is numerically calculated.

`intmethod()` specifies the integration method. The default method is mean-variance adaptive Gauss–Hermite quadrature, `intmethod(mvaghermite)`. We recommend this method.

`intmethod(ghermite)` specifies that nonadaptive Gauss–Hermite quadrature be used. This method is less computationally intensive and less accurate. It is sometimes useful to try `intmethod(ghermite)` to get the model to converge and then perhaps use the results as initial values specified in option `from` when fitting the model using the more accurate `intmethod(mvaghermite)`. See [Methods and formulas](#) for more details.

`intpoints()` sets the number of integration (quadrature) points used for integration of the random effects. The default is `intpoints(7)`. Increasing the number increases accuracy but also increases computational time. Computational time is roughly proportional to the number specified. See [Methods and formulas](#) for more details.

Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, [no] `log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] **Maximize**. These options are seldom used.

The default technique is `technique(bhhh 10 nr 2)`.

Setting the optimization type to `technique(bhhh)` resets the default `vcetype` to `vce(opg)`.

The following options are available with `xheckman` but are not shown in the dialog box:

`collinear`, `coeflegend`; see [R] **Estimation options**.

## Remarks and examples

`xheckman` fits a panel-data model with endogenous sample selection. Endogenous sample selection is sometimes called nonignorability of selection, missing not at random, or selection bias. Within-panel correlation is accounted for by using panel-level random effects.

The outcome of interest  $y_{it}$  is modeled as

$$y_{it} = \mathbf{x}_{it}\boldsymbol{\beta} + \nu_{1i} + \epsilon_{1it}$$

where  $\mathbf{x}_{it}$  are the covariates modeling the outcome,  $\nu_{1i}$  is the panel-level random effect, and  $\epsilon_{1it}$  is the observation-level error.

We model the selection process for the outcome by

$$s_{it} = 1 (\mathbf{z}_{it}\boldsymbol{\alpha} + \nu_{2i} + \epsilon_{2it} > 0)$$

where  $s_{it} = 1$  if we observe  $y_{it}$  and 0 otherwise,  $\mathbf{z}_{it}$  are the covariates modeling selection,  $\nu_{2i}$  is the panel-level random effect for selection, and  $\epsilon_{2it}$  is the observation-level selection error.

The random effects  $\nu_{1i}$  and  $\nu_{2i}$  are bivariate normal with mean 0 and variance

$$\begin{bmatrix} \sigma_{1\nu}^2 & \rho_{\nu}\sigma_{1\nu}\sigma_{2\nu} \\ \rho_{\nu}\sigma_{1\nu}\sigma_{2\nu} & \sigma_{2\nu}^2 \end{bmatrix}$$

The observation-level errors  $\epsilon_{1it}$  and  $\epsilon_{2it}$  are bivariate normal, with mean 0 and variance

$$\begin{bmatrix} \sigma_1^2 & \rho\sigma_1 \\ \rho\sigma_1 & 1 \end{bmatrix}$$

These observation-level errors are independent of the random effects.

Using the Heckman estimator (`heckman`) for this model will provide inefficient estimates because it ignores the within-panel correlation. Instead, we use maximum likelihood to model both the selection and outcome equations and account for the panel structure of the data. This random-effects estimator is used by `xteregress` and was discussed in Rabe-Hesketh, Skrondal, and Pickles (2002). There is no parametric fixed-effects estimator for panel data from an endogenously selected sample. See Honoré, Kyriazidou, and Powell (2000) and Kyriazidou (1997) for semiparametric fixed-effects estimators of panel-data endogenous sample-selection models.

## ▷ Example 1

Suppose that we wish to study the relationship between wage, job tenure, and age for college-educated adults. We have fictional data on 600 adults observed from 2013 to 2016. We use these data to model hourly wage as a function of age, age squared, and job tenure. However, an individual's wage is observed only if he or she works, and not everyone was employed on the dates the data were collected. We are not interested in modeling only the subpopulation of individuals who were employed at the time. We are also interested in the relationship of job tenure and age with the wage an individual would have received if he or she had been employed.

We suspect that the unobserved factors that affect an individual's wage are related to the unobserved factors that affect employment status. These unobserved factors could include person-level characteristics like ability and time-varying factors like an individual's family situation. We suspect that we have an endogenously selected sample. We have data on the local job market conditions (`market`). This variable is used with age and tenure to model the employment status of an individual.

Before we can fit a random-effects model to our data, we need to specify the panel structure of the data using `xtset`. Our panel variable is `personid`, the identification code for the individual. The time variable is `year`, and it ranges from 2013 to 2016.

```
. use https://www.stata-press.com/data/r16/wagework  
(Wages for 20 to 77 year olds, 2013-2016)  
. xtset personid year  
    panel variable: personid (strongly balanced)  
    time variable: year, 2013 to 2016  
        delta: 1 unit
```

We are now ready to fit our model.

```
. xheckman wage c.age##c.age tenure, select(working = c.age##c.age market)
(setting technique to bhhh)
Iteration 0: log likelihood = -5384.5076
Iteration 1: log likelihood = -5377.4625
Iteration 2: log likelihood = -5376.4805
Iteration 3: log likelihood = -5376.4505
Iteration 4: log likelihood = -5376.4464
Iteration 5: log likelihood = -5376.4454
Iteration 6: log likelihood = -5376.4451
Iteration 7: log likelihood = -5376.4451
Iteration 8: log likelihood = -5376.445
Iteration 9: log likelihood = -5376.445
(setting technique to nr)
Iteration 10: log likelihood = -5376.445

Random-effects regression with selection
Number of obs      =      2,400
Selected          =      1,928
Nonselected       =       472

Group variable: personid
Number of groups   =       600
Obs. per group:
min              =         4
avg              =      4.0
max              =         4

Integration method: mvaghermite
Integration pts.   =        7
Wald chi2(3)      =     2827.78
Prob > chi2       =     0.0000

Log likelihood = -5376.445
```

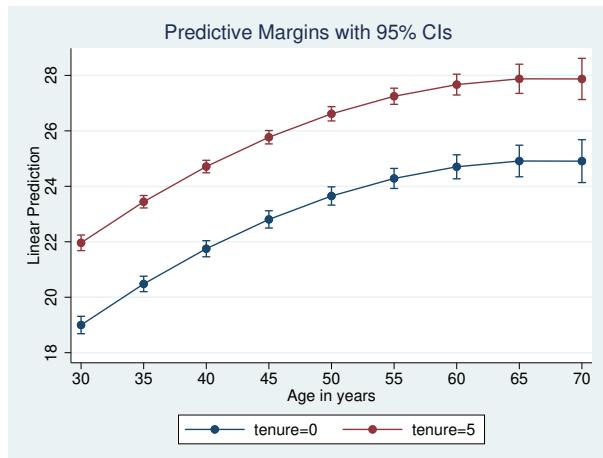
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
wage					
age	.5722234	.0477613	11.98	0.000	.4786129 .6658339
c.age#c.age	-.0042448	.0005329	-7.97	0.000	-.0052893 -.0032003
tenure	.5927719	.0169866	34.90	0.000	.5594787 .626065
_cons	5.651812	1.038011	5.44	0.000	3.617347 7.686277
working					
age	.2305309	.0207988	11.08	0.000	.1897661 .2712958
c.age#c.age	-.0026832	.0002241	-11.97	0.000	-.0031225 -.0022439
market	.1894934	.019038	9.95	0.000	.1521796 .2268072
_cons	-3.276904	.4352836	-7.53	0.000	-4.130045 -2.423764
var(e.wage)	4.458219	.2235342			4.040939 4.918588
corr(e.wor~g, e.wage)	.4091115	.1391856	2.94	0.003	.1065022 .642359
var( wage[pers~d])	2.493737	.2547628			2.041226 3.046564
var( wor~g[per~d])	.3831411	.0830963			.250466 .5860961
corr( wor~g[per~d], wage[pers~d])	.6021096	.0845675	7.12	0.000	.4106863 .7426953

The first two sections of the output provide the estimated coefficients for the wage equation and the selection (working) equation. We can interpret the coefficients in the wage equation using the standard linear regression interpretation. For example, we expect an increase of \$0.59 per hour for an additional year of job tenure.

Next we see `var(e.wage)`, an estimate of the variance of the observation-level error for wage; this is followed by `corr(e.working,e.wage)`, an estimate of its correlation with the observation-level error for the selection model. The next section of the output reports estimates of the variances of the random effects, `var(wage[personid])` and `var(working[personid])`. The last section reports an estimate of the correlation of these random effects. If at least one of the correlations is significantly different from zero, we can conclude that we have endogenous sample selection. In our case, the correlation between the observation-level errors is 0.41, and the correlation between the random effects is 0.60. Because both are positive and significantly different from zero, we conclude that we have endogenous selection and that unobserved individual-level factors that increase the chance of being employed tend to increase wage. Additionally, unobserved observation-level (time-varying) factors that increase the chance of being employed tend to increase wage.

We estimated coefficients for age and age squared. We can use `margins` and `marginsplot` to gain a clearer understanding of the effect of the individuals' age on hourly wage. We use `margins` with `at()` to profile the expected wages for individuals between ages 30 and 70 and with 0 and 5 years of job tenure. Then, we use `marginsplot` to graph the estimates.

```
. margins, at(age=(30(5)70) tenure =(0 5))
. marginsplot
```



Based on this model, and assuming the data are from a random or otherwise representative sample, the plotted points represent the expected wage for individuals with the specified job tenure and age. We see that age has an increasing effect on expected wage until the mid-60s and then attenuates. Having 5 years of job tenure instead of none shifts the curve up by about \$3.00 per hour.



## Stored results

`xheckman` stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_selected)</code>	number of selected observations
<code>e(N_nonselected)</code>	number of nonselected observations
<code>e(k)</code>	number of parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(N_clust)</code>	number of clusters
<code>e(chi2)</code>	$\chi^2$
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(n_requad)</code>	number of integration points for random effects
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

### Macros

<code>e(cmd)</code>	<code>xheckman</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	names of dependent variables
<code>e(ivars)</code>	variable denoting groups
<code>e(title)</code>	title in estimation output
<code>e(clustvar)</code>	name of cluster variable
<code>e(offset#)</code>	offset for the #th <code>depvar</code> , where # is determined by equation order in output
<code>e(chi2type)</code>	Wald; type of model $\chi^2$ test
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(reintmethod)</code>	integration method for random effects
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	<code>max</code> or <code>min</code> ; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of <code>ml</code> method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(estat_cmd)</code>	program used to implement <code>estat</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

### Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(iolog)</code>	iteration log (up to 20 iterations)
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

`xheckman` fits a random-effects linear regression model with endogenous sample selection via maximum likelihood estimation. For details on maximum likelihood estimators, see the results in Wooldridge (2010, chap. 13) and White (1996).

The log-likelihood function maximized by `xheckman` is implied by the triangular structure of the model. Specifically, the joint distribution of the outcome and selection variables is a product of conditional and marginal distributions because the model is triangular. For a few of the many relevant applications of this result in literature, see Amemiya (1985, chap. 10); Heckman (1976, 1979); Maddala (1983, chap. 5); Maddala and Lee (1976); Wooldridge (2010, sec. 15.7.2, 15.7.3, 16.3.3, 17.5.2, and 19.7.1; 2014). Roodman (2011) and Bartus and Roodman (2014) used this result to derive the formulas discussed below.

We have panels  $i = 1, \dots, N$  and observations  $t = 1, \dots, N_i$ . We model  $y_{it}$  as

$$y_{it} = \mathbf{x}_{it}\boldsymbol{\beta} + \nu_{1i} + \epsilon_{1it}$$

where  $\mathbf{x}_{it}$  are the outcome covariates,  $\nu_{1i}$  is the panel-level random effect, and  $\epsilon_{1it}$  is the observation-level error.

The selection process for the outcome is modeled by

$$s_{it} = 1(\mathbf{z}_{it}\boldsymbol{\alpha} + \nu_{2i} + \epsilon_{2it} > 0)$$

where  $s_{it} = 1$  if we observe  $y_{it}$  and 0 otherwise,  $\mathbf{z}_{it}$  are the selection covariates,  $\nu_{2i}$  is the panel-level random effect for selection, and  $\epsilon_{2it}$  is the observation-level selection error.

The random effects  $\nu_{1i}$  and  $\nu_{2i}$  are bivariate normal with mean 0 and variance

$$\boldsymbol{\Sigma}_\nu = \begin{bmatrix} \sigma_{1\nu}^2 & \rho_\nu \sigma_{1\nu} \sigma_{2\nu} \\ \rho_\nu \sigma_{1\nu} \sigma_{2\nu} & \sigma_{2\nu}^2 \end{bmatrix}$$

The observation-level errors  $\epsilon_{1it}$  and  $\epsilon_{2it}$  are independent of the random effects and are also bivariate normal, with mean 0 and variance

$$\boldsymbol{\Sigma} = \begin{bmatrix} \sigma_1^2 & \rho \sigma_1 \\ \rho \sigma_1 & 1 \end{bmatrix}$$

When we condition on the random effects  $\nu_{1i}$  and  $\nu_{2i}$ , we can write the joint density of the  $y_{it}$  and  $s_{it}$  using the conditional density of the selection error  $\epsilon_{2it}$  on the outcome error  $\epsilon_{1it}$ .

For the selection indicator  $s_{it}$ , we have lower limit  $l_{it}$  and upper limit  $u_{it}$ ,

$$l_{it} = \begin{cases} -\infty & s_{it} = 0 \\ -\mathbf{z}_{it}\boldsymbol{\alpha} - \nu_{2i} - \frac{\rho}{\sigma_1}(y_{it} - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_{1i}) & s_{it} = 1 \end{cases} \quad u_{it} = \begin{cases} -\mathbf{z}_{it}\boldsymbol{\alpha} - \nu_{2i} & s_{it} = 0 \\ \infty & s_{it} = 1 \end{cases}$$

Then, the joint density of  $y_{it}$  and  $s_{it}$  conditional on the random effects is

$$f(y_{it}, s_{it} | \nu_{1i}, \nu_{2i}) = \begin{cases} \Phi\left(\frac{-l_{it}}{\sqrt{1-\rho^2}}\right) + \phi\left(\frac{y_{it} - \mathbf{x}_{it}\boldsymbol{\beta}}{\sigma_1}\right) & s_{it} = 1 \\ \Phi\left(\frac{u_{it}}{\sqrt{1-\rho^2}}\right) & s_{it} = 0 \end{cases}$$

Note that each panel has the same random effects for each observation. So the likelihood for panel  $i$  is

$$L_i = \int_{\mathbb{R}^2} \left[ \prod_{t=1}^{N_i} f(y_{it}, s_{it} | (\nu_{1i}, \nu_{2i})) \phi_2\{(\nu_{1i}, \nu_{2i}), \Sigma_\nu\} d\nu_{1i} d\nu_{2i} \right] \quad (1)$$

This multivariate integral is generally not tractable. We can use a change-of-variables technique to transform it into a set of nested univariate integrals. Let  $\mathbf{L}$  be the Cholesky decomposition of  $\Sigma_\nu$ ; that is,  $\Sigma_\nu = \mathbf{L}\mathbf{L}'$ . It follows that  $(\nu_{1i}, \nu_{2i})' = \mathbf{L}\psi_i$ , where  $\psi_i$  is a vector of independent standard normal random variables.

We can rewrite (1) as

$$L_i = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \left\{ \prod_{t=1}^{N_i} f(y_{it}, s_{it} | (\nu_{1i}, \nu_{2i})' = \mathbf{L}\psi_i) \right\} \phi(\psi_{1i}) \phi(\psi_{2i}) d\psi_{1i} d\psi_{2i}$$

Now the univariate integral can be approximated using Gauss–Hermite quadrature (GHQ). For  $q$ -point GHQ, let the abscissa and weight pairs be denoted by  $(a_k^*, w_k^*)$ , where  $k = 1, \dots, q$ . The GHQ approximation is then

$$\int_{-\infty}^{\infty} f(x) \exp(-x^2) dx \approx \sum_{k=1}^q w_k^* f(a_k^*)$$

Consider a 2-dimensional quadrature grid containing  $q$  quadrature points in both dimensions. Let the vector of abscissas  $\mathbf{a}_k = (a_{k1}, a_{k2})'$  be a point in this grid, and let  $\mathbf{w}_k = (w_{k1}, w_{k2})'$  be the vector of corresponding weights.

The GHQ approximation to the likelihood for a given panel is

$$L_i = \sum_{k_1=1}^q \sum_{k_2=1}^q \left[ \left\{ \prod_{t=1}^{N_i} f(y_{it}, s_{it} | (\nu_{1i}, \nu_{2i})' = \mathbf{L}\mathbf{a}_k) \right\} \left\{ \prod_{s=1}^2 w_{ks} \right\} \right]$$

Rather than using regular GHQ, we can use mean–variance adaptive GHQ. Fixing the observed variables and model parameters in the integrand of (1), we see the posterior density for  $\psi_i$  is proportional to

$$\left\{ \prod_{t=1}^{N_i} f(y_{it}, s_{it} | (\nu_{1i}, \nu_{2i})' = \mathbf{L}\psi_i) \right\} \phi(\psi_i)$$

It is reasonable to assume that this posterior density can be approximated by a multivariate normal density with mean vector  $\mu_{vi}$  and variance matrix  $\tau_{vi}$ . Instead of using the prior density of  $\psi_i$  as the weighting distribution in the integral, we can use our approximation for the posterior density,

$$L_i = \int_{\mathbb{R}^2} \frac{\left\{ \prod_{t=1}^{N_i} f(y_{it}, s_{it} | (\nu_{1i}, \nu_{2i})' = \mathbf{L}\psi_i) \right\} \phi(\psi_i)}{\phi(\psi_i, \mu_{vi}, \tau_{vi})} \phi(\psi_i, \mu_{vi}, \tau_{vi}) d\psi_i$$

The likelihood is then approximated by

$$L_i = \sum_{k_1=1}^q \dots \sum_{k_2=1}^q \left[ \left\{ \prod_{t=1}^{N_i} f(y_{it}, s_{it} | (\nu_{1i}, \nu_{2i})' = \mathbf{L}\alpha_k) \right\} \left\{ \prod_{s=1}^2 \omega_{k_s} \right\} \right]$$

where  $\alpha_k$  and  $\omega_{k_s}$  are the adaptive versions of the abscissas and weights after an orthogonalizing transformation, which eliminates posterior covariances between elements of  $\psi_i$ . The posterior means  $\mu_{vi}$  and posterior variances  $\tau_{vi}$  are computed iteratively by updating the posterior moments by using the mean-variance adaptive GHQ approximation, starting with a 0 mean vector and identity variance matrix.

The log likelihood for all panels is then

$$\ln L = \sum_{i=1}^N \left( \ln \sum_{k_1=1}^q \dots \sum_{k_2=1}^q \left[ \left\{ \prod_{t=1}^{N_i} f(y_{it}, s_{it} | (\nu_{1i}, \nu_{2i})' = \mathbf{L}\alpha_k) \right\} \left\{ \prod_{s=1}^2 \omega_{k_s} \right\} \right] \right)$$

The conditional mean of  $y_{it}$  is

$$E(y_{it} | \mathbf{x}_{it}) = \mathbf{x}_{it}\beta$$

`xheckman` results are obtained using `xteregress`; see *Methods and formulas* of [ERMS] `erregress`.

## References

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- Wooldridge, J. M. 2010. *Econometric Analysis of Cross Section and Panel Data*. 2nd ed. Cambridge, MA: MIT Press.
- . 2014. Quasi-maximum likelihood estimation and testing for nonlinear models with endogenous explanatory variables. *Journal of Econometrics* 182: 226–234.

## Also see

- [XT] **xheckman postestimation** — Postestimation tools for xheckman
- [XT] **xteregress** — Extended random-effects linear regression
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtset** — Declare data to be panel data
- [ERM] **eregress** — Extended linear regression
- [R] **heckman** — Heckman selection model
- [R] **regress** — Linear regression
- [U] **20 Estimation and postestimation commands**

**xheckman postestimation** — Postestimation tools for xheckman

Postestimation commands predict margins Remarks and examples  
 Also see

## Postestimation commands

The following postestimation commands are available after `xheckman`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

## predict

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions, probabilities, and expected values.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

`predict [type] newvar [if] [in] [, statistic nooffset]`

`predict [type] { stub* | newvarlist } [if] [in] , scores`

statistic	Description
<hr/>	
Main	
<code>xb</code>	linear prediction; the default
<code>xbsel</code>	linear prediction for selection equation
<code>pr(a,b)</code>	$\Pr(y_{it}   a < y_{it} < b)$
<code>e(a,b)</code>	$E(y_{it}   a < y_{it} < b)$
<code>ystar(a,b)</code>	$E(y_{it}^*), y_{it}^* = \max\{a, \min(y_{it}, b)\}$
<code>ycond</code>	$E(y_{it}   y_{it} \text{ observed})$
<code>psel</code>	$\Pr(y_{it} \text{ observed})$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

where  $a$  and  $b$  may be numbers or variables;  $a$  missing ( $a \geq .$ ) means  $-\infty$ , and  $b$  missing ( $b \geq .$ ) means  $+\infty$ ; see [U] 12.2.1 Missing values.

### Options for predict

#### Main

`xb`, the default, calculates the linear prediction  $\mathbf{x}_{it}\mathbf{b}$ .

`xbsel` calculates the linear prediction for the selection equation.

`pr(a,b)` calculates  $\Pr(a < \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} < b)$ , the probability that  $y_{it}|\mathbf{x}_{it}$  would be observed in the interval  $(a, b)$ .

$a$  and  $b$  may be specified as numbers or variable names;  $lb$  and  $ub$  are variable names; `pr(20,30)` calculates  $\Pr(20 < \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} < 30)$ ; `pr(lb,ub)` calculates  $\Pr(lb < \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} < ub)$ ; and `pr(20,ub)` calculates  $\Pr(20 < \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} < ub)$ .

$a$  missing ( $a \geq .$ ) means  $-\infty$ ; `pr(.,30)` calculates  $\Pr(-\infty < \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} < 30)$ ; `pr(lb,30)` calculates  $\Pr(-\infty < \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} < 30)$  in observations for which  $lb \geq .$  and calculates  $\Pr(lb < \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} < 30)$  elsewhere.

$b$  missing ( $b \geq .$ ) means  $+\infty$ ; `pr(20,.)` calculates  $\Pr(+\infty > \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} > 20)$ ; `pr(20,ub)` calculates  $\Pr(+\infty > \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} > 20)$  in observations for which  $ub \geq .$  and calculates  $\Pr(20 < \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} < ub)$  elsewhere.

`e(a,b)` calculates  $E(\mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} | a < \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} < b)$ , the expected value of  $y_{it}|\mathbf{x}_{it}$  conditional on  $y_{it}|\mathbf{x}_{it}$  being in the interval  $(a,b)$ , meaning that  $y_{it}|\mathbf{x}_{it}$  is truncated.  $a$  and  $b$  are specified as they are for `pr()`.

`ystar(a,b)` calculates  $E(y_{it}^*)$ , where  $y_{it}^* = a$  if  $\mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} \leq a$ ,  $y_{it}^* = b$  if  $\mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it} \geq b$ , and  $y_{it}^* = \mathbf{x}_{it}\mathbf{b} + \nu_{1i} + \epsilon_{1it}$  otherwise, meaning that  $y_{it}^*$  is not selected.  $a$  and  $b$  are specified as they are for `pr()`.

`ycond` calculates the expected value of the dependent variable conditional on the dependent variable being observed, that is, selected;  $E(y_{it} | y_{it} \text{ observed})$ .

`psel` calculates the probability of selection (or being observed):

$$\Pr(y_{it} \text{ observed}) = \Pr(\mathbf{z}_{it}\boldsymbol{\alpha} + \nu_{2i} + \epsilon_{2it} > 0).$$

`nooffset` is relevant when you specify `offset(varname)` for **xheckman**. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\mathbf{b}$  rather than as  $\mathbf{x}_{it}\mathbf{b} + \text{offset}_{it}$ .

`scores` calculates parameter-level score variables.

## margins

### Description for margins

`margins` estimates margins of response for linear predictions, probabilities, and expected values.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist] , predict(statistic ...) [predict(statistic ...) ...] [options]
```

statistic	Description
<code>xb</code>	linear prediction; the default
<code>xbsel</code>	linear prediction for selection equation
<code>pr(a,b)</code>	$\Pr(y_{it}   a < y_{it} < b)$
<code>e(a,b)</code>	$E(y_{it}   a < y_{it} < b)$
<code>ystar(a,b)</code>	$E(y_{it}^*), y_{it}^* = \max\{a, \min(y_{it}, b)\}$
<code>ycond</code>	$E(y_{it}   y_{it} \text{ observed})$
<code>psel</code>	$\Pr(y_{it} \text{ observed})$

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] **margins**.

## Remarks and examples

The default statistic produced by `predict` after `xheckman` is the expected value of the dependent variable from the underlying distribution of the regression model. See example 1 of [XT] `xheckman` for an example where `margins` is used to predict the conditional mean.

## Also see

[XT] `xheckman` — Random-effects regression with sample selection

[U] 20 Estimation and postestimation commands

**xthtaylor** — Hausman–Taylor estimator for error-components models

Description  
Options  
References

Quick start  
Remarks and examples  
Also see

Menu  
Stored results

Syntax  
Methods and formulas

## Description

**xthtaylor** fits a random-effects model for panel data in which some of the covariates are correlated with the unobserved individual-level random effects. The command implements the Hausman–Taylor estimator by default, but the Amemiya–MacCurdy estimator is available for balanced panels.

## Quick start

Hausman–Taylor model of *y* as a function of time-varying exogenous variable *x1*, time-invariant binary variable *a*, and time-varying endogenous variable *x2* using **xtset** data

```
xthtaylor y x1 x2 a, endog(x2)
```

As above, and verify that *a* is the only time-invariant variable in the model

```
xthtaylor y x1 x2 a, endog(x2) constant(a)
```

Add time-invariant *x3* as an endogenous covariate, but do not verify that *a* and *x3* are the only time-invariant variables

```
xthtaylor y x1 x2 a x3, endog(x2 x3)
```

As above, but use Amemiya–MacCurdy estimator for balanced panels

```
xthtaylor y x1 x2 a x3, endog(x2 x3) am
```

## Menu

Statistics > Longitudinal/panel data > Endogenous covariates > Hausman–Taylor regression (RE)

## Syntax

`xthtaylor depvar indepvars [if] [in] [weight], endog(varlist) [options]`

<i>options</i>	Description
<hr/>	
Model	
<u>noconstant</u>	suppress constant term
* <u>endog(varlist)</u>	explanatory variables in <i>indepvars</i> to be treated as endogenous
<u>constant(varlist<sub>ti</sub>)</u>	independent variables that are constant within panel
<u>varying(varlist<sub>tv</sub>)</u>	independent variables that are time varying within panel
<u>amacurdy</u>	fit model based on Amemiya and MaCurdy estimator
SE/Robust	
<u>vce(vcetype)</u>	<i>vcetype</i> may be conventional, <u>robust</u> , <u>cluster clustvar</u> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level(#)</u>	set confidence level; default is <code>level(95)</code>
<u>small</u>	report small-sample statistics

\* `endog(varlist)` is required.

A panel variable must be specified. For `xthtaylor`, `amacurdy`, a time variable must also be specified. Use `xtset`; see [XT] `xtset`.

*depvar*, *indepvars*, and all *varlists* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

*by*, *statsby*, and *xi* are allowed; see [U] 11.1.10 Prefix commands.

*iweights* and *fweights* are allowed unless the `amacurdy` option is specified. Weights must be constant within panel; see [U] 11.1.6 weight.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

noconstant; see [R] Estimation options.

endog(varlist) specifies that a subset of explanatory variables in *indepvars* be treated as endogenous variables, that is, the explanatory variables that are assumed to be correlated with the unobserved random effect. `endog()` is required.

constant(varlist<sub>ti</sub>) specifies the subset of variables in *indepvars* that are time invariant, that is, constant within panel. By using this option, you assert not only that the variables specified in *varlist<sub>ti</sub>* are time invariant but also that all other variables in *indepvars* are time varying. If this assertion is false, `xthtaylor` does not perform the estimation and will issue an error message. `xthtaylor` automatically detects which variables are time invariant and which are not. However, users may want to check their understanding of the data and specify which variables are time invariant and which are not.

varying(varlist<sub>tv</sub>) specifies the subset of variables in *indepvars* that are time varying. By using this option, you assert not only that the variables specified in *varlist<sub>tv</sub>* are time varying but also that all other variables in *indepvars* are time invariant. If this assertion is false, `xthtaylor` does not perform the estimation and will issue an error message. `xthtaylor` automatically detects which variables are time varying and which are not. However, users may want to check their understanding of the data and specify which variables are time varying and which are not.

`amacurdy` specifies that the Amemiya–MacCurdy estimator be used. This estimator uses extra instruments to gain efficiency at the cost of additional assumptions on the data-generating process. This option may be specified only for samples containing balanced panels, and weights may not be specified. The panels must also have a common initial period.

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 SE/Robust
 

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`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] *vce\_options*.

`vce(conventional)`, the default, uses the conventionally derived variance estimator for this Hausman–Taylor model.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see *xtpoisson, re and the robust VCE estimator* in Methods and formulas of [XT] *xtpoisson*.

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 Reporting
 

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`level(#)`; see [R] *Estimation options*.

`small` specifies that the  $p$ -values from the Wald tests in the output and all subsequent Wald tests obtained via `test` use  $t$  and  $F$  distributions instead of the large-sample normal and  $\chi^2$  distributions. By default, the  $p$ -values are obtained using the normal and  $\chi^2$  distributions.

## Remarks and examples

If you have not read [XT] *xt*, please do so.

Consider a random-effects model of the form

$$y_{it} = \mathbf{X}_{1it}\boldsymbol{\beta}_1 + \mathbf{X}_{2it}\boldsymbol{\beta}_2 + \mathbf{Z}_{1i}\delta_1 + \mathbf{Z}_{2i}\delta_2 + \mu_i + \epsilon_{it}$$

where

$\mathbf{X}_{1it}$  is a  $1 \times k_1$  vector of observations on exogenous, time-varying variables assumed to be uncorrelated with  $\mu_i$  and  $\epsilon_{it}$ ;

$\mathbf{X}_{2it}$  is a  $1 \times k_2$  vector of observations on endogenous, time-varying variables assumed to be (possibly) correlated with  $\mu_i$  but orthogonal to  $\epsilon_{it}$ ;

$\mathbf{Z}_{1i}$  is a  $1 \times g_1$  vector of observations on exogenous, time-invariant variables assumed to be uncorrelated with  $\mu_i$  and  $\epsilon_{it}$ ;

$\mathbf{Z}_{2i}$  is a  $1 \times g_2$  vector of observations on endogenous, time-invariant variables assumed to be (possibly) correlated with  $\mu_i$  but orthogonal to  $\epsilon_{it}$ ;

$\mu_i$  is the unobserved, panel-level random effect that is assumed to have zero mean and finite variance  $\sigma_\mu^2$  and to be independent and identically distributed (i.i.d.) over the panels;

$\epsilon_{it}$  is the idiosyncratic error that is assumed to have zero mean and finite variance  $\sigma_\epsilon^2$  and to be i.i.d. over all the observations in the data;

$\boldsymbol{\beta}_1$ ,  $\boldsymbol{\beta}_2$ ,  $\delta_1$ , and  $\delta_2$  are  $k_1 \times 1$ ,  $k_2 \times 1$ ,  $g_1 \times 1$ , and  $g_2 \times 1$  coefficient vectors, respectively; and  $i = 1, \dots, n$ , where  $n$  is the number of panels in the sample and, for each  $i$ ,  $t = 1, \dots, T_i$ .

Because  $\mathbf{X}_{2it}$  and  $\mathbf{Z}_{2i}$  may be correlated with  $\mu_i$ , the simple random-effects estimators—`xtreg, re` and `xtreg, mle`—are generally not consistent for the parameters in this model. Because the within estimator, `xtreg, fe`, removes the  $\mu_i$  by mean-differencing the data before estimating  $\beta_1$  and  $\beta_2$ , it is consistent for these parameters. However, in the process of removing the  $\mu_i$ , the within estimator also eliminates the  $\mathbf{Z}_{1i}$  and the  $\mathbf{Z}_{2i}$ . Thus it cannot estimate  $\delta_1$  nor  $\delta_2$ . The Hausman–Taylor and Amemiya–MaCurdy estimators implemented in `xthtaylor` are designed to resolve this problem.

The within estimator consistently estimates  $\beta_1$  and  $\beta_2$ . Using these estimates, we can obtain the within residuals, called  $\hat{d}_i$ . Intermediate, albeit consistent, estimates of  $\delta_1$  and  $\delta_2$ —called  $\hat{\delta}_{1IV}$  and  $\hat{\delta}_{2IV}$ , respectively—are obtained by regressing the within residuals on  $\mathbf{Z}_{1i}$  and  $\mathbf{Z}_{2i}$ , using  $\mathbf{X}_{1it}$  and  $\mathbf{Z}_{1i}$  as instruments. The order condition for identification requires that the number of variables in  $\mathbf{X}_{1it}$ ,  $k_1$ , be at least as large as the number of elements in  $\mathbf{Z}_{2i}$ ,  $g_2$  and that there be sufficient correlation between the instruments and  $\mathbf{Z}_{2i}$  to avoid a weak-instrument problem.

The within estimates of  $\beta_1$  and  $\beta_2$  and the intermediate estimates  $\hat{\delta}_{1IV}$  and  $\hat{\delta}_{2IV}$  can be used to obtain sets of within and overall residuals. These two sets of residuals can be used to estimate the variance components (see *Methods and formulas* for details).

The estimated variance components can then be used to perform a GLS transform on each of the variables. For what follows, define the general notation  $\check{w}_{it}$  to represent the GLS transform of the variable  $w_{it}$ ,  $\bar{w}_i$  to represent the within-panel mean of  $w_{it}$ , and  $\tilde{w}_{it}$  to represent the within transform of  $w_{it}$ . With this notational convention, the Hausman–Taylor (1981) estimator of the coefficients of interest can be obtained by the instrumental-variables regression

$$\check{y}_{it} = \check{\mathbf{X}}_{1it}\beta_1 + \check{\mathbf{X}}_{2it}\beta_2 + \check{\mathbf{Z}}_{1i}\delta_1 + \check{\mathbf{Z}}_{2i}\delta_2 + \check{\mu}_i + \check{\epsilon}_{it} \quad (1)$$

using  $\tilde{\mathbf{X}}_{1it}$ ,  $\tilde{\mathbf{X}}_{2it}$ ,  $\bar{\mathbf{X}}_{1i}$ ,  $\bar{\mathbf{X}}_{2i}$ , and  $\mathbf{Z}_{1i}$  as instruments.

For the instruments to be valid, this estimator requires that  $\bar{\mathbf{X}}_{1i}$  and  $\mathbf{Z}_{1i}$  be uncorrelated with the random-effect  $\mu_i$ . More precisely, the instruments are valid when

$$\text{plim}_{n \rightarrow \infty} \frac{1}{n} \sum_{i=1}^n \bar{\mathbf{X}}_{1i} \mu_i = 0$$

and

$$\text{plim}_{n \rightarrow \infty} \frac{1}{n} \sum_{i=1}^n \mathbf{Z}_{1i} \mu_i = 0$$

Amemiya and MaCurdy (1986) place stricter requirements on the instruments that vary within panels to obtain a more efficient estimator. Specifically, Amemiya and MaCurdy (1986) assume that  $\mathbf{X}_{1it}$  is orthogonal to  $\mu_i$  in every period; that is,  $\text{plim}_{n \rightarrow \infty} 1/n \sum_{i=1}^n \mathbf{X}_{1it} \mu_i = 0$  for  $t = 1, \dots, T$ . With this restriction, they derive the Amemiya–MaCurdy estimator as the instrumental-variables regression of (1) using instruments  $\tilde{\mathbf{X}}_{1it}$ ,  $\tilde{\mathbf{X}}_{2it}$ ,  $\mathbf{X}_{1it}^*$ , and  $\mathbf{Z}_{1i}$ . The order condition for the Amemiya–MaCurdy estimator is now  $T k_1 > g_2$ . `xthtaylor` uses the Amemiya–MaCurdy estimator when the `amacurdy` option is specified.

Although the estimators implemented in `xthtaylor` and `xtivreg` (see [XT] `xtivreg`) use the method of instrumental variables, each command is designed for different problems. The estimators implemented in `xtivreg` assume that a subset of the explanatory variables in the model are correlated with the idiosyncratic error  $\epsilon_{it}$ . In contrast, the Hausman–Taylor and Amemiya–MaCurdy estimators that are implemented in `xthtaylor` assume that some of the explanatory variables are correlated with the individual-level random effects,  $u_i$ , but that none of the explanatory variables are correlated with the idiosyncratic error,  $\epsilon_{it}$ .

## ► Example 1

This example replicates the results of [Baltagi and Khanti-Akom \(1990\)](#), table II, column HT) using 595 observations on individuals over 1976–1982 that were extracted from the Panel Study of Income Dynamics (PSID). In the model, the log-transformed wage `lwage` is assumed to be a function of how long the person has worked for a firm, `wks`; binary variables indicating whether a person lives in a large metropolitan area or in the south, `smsa` and `south`; marital status is `ms`; years of education, `ed`; a quadratic of work experience, `exp` and `exp2`; occupation, `occ`; a binary variable indicating employment in a manufacture industry, `ind`; a binary variable indicating that wages are set by a union contract, `union`; a binary variable indicating gender, `fem`; and a binary variable indicating whether the individual is African American, `blk`.

We suspect that the time-varying variables `exp`, `exp2`, `wks`, `ms`, and `union` are all correlated with the unobserved individual random effect. We can inspect these variables to see if they exhibit sufficient within-panel variation to serve as their own instruments.

```
. use https://www.stata-press.com/data/r16/psidextract
. xtsum exp exp2 wks ms union
```

Variable		Mean	Std. Dev.	Min	Max	Observations
exp	overall	19.85378	10.96637	1	51	N = 4165
	between		10.79018	4	48	n = 595
	within		2.00024	16.85378	22.85378	T = 7
exp2	overall	514.405	496.9962	1	2601	N = 4165
	between		489.0495	20	2308	n = 595
	within		90.44581	231.405	807.405	T = 7
wks	overall	46.81152	5.129098	5	52	N = 4165
	between		3.284016	31.57143	51.57143	n = 595
	within		3.941881	12.2401	63.66867	T = 7
ms	overall	.8144058	.3888256	0	1	N = 4165
	between		.3686109	0	1	n = 595
	within		.1245274	-.0427371	1.671549	T = 7
union	overall	.3639856	.4812023	0	1	N = 4165
	between		.4543848	0	1	n = 595
	within		.1593351	-.4931573	1.221128	T = 7

We are also going to assume that the exogenous variables `occ`, `south`, `smsa`, `ind`, `fem`, and `blk` are instruments for the endogenous, time-invariant variable `ed`. The output below indicates that although `fem` appears to be a weak instrument, the remaining instruments are probably sufficiently correlated to identify the coefficient on `ed`. (See [Baltagi and Khanti-Akom \[1990\]](#) for more discussion.)

```
. correlate fem blk occ south smsa ind ed
(obs=4,165)
```

	fem	blk	occ	south	smsa	ind	ed
fem	1.0000						
blk	0.2086	1.0000					
occ	-0.0847	0.0837	1.0000				
south	0.0516	0.1218	0.0413	1.0000			
smsa	0.1044	0.1154	-0.2018	-0.1350	1.0000		
ind	-0.1778	-0.0475	0.2260	-0.0769	-0.0689	1.0000	
ed	-0.0012	-0.1196	-0.6194	-0.1216	0.1843	-0.2365	1.0000

We will assume that the correlations are strong enough and proceed with the estimation. The output below gives the Hausman–Taylor estimates for this model.

```
. xhtaylor lwage occ south smsa ind exp exp2 wks ms union fem blk ed,
> endog(exp exp2 wks ms union ed)
Hausman-Taylor estimation
Group variable: id
Number of obs      =      4,165
Number of groups   =       595
Obs per group:
min =           7
avg =           7
max =           7
Random effects u_i ~ i.i.d.
Wald chi2(12)     =    6891.87
Prob > chi2       =    0.0000
```

lwage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
TVexogenous					
occ	-.0207047	.0137809	-1.50	0.133	-.0477149 .0063055
south	.0074398	.031955	0.23	0.816	-.0551908 .0700705
smsa	-.0418334	.0189581	-2.21	0.027	-.0789906 -.0046761
ind	.0136039	.0152374	0.89	0.372	-.0162608 .0434686
TVendogenous					
exp	.1131328	.002471	45.79	0.000	.1082898 .1179758
exp2	-.0004189	.0000546	-7.67	0.000	-.0005259 -.0003119
wks	.0008374	.0005997	1.40	0.163	-.0003381 .0020129
ms	-.0298508	.01898	-1.57	0.116	-.0670508 .0073493
union	.0327714	.0149084	2.20	0.028	.0035514 .0619914
TIexogenous					
fem	-.1309236	.126659	-1.03	0.301	-.3791707 .1173234
blk	-.2857479	.1557019	-1.84	0.066	-.5909179 .0194221
TIendogenous					
ed	.137944	.0212485	6.49	0.000	.0962977 .1795902
_cons	2.912726	.2836522	10.27	0.000	2.356778 3.468674
sigma_u	.94180304				
sigma_e	.15180273				
rho	.97467788				(fraction of variance due to u_i)

Note: TV refers to time varying; TI refers to time invariant.

The estimated  $\sigma_\mu$  and  $\sigma_\epsilon$  are 0.9418 and 0.1518, respectively, indicating that a large fraction of the total error variance is attributed to  $\mu_i$ . The  $z$  statistics indicate that several the coefficients may not be significantly different from zero. Whereas the coefficients on the time-invariant variables `fem` and `blk` have relatively large standard errors, the standard error for the coefficient on `ed` is relatively small.

Baltagi and Khanti-Akom (1990) also present evidence that the efficiency gains of the Amemiya–MaCurdy estimator over the Hausman–Taylor estimator are small for these data. This point is especially important given the additional restrictions that the estimator places on the data-generating process. The output below replicates the Baltagi and Khanti-Akom (1990) results from column AM of table II.

```
. xtaylor lwage occ south smsa ind exp exp2 wks ms union fem blk ed,
> endog(exp exp2 wks ms union ed) amacurdy
Amemiya-MaCurdy estimation
Number of obs      =      4,165
Group variable: id          Number of groups =       595
Time variable: t           Obs per group:
                                         min =        7
                                         avg =        7
                                         max =        7
Random effects u_i ~ i.i.d.    Wald chi2(12) =   6879.20
                                         Prob > chi2 = 0.0000
```

lwage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
TVexogenous					
occ	-.0208498	.0137653	-1.51	0.130	-.0478292 .0061297
south	.0072818	.0319365	0.23	0.820	-.0553126 .0698761
smsa	-.0419507	.0189471	-2.21	0.027	-.0790864 -.0048149
ind	.0136289	.015229	0.89	0.371	-.0162194 .0434771
TVendogenous					
exp	.1129704	.0024688	45.76	0.000	.1081316 .1178093
exp2	-.0004214	.0000546	-7.72	0.000	-.0005283 -.0003145
wks	.0008381	.0005995	1.40	0.162	-.0003368 .002013
ms	-.0300894	.0189674	-1.59	0.113	-.0672649 .0070861
union	.0324752	.0148939	2.18	0.029	.0032837 .0616667
TIexogenous					
fem	-.132008	.1266039	-1.04	0.297	-.380147 .1161311
blk	-.2859004	.1554857	-1.84	0.066	-.5906468 .0188459
TIendogenous					
ed	.1372049	.0205695	6.67	0.000	.0968894 .1775205
_cons	2.927338	.2751274	10.64	0.000	2.388098 3.466578
sigma_u	.94180304				
sigma_e	.15180273				
rho	.97467788				(fraction of variance due to u_i)

Note: TV refers to time varying; TI refers to time invariant.



## □ Technical note

We mentioned earlier that insufficient correlation between an endogenous variable and the instruments can give rise to a weak-instrument problem. Suppose that we simulate data for a model of the form

$$y = 3 + 3x_{1a} + 3x_{1b} + 3x_2 + 3z_1 + 3z_2 + u_i + e_{it}$$

and purposely construct the instruments so that they exhibit little correlation with the endogenous variable  $z_2$ .

```
. use https://www.stata-press.com/data/r16/xhtaylor1
. correlate ui z1 z2 x1a x1b x2 eit
(obs=10,000)
```

	ui	z1	z2	x1a	x1b	x2	eit
ui	1.0000						
z1	0.0268	1.0000					
z2	0.8777	0.0286	1.0000				
x1a	-0.0145	0.0065	-0.0034	1.0000			
x1b	0.0026	0.0079	0.0038	-0.0030	1.0000		
x2	0.8765	0.0191	0.7671	-0.0192	0.0037	1.0000	
eit	0.0060	-0.0198	0.0123	-0.0100	-0.0138	0.0092	1.0000

In the output below, weak instruments have serious consequences on the estimates produced by `xhtaylor`. The estimate of the coefficient on `z2` is three times larger than its true value, and its standard error is rather large. Without sufficient correlation between the endogenous variable and its instruments in a given sample, there is insufficient information for identifying the parameter. Also, given the results of Stock, Wright, and Yogo (2002), weak instruments will cause serious size distortions in any tests performed.

```
. xhtaylor yit x1a x1b x2 z1 z2, endog(x2 z2)
Hausman-Taylor estimation
Number of obs      =      10,000
Group variable: id
Number of groups   =        1,000
Obs per group:
    min =          10
    avg =          10
    max =          10
Random effects u_i ~ i.i.d.
Wald chi2(5)      =     24172.91
Prob > chi2       =      0.0000
```

yit	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
TVexogenous					
x1a	2.959736	.0330233	89.63	0.000	2.895011 3.02446
x1b	2.953891	.0333051	88.69	0.000	2.888614 3.019168
TVendogenous					
x2	3.022685	.033085	91.36	0.000	2.957839 3.08753
TIexogenous					
z1	2.709179	.587031	4.62	0.000	1.55862 3.859739
TIendogenous					
z2	9.525973	8.572966	1.11	0.266	-7.276732 26.32868
_cons	2.837072	.4276595	6.63	0.000	1.998875 3.675269
sigma_u	8.729479				
sigma_e	3.1657492				
rho	.88377062	(fraction of variance due to u_i)			

Note: TV refers to time varying; TI refers to time invariant.



## ▷ Example 2

Now let's consider why we might want to specify the `constant(varlistti)` option. For this example, we will use simulated data. In the output below, we fit a model over the full sample. Note the placement in the output of the coefficient on the exogenous variable `x1c`.

```
. use https://www.stata-press.com/data/r16/xtaylor2
. xtaylor yit x1a x1b x1c x2 z1 z2, endog(x2 z2)
Hausman-Taylor estimation
Group variable: id
Number of obs      =     10,000
Number of groups   =      1,000
Obs per group:
min =          10
avg =          10
max =          10
Random effects u_i ~ i.i.d.
Wald chi2(6)      =  10341.63
Prob > chi2       =    0.0000
```

yit	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
TVexogenous					
x1a	3.023647	.0570274	53.02	0.000	2.911875 3.135418
x1b	2.966666	.0572659	51.81	0.000	2.854427 3.078905
x1c	.2355318	.123502	1.91	0.057	-.0065276 .4775912
TVendogenous					
x2	14.17476	3.128385	4.53	0.000	8.043234 20.30628
TIexogenous					
z1	1.741709	.4280022	4.07	0.000	.9028398 2.580578
TIendogenous					
z2	7.983849	.6970903	11.45	0.000	6.617577 9.350121
_cons	2.146038	.3794179	5.66	0.000	1.402393 2.889684
sigma_u	5.6787791				
sigma_e	3.1806188				
rho	.76120931	(fraction of variance due to u_i)			

Note: TV refers to time varying; TI refers to time invariant.

Now suppose that we want to fit the model using only the first eight periods. Below, x1c now appears under the TIexogenous heading rather than the TVexogenous heading because x1c is time invariant in the subsample defined by t<9.

```
. xhtaylor yit x1a x1b x1c x2 z1 z2 if t<9, endog(x2 z2)
Hausman-Taylor estimation
Group variable: id
Number of obs      =     8,000
Number of groups   =    1,000
Obs per group:
min =          8
avg =          8
max =          8
Random effects u_i ~ i.i.d.
Wald chi2(6)      =  15354.87
Prob > chi2       = 0.0000
```

yit	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
TVexogenous					
x1a	3.051966	.0367026	83.15	0.000	2.98003 3.123901
x1b	2.967822	.0368144	80.62	0.000	2.895667 3.039977
TVendogenous					
x2	.7361217	3.199764	0.23	0.818	-5.5353 7.007543
TIexogenous					
x1c	3.215907	.5657191	5.68	0.000	2.107118 4.324696
z1	3.347644	.5819756	5.75	0.000	2.206992 4.488295
TIendogenous					
z2	2.010578	1.143982	1.76	0.079	-.231586 4.252742
_cons	3.257004	.5295828	6.15	0.000	2.219041 4.294967
sigma_u	15.445594				
sigma_e	3.175083				
rho	.95945606	(fraction of variance due to u_i)			

Note: TV refers to time varying; TI refers to time invariant.

To prevent a variable from becoming time invariant, you can use either `constant(varlistti)` or `varying(varlisttv)`. `constant(varlistti)` specifies the subset of variables in `varlist` that are time invariant and requires the remaining variables in `varlist` to be time varying. If you specify `constant(varlistti)` and any of the variables contained in `varlistti` are time varying, or if any of the variables not contained in `varlistti` are time invariant, `xhtaylor` will not perform the estimation and will issue an error message.

```
. xhtaylor yit x1a x1b x1c x2 z1 z2 if t<9, endog(x2 z2) constant(z1 z2)
  x1c not included in constant().
r(198);
```

The same thing happens when you use the `varying(varlisttv)` option.



## Stored results

**xhtaylor** stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(df_r)</code>	residual degrees of freedom (small only)
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(Tcon)</code>	1 if panels balanced, 0 otherwise
<code>e(N_clust)</code>	number of clusters
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of $\epsilon_{it}$
<code>e(chi2)</code>	$\chi^2$
<code>e(rho)</code>	$\rho$
<code>e(F)</code>	model $F$ (small only)
<code>e(Tbar)</code>	harmonic mean of group sizes
<code>e(rank)</code>	rank of <code>e(V)</code>

### Macros

<code>e(cmd)</code>	<b>xhtaylor</b>
<code>e(cmdline)</code>	command as typed
<code>e(depar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups, amacurdy only
<code>e(TVexogenous)</code>	exogenous time-varying variables
<code>e(TIexogenous)</code>	exogenous time-invariant variables
<code>e(TVendogenous)</code>	endogenous time-varying variables
<code>e(TIendogenous)</code>	endogenous time-invariant variables
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	Hausman–Taylor or Amemiya–MaCurdy
<code>e(clustvar)</code>	name of cluster variable
<code>e(chi2type)</code>	Wald; type of model $\chi^2$ test
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement <code>predict</code>

### Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

Consider an error-components model of the form

$$y_{it} = \mathbf{X}_{1it}\boldsymbol{\beta}_1 + \mathbf{X}_{2it}\boldsymbol{\beta}_2 + \mathbf{Z}_{1i}\delta_1 + \mathbf{Z}_{2i}\delta_2 + \mu_i + \epsilon_{it} \quad (2)$$

for  $i = 1, \dots, n$  and, for each  $i$ ,  $t = 1, \dots, T_i$ , of which  $T_i$  periods are observed;  $n$  is the number of panels in the sample. The covariates in  $\mathbf{X}$  are time varying, and the covariates in  $\mathbf{Z}$  are time invariant. Both  $\mathbf{X}$  and  $\mathbf{Z}$  are decomposed into two parts. The covariates in  $\mathbf{X}_1$  and  $\mathbf{Z}_1$  are assumed to be uncorrelated with  $\mu_i$  and  $\epsilon_{it}$ , whereas the covariates in  $\mathbf{X}_2$  and  $\mathbf{Z}_2$  are allowed to be correlated with  $\mu_i$  but not with  $\epsilon_{it}$ . [Hausman and Taylor \(1981\)](#) suggest an instrumental-variable estimator for this model.

For some variable  $w$ , the within transformation of  $w$  is defined as

$$\tilde{w}_{it} = w_{it} - \bar{w}_i, \quad \bar{w}_i = \frac{1}{T_i} \sum_{t=1}^{T_i} w_{it}$$

Because the within estimator removes  $\mathbf{Z}$ , the within transformation reduces the model to

$$\tilde{y}_{it} = \tilde{\mathbf{X}}_{1it}\beta_1 + \tilde{\mathbf{X}}_{2it}\beta_2 + \tilde{\epsilon}_{it}$$

The within estimators  $\hat{\beta}_{1w}$  and  $\hat{\beta}_{2w}$  are consistent for  $\beta_1$  and  $\beta_2$ , but they may not be efficient. Also, note that the within estimator cannot estimate  $\delta_1$  and  $\delta_2$ .

From the within estimator, we can obtain an estimate of the idiosyncratic error component,  $\sigma_\epsilon^2$ , as

$$\hat{\sigma}_\epsilon^2 = \frac{\text{RSS}}{N - n}$$

where RSS is the residual sum of squares from the within regression and  $N$  is the total number of observations in the sample.

Using the results of the within estimation, we can define

$$\bar{d}_{it} = \bar{y}_{it} - \bar{X}_{1it}\hat{\beta}_{1w} - \bar{X}_{2it}\hat{\beta}_{2w}$$

where  $\bar{y}_{it}$ ,  $\bar{X}_{1it}$ , and  $\bar{X}_{2it}$  contain the panel level means of these variables in all observations.

Regressing  $\bar{d}_{it}$  on  $\mathbf{Z}_1$  and  $\mathbf{Z}_2$ , using  $\mathbf{X}_1$  and  $\mathbf{Z}_1$  as instruments, provides intermediate, consistent estimates of  $\delta_1$  and  $\delta_2$ , which we will call  $\hat{\delta}_{1IV}$  and  $\hat{\delta}_{2IV}$ .

Using the within estimates,  $\hat{\delta}_{1IV}$ , and  $\hat{\delta}_{2IV}$ , we can obtain an estimate of the variance of the random effect,  $\sigma_\mu^2$ . First, let

$$\hat{e}_{it} = \left( y_{it} - \mathbf{X}_{1it}\hat{\beta}_{1w} - \mathbf{X}_{2it}\hat{\beta}_{2w} - \mathbf{Z}_{1it}\hat{\delta}_{1IV} - \mathbf{Z}_{2it}\hat{\delta}_{2IV} \right)$$

Then define

$$s^2 = \frac{1}{N} \sum_{i=1}^n \sum_{t=1}^{T_i} \left( \frac{1}{T_i} \sum_{t=1}^{T_i} \hat{e}_{it} \right)^2$$

Hausman and Taylor (1981) showed that, for balanced panels,

$$\text{plim}_{n \rightarrow \infty} s^2 = T\sigma_\mu^2 + \sigma_\epsilon^2$$

For unbalanced panels,

$$\text{plim}_{n \rightarrow \infty} s^2 = \bar{T}\sigma_\mu^2 + \sigma_\epsilon^2$$

where

$$\bar{T} = \frac{n}{\sum_{i=1}^n \frac{1}{T_i}}$$

After we plug in  $\hat{\sigma}_\epsilon^2$ , our consistent estimate for  $\sigma_\epsilon^2$ , a little algebra suggests the estimate

$$\hat{\sigma}_\mu^2 = (s^2 - \hat{\sigma}_\epsilon^2)(\bar{T})^{-1}$$

Define  $\widehat{\theta}_i$  as

$$\widehat{\theta}_i = 1 - \left( \frac{\widehat{\sigma}_\epsilon^2}{\widehat{\sigma}_\epsilon^2 + T_i \widehat{\sigma}_\mu^2} \right)^{\frac{1}{2}}$$

With  $\widehat{\theta}_i$  in hand, we can perform the standard random-effects GLS transform on each of the variables. The transform is given by

$$w_{it}^* = w_{it} - \widehat{\theta}_i \bar{w}_i.$$

where  $\bar{w}_i$  is the within-panel mean.

We can then obtain the Hausman–Taylor estimates of the coefficients in (2) and the conventional VCE by fitting an instrumental-variables regression of the GLS-transformed  $y_{it}^*$  on  $\mathbf{X}_{it}^*$  and  $\mathbf{Z}_{it}^*$ , with instruments  $\tilde{\mathbf{X}}_{it}$ ,  $\bar{\mathbf{X}}_{1i}$ , and  $\mathbf{Z}_{1i}$ .

We can obtain Amemiya–MaCurdy estimates of the coefficients in (2) and the conventional VCE by fitting an instrumental-variables regression of the GLS-transformed  $y_{it}^*$  on  $\mathbf{X}_{it}^*$  and  $\mathbf{Z}_{it}^*$ , using  $\tilde{\mathbf{X}}_{it}$ ,  $\tilde{\mathbf{X}}_{1it}$ , and  $\mathbf{Z}_{1i}$  as instruments, where  $\tilde{\mathbf{X}}_{1it} = \mathbf{X}_{1i1}, \mathbf{X}_{1i2}, \dots, \mathbf{X}_{1iT_i}$ . The order condition for the Amemiya–MaCurdy estimator is  $Tk_1 > g_2$ , and this estimator is available only for balanced panels.

## References

- Amemiya, T., and T. E. MaCurdy. 1986. Instrumental-variable estimation of an error-components model. *Econometrica* 54: 869–880.
- Baltagi, B. H. 2009. *A Companion to Econometric Analysis of Panel Data*. Chichester, UK: Wiley.
- . 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.
- Baltagi, B. H., and S. Khanti-Akom. 1990. On efficient estimation with panel data: An empirical comparison of instrumental variables estimators. *Journal of Applied Econometrics* 5: 401–406.
- Hausman, J. A., and W. E. Taylor. 1981. Panel data and unobservable individual effects. *Econometrica* 49: 1377–1398.
- Stock, J. H., J. H. Wright, and M. Yogo. 2002. A survey of weak instruments and weak identification in generalized method of moments. *Journal of Business & Economic Statistics* 20: 518–529.

## Also see

[XT] **xhtaylor postestimation** — Postestimation tools for xhtaylor

[XT] **xtivreg** — Instrumental variables and two-stage least squares for panel-data models

[XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models

[XT] **xtset** — Declare data to be panel data

[U] **20 Estimation and postestimation commands**

[Postestimation commands](#)  
[References](#)

[predict](#)  
[Also see](#)

[margins](#)[Remarks and examples](#)

## Postestimation commands

The following postestimation commands are available after `xhtaylor`:

Command	Description
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from <code>margins</code> (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as fitted values, standard errors, combined residuals, predictions, random-error components, and idiosyncratic error components.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

`predict [type] newvar [if] [in] [, statistic]`

<i>statistic</i>	Description
<hr/>	
Main	
<code>xb</code>	$\mathbf{X}_{it}\hat{\beta} + \mathbf{Z}_i\hat{\delta}$ , fitted values; the default
<code>stdp</code>	standard error of the fitted values
<code>ue</code>	$\hat{\mu}_i + \hat{\epsilon}_{it}$ , the combined residual
<code>* xbu</code>	$\mathbf{X}_{it}\hat{\beta} + \mathbf{Z}_i\hat{\delta} + \hat{\mu}_i$ , prediction including effect
<code>* u</code>	$\hat{\mu}_i$ , the random-error component
<code>* e</code>	$\hat{\epsilon}_{it}$ , prediction of the idiosyncratic error component

Unstarred statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample. Starred statistics are calculated only for the estimation sample, even when `if e(sample)` is not specified.

### Options for predict

---

Main

`xb`, the default, calculates the linear prediction, that is,  $\mathbf{X}_{it}\hat{\beta} + \mathbf{Z}_i\hat{\delta}$ .

`stdp` calculates the standard error of the linear prediction.

`ue` calculates the prediction of  $\hat{\mu}_i + \hat{\epsilon}_{it}$ .

`xbu` calculates the prediction of  $\mathbf{X}_{it}\hat{\beta} + \mathbf{Z}_i\hat{\delta} + \hat{\mu}_i$ , the prediction including the random effect.

`u` calculates the prediction of  $\hat{\mu}_i$ , the estimated random effect.

`e` calculates the prediction of  $\hat{\epsilon}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for fitted values.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist] , predict(statistic ...) [options]
```

<i>statistic</i>	Description
<code>xb</code>	$\mathbf{X}_{it}\hat{\beta} + \mathbf{Z}_i\hat{\delta}$ , fitted values; the default
<code>stdp</code>	not allowed with <code>margins</code>
<code>ue</code>	not allowed with <code>margins</code>
<code>xbu</code>	not allowed with <code>margins</code>
<code>u</code>	not allowed with <code>margins</code>
<code>e</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] `margins`.

## Remarks and examples

### ▷ Example 1

Continuing with example 1 of [XT] `xhtaylor`, we use `hausman` to test whether we should use the Hausman–Taylor estimator instead of the fixed-effects estimator. We follow the empirical illustration in Baltagi (2013, sec. 7.5), but we fit the model without including the `exp2` and `wks` variables.

We first fit the model with `xhtaylor` and then with `xtreg`, `fe`:

```
. use https://www.stata-press.com/data/r16/psidextract
. xhtaylor lwage occ south smsa ind exp ms union fem blk ed,
> endog(exp ms union ed)
(output omitted)
. estimates store eq_ht
. xtreg lwage occ south smsa ind exp ms union fem blk ed, fe
(output omitted)
. estimates store eq_fe
```

We can now use `hausman` to compare the two estimators, but we need to specify the `df()` to indicate the degrees of freedom for the  $\chi^2$  statistic, which would be determined by the overidentifying restrictions in the Hausman–Taylor estimation. In this case, there are three degrees of freedom because there are four time-varying exogenous variables (`occ`, `south`, `smsa`, `ind`) that can be used as instruments for only one time-invariant endogenous variable (`ed`).

```
. hausman eq_fe eq_ht, df(3)
```

	Coefficients		(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
	(b) eq_fe	(B) eq_ht		
occ	-.0239323	-.0231694	-.0007629	.0002395
south	-.0037282	.0062699	-.0099982	.0124188
smsa	-.0436251	-.0433518	-.0002733	.0042296
ind	.021184	.0156376	.0055465	.0025159
exp	.0965738	.0964748	.0000991	.000063
ms	-.0299908	-.0300703	.0000795	.000321
union	.0349156	.0348494	.0000662	.0006336

b = consistent under Ho and Ha; obtained from xtreg

B = inconsistent under Ha, efficient under Ho; obtained from xhtaylor

Test: Ho: difference in coefficients not systematic

$$\begin{aligned} \text{chi2}(3) &= (\mathbf{b}-\mathbf{B})'[(V_b-V_B)^{-1}](\mathbf{b}-\mathbf{B}) \\ &= 5.22 \\ \text{Prob>chi2} &= 0.1567 \\ (V_b-V_B) &\text{ is not positive definite} \end{aligned}$$

The *p*-value for the test provides evidence favoring the null hypothesis; therefore, in this case, the Hausman–Taylor estimation is adequate.

Notice that the variance–covariance matrix for the difference ( $\mathbf{b}-\mathbf{B}$ ) is not positive definite. As Greene (2012, 237) points out, this kind of result is due to finite-sample conditions. He also states that Hausman considers it preferable to take the test statistic as zero and, therefore, not to reject the null hypothesis.



## ▷ Example 2

We now want to determine whether the Amemiya–McCurdy estimator produces significant efficiency gains with respect to the Hausman–Taylor estimator. We refit the two models, and we use the Hausman test again:

```
. use https://www.stata-press.com/data/r16/psidextract
. xhtaylor lwage occ south smsa ind exp ms union fem blk ed,
> endog(exp ms union ed)
(output omitted)

. estimates store eq_ht

. xhtaylor lwage occ south smsa ind exp ms union fem blk ed,
> endog(exp ms union ed) amacurdy
(output omitted)

. estimates store eq_am
```

```
. hausman eq_ht eq_am
```

	Coefficients		(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
	(b) eq_ht	(B) eq_am		
occ	-.0231694	-.023354	.0001846	.0006485
south	.0062699	.0060857	.0001842	.0010641
smsa	-.0433518	-.0434638	.0001121	.0006297
ind	.0156376	.0156602	-.0000226	.000492
exp	.0964748	.0962147	.00026	.0000694
ms	-.0300703	-.0303139	.0002436	.0006735
union	.0348494	.0345742	.0002752	.0006471
fem	-.1277756	-.1287857	.0010101	.0036717
blk	-.2911574	-.291645	.0004876	.0082831
ed	.1390257	.1380699	.0009558	.005436

b = consistent under  $H_0$  and  $H_A$ ; obtained from xhtaylor

B = inconsistent under  $H_A$ , efficient under  $H_0$ ; obtained from xhtaylor

Test:  $H_0$ : difference in coefficients not systematic

$$\begin{aligned} \text{chi2}(10) &= (b-B)'[(V_b-V_B)^{-1}](b-B) \\ &= 14.42 \\ \text{Prob}>\text{chi2} &= 0.1548 \end{aligned}$$

The result indicates that we should use the more efficient estimation produced by the Amemiya–McCurdy estimator.



## References

- Baltagi, B. H. 2013. *Econometric Analysis of Panel Data*. 5th ed. Chichester, UK: Wiley.  
 Greene, W. H. 2012. *Econometric Analysis*. 7th ed. Upper Saddle River, NJ: Prentice Hall.

## Also see

- [XT] **xhtaylor** — Hausman–Taylor estimator for error-components models  
 [U] **20 Estimation and postestimation commands**

**xtintreg** — Random-effects interval-data regression models

Description	Quick start	Menu	Syntax
Options	Remarks and examples	Stored results	Methods and formulas
References	Also see		

## Description

`xtintreg` fits a random-effects regression model in which the dependent variable may be measured as point data, interval data, left-censored data, or right-censored data. The dependent variable must be specified using two *depvars* that indicate how the dependent variable was measured. The user can request that a likelihood-ratio test comparing the panel interval regression model with the pooled model be conducted at estimation time.

## Quick start

Regression on *x* of an interval-measured dependent variable with lower endpoint *y\_lower* and upper endpoint *y\_upper* using `xtset` data

```
xtintreg y_lower y_upper x
```

Add *indicators* for levels of categorical variable *a* as covariates

```
xtintreg y_lower y_upper x i.a
```

Perform likelihood-ratio test against pooled model

```
xtintreg y_lower y_upper x i.a, intreg
```

## Menu

Statistics > Longitudinal/panel data > Censored outcomes > Interval regression (RE)

## Syntax

**xtintreg** *depvar*<sub>lower</sub> *depvar*<sub>upper</sub> [*indepvars*] [*if*] [*in*] [*weight*] [, *options*]

The values in *depvar*<sub>lower</sub> and *depvar*<sub>upper</sub> should have the following form:

Type of data		<i>depvar</i> <sub>lower</sub>	<i>depvar</i> <sub>upper</sub>
point data	$a = [a, a]$	$a$	$a$
interval data	$[a, b]$	$a$	$b$
left-censored data	$(-\infty, b]$	.	$b$
right-censored data	$[a, +\infty)$	$a$	.
missing		.	.

<i>options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> ( <i>constraints</i> )	apply specified linear constraints
<b>SE</b>	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be <u>oim</u> , <u>bootstrap</u> , or <u>jackknife</u>
<b>Reporting</b>	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>lrmodel</u>	perform the likelihood-ratio model test instead of the default Wald test
<u>intreg</u>	perform likelihood-ratio test against pooled model
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Integration</b>	
<u>intmethod</u> ( <i>intmethod</i> )	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is <u>intpoints</u> (12)
<b>Maximization</b>	
<u>maximize_options</u>	control the maximization process; see [R] <b>Maximize</b>
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

A panel variable must be specified; use **xtset**; see [XT] **xtset**.

*indepvars* may contain factor variables; see [U] 11.4.3 **Factor variables**.

*depvar*<sub>lower</sub>, *depvar*<sub>upper</sub>, and *indepvars* may contain time-series operators; see [U] 11.4.4 **Time-series varlists**.

*by* and *statsby* are allowed; see [U] 11.1.10 **Prefix commands**.

*iweights* are allowed; see [U] 11.1.6 **weight**. Weights must be constant within panel.

*collinear* and *coeflegend* do not appear in the dialog box.

See [U] 20 **Estimation and postestimation commands** for more capabilities of estimation commands.

## Options

### Model

`noconstant`, `offset(varname)`, `constraints(constraints)`; see [R] Estimation options.

### SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] vce\_options.

### Reporting

`level(#)`, `lrmodel`; see [R] Estimation options.

`intreg` specifies that a likelihood-ratio test comparing the random-effects model with the pooled (`intreg`) model be included in the output.

`nocnsreport`; see [R] Estimation options.

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] Estimation options.

### Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] Estimation options.

### Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] Maximize. These options are seldom used.

The following options are available with `xtintreg` but are not shown in the dialog box:  
`collinear`, `coeflegend`; see [R] Estimation options.

## Remarks and examples

`xtintreg` may be used to fit a random-effects interval regression model. Consider the linear regression model with panel-level random effects

$$y_{it} = \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it}$$

for  $i = 1, \dots, n$  panels, where  $t = 1, \dots, n_i$ . The random effects,  $\nu_i$ , are i.i.d.,  $N(0, \sigma_\nu^2)$ , and  $\epsilon_{it}$  are i.i.d.,  $N(0, \sigma_\epsilon^2)$  independently of  $\nu_i$ . The observed data consist of the couples,  $(y_{1it}, y_{2it})$ , such that all that is known is that  $y_{1it} \leq y_{it} \leq y_{2it}$ , where  $y_{1it}$  is possibly  $-\infty$  and  $y_{2it}$  is possibly  $+\infty$ .

### Example 1: Random-effects interval regression

We begin with the `nlswork` dataset described in [XT] xt and create two fictional dependent variables, where the wages are instead reported sometimes as ranges. The wages have been adjusted to 1988 dollars and have further been recoded such that some of the observations are known exactly, some are left-censored, some are right-censored, and some are known only in an interval.

We wish to fit a random-effects interval regression model of adjusted (log) wages. We specify the `intreg` option to test our random-effects model against our pooled estimator.

```
. use https://www.stata-press.com/data/r16/nlswork5
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xtintreg ln_wage1 ln_wage2 i.union age grade not_smsa south##c.year, intreg
(output omitted)

Random-effects interval regression
Number of obs      =    19,224
Uncensored          =     4,810
Left-censored       =     4,781
Right-censored      =     4,848
Interval-cens.     =     4,785

Group variable: idcode
Random effects u_i ~ Gaussian
Number of groups   =     4,148
Obs per group:
min =           1
avg =         4.6
max =        12

Integration method: mvaghermite
Integration pts.   =        12
Wald chi2(7)      =    2461.69
Prob > chi2       =    0.0000

Log likelihood = -23260.672
```

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
1.union	.1229681	.0092943	13.23	0.000	.1047516 .1411846
age	.0096333	.0019	5.07	0.000	.0059094 .0133572
grade	.0756045	.0023828	31.73	0.000	.0709343 .0802747
not_smsa	-.1481304	.011433	-12.96	0.000	-.1705387 -.1257221
1.south	-.3586443	.0977512	-3.67	0.000	-.5502331 -.1670555
year	.0029219	.0020353	1.44	0.151	-.0010671 .0069109
south#c.year					
1	.0032699	.0012076	2.71	0.007	.000903 .0056368
_cons	.2747391	.1141328	2.41	0.016	.0510429 .4984352
/sigma_u	.3044775	.0052644	57.84	0.000	.2941594 .3147956
/sigma_e	.3516248	.00307	114.54	0.000	.3456078 .3576418
rho	.4285095	.0101261			.4087613 .4484385

LR test of sigma\_u=0: chibar2(01) = 2683.77 Prob >= chibar2 = 0.000

The results from an interval regression can be interpreted as we would those from a linear regression. Because the dependent variable is log transformed, the coefficients can be interpreted in terms of a percentage change. We see, for example, that on average, union members make 12.3% more than nonunion members.

The output also includes the overall and panel-level variance components (labeled `sigma_e` and `sigma_u`, respectively) together with  $\rho$  (labeled `rho`),

$$\rho = \frac{\sigma_\nu^2}{\sigma_\epsilon^2 + \sigma_\nu^2}$$

which is the proportion of the total variance contributed by the panel-level variance component.

When `rho` is zero, the panel-level variance component is unimportant, and the panel estimator is not different from the pooled estimator. A likelihood-ratio test of this is included at the bottom of the output. This test formally compares the pooled estimator (interval regression) with the panel estimator. In this case, we reject the null hypothesis that there are no panel-level effects.



## □ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [XT] `quadchk` for details and [XT] `xtprobit` for an example.

Because the `xtintreg` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.



## Stored results

`xtintreg` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_unc)</code>	number of uncensored observations
<code>e(N_lc)</code>	number of left-censored observations
<code>e(N_rc)</code>	number of right-censored observations
<code>e(N_int)</code>	number of interval observations
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(l1_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	$\chi^2$
<code>e(chi2_c)</code>	$\chi^2$ for comparison test
<code>e(rho)</code>	$\rho$
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of $\epsilon_{it}$
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size

<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise
 Macros	
<code>e(cmd)</code>	<code>xtintreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	names of dependent variables
<code>e(ivar)</code>	variable denoting groups
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(offset)</code>	offset
<code>e(chi2type)</code>	Wald or LR; type of model $\chi^2$ test
<code>e(chi2_ct)</code>	Wald or LR; type of model $\chi^2$ test corresponding to <code>e(chi2_c)</code>
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	<code>max</code> or <code>min</code> ; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of <code>ml</code> method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>
 Matrices	
<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(iolog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimators
 Functions	
<code>e(sample)</code>	marks estimation sample

## Methods and formulas

Assuming a normal distribution,  $N(0, \sigma_\nu^2)$ , for the random effects  $\nu_i$ , we have the joint (unconditional of  $\nu_i$ ) density of the observed data for the *i*th panel

$$f\{(y_{1i1}, y_{2i1}), \dots, (y_{1ini}, y_{2ini}) | \mathbf{x}_{1i}, \dots, \mathbf{x}_{ini}\} = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{1it}, y_{2it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i$$

where

$$F(y_{1it}, y_{2it}, \Delta_{it}) = \begin{cases} (\sqrt{2\pi}\sigma_\epsilon)^{-1} e^{-(y_{1it}-\Delta_{it})^2/(2\sigma_\epsilon^2)} & \text{if } (y_{1it}, y_{2it}) \in C \\ \Phi\left(\frac{y_{2it}-\Delta_{it}}{\sigma_\epsilon}\right) & \text{if } (y_{1it}, y_{2it}) \in L \\ 1 - \Phi\left(\frac{y_{1it}-\Delta_{it}}{\sigma_\epsilon}\right) & \text{if } (y_{1it}, y_{2it}) \in R \\ \Phi\left(\frac{y_{2it}-\Delta_{it}}{\sigma_\epsilon}\right) - \Phi\left(\frac{y_{1it}-\Delta_{it}}{\sigma_\epsilon}\right) & \text{if } (y_{1it}, y_{2it}) \in I \end{cases}$$

where  $C$  is the set of noncensored observations ( $y_{1it} = y_{2it}$  and both nonmissing),  $L$  is the set of left-censored observations ( $y_{1it}$  missing and  $y_{2it}$  nonmissing),  $R$  is the set of right-censored observations ( $y_{1it}$  nonmissing and  $y_{2it}$  missing),  $I$  is the set of interval observations ( $y_{1it} < y_{2it}$  and both nonmissing), and  $\Phi()$  is the cumulative normal distribution.

The panel-level likelihood  $l_i$  is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{1it}, y_{2it}, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{1it}, y_{2it}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with  $M$ -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the  $w_m^*$  denote the quadrature weights and the  $a_m^*$  denote the quadrature abscissas. The log likelihood,  $L$ , is the sum of the logs of the panel-level likelihoods  $l_i$ .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{1it}, y_{2it}, x_{it}, \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)$$

where  $\hat{\sigma}_i$  and  $\hat{\mu}_i$  are the adaptive parameters for panel  $i$ . Therefore, using the definition of  $g(y_{1it}, y_{2it}, x_{it}, \nu_i)$ , the total log likelihood is approximated by

$$L \approx \sum_{i=1}^n w_i \log \left[ \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)^2/2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \right] \\ \prod_{t=1}^{n_i} F(y_{1it}, y_{2it}, x_{it}\beta + \sqrt{2\hat{\sigma}_i} a_m^* + \hat{\mu}_i) \quad (1)$$

where  $w_i$  is the user-specified weight for panel  $i$ ; if no weights are specified,  $w_i = 1$ .

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for  $\hat{\mu}_i$  and  $\hat{\sigma}_i$  by following the method of Naylor and Smith (1982), further discussed in Skrondal and Rabe-Hesketh (2004). We start with  $\hat{\sigma}_{i,0} = 1$  and  $\hat{\mu}_{i,0} = 0$ , and the posterior means and variances are updated in the  $k$ th iteration. That is, at the  $k$ th iteration of the optimization for  $l_i$  we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{1it}, y_{2it}, x_{it}, \sqrt{2\hat{\sigma}_{i,k-1}} a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2\hat{\sigma}_{i,k-1}} a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{1it}, y_{2it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{1it}, y_{2it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until  $\hat{\mu}_{i,k}$  and  $\hat{\sigma}_{i,k}$  have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of  $1e-6$ ; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature if the `intmethod(ghermite)` option is specified. For nonadaptive Gauss–Hermite quadrature, the following formula for the log likelihood is used in place of (1).

$$L = \sum_{i=1}^n w_i \log f\{(y_{1i1}, y_{2i1}), \dots, (y_{1in_i}, y_{2in_i}) | \mathbf{x}_{1i}, \dots, \mathbf{x}_{in_i}\} \\ \approx \sum_{i=1}^n w_i \log \left\{ \frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F(y_{1it}, y_{2it}, \mathbf{x}_{it}\beta + \sqrt{2\sigma_\nu} a_m^*) \right\}$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. Panel size can affect whether

$$\prod_{t=1}^{n_i} F(y_{1it}, y_{2it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

is well approximated by a polynomial. As panel size and  $\rho$  increase, the quadrature approximation can become less accurate. For large  $\rho$ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the **quadchk** command (see [XT] **quadchk**) to verify the quadrature approximation used in this command, whichever approximation you choose.

## References

- Naylor, J. C., and A. F. M. Smith. 1982. Applications of a method for the efficient computation of posterior distributions. *Journal of the Royal Statistical Society, Series C* 31: 214–225.
- Neuhaus, J. M. 1992. Statistical methods for longitudinal and clustered designs with binary responses. *Statistical Methods in Medical Research* 1: 249–273.
- Pendergast, J. F., S. J. Gange, M. A. Newton, M. J. Lindstrom, M. Palta, and M. R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. *International Statistical Review* 64: 89–118.
- Skrondal, A., and S. Rabe-Hesketh. 2004. *Generalized Latent Variable Modeling: Multilevel, Longitudinal, and Structural Equation Models*. Boca Raton, FL: Chapman & Hall/CRC.

## Also see

- [XT] **xtintreg postestimation** — Postestimation tools for xtintreg
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xteintreg** — Extended random-effects interval regression
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtset** — Declare data to be panel data
- [XT] **xttobit** — Random-effects tobit models
- [ME] **meintreg** — Multilevel mixed-effects interval regression
- [R] **intreg** — Interval regression
- [R] **tobit** — Tobit regression
- [ST] **stintreg** — Parametric models for interval-censored survival-time data
- [U] **20 Estimation and postestimation commands**

**xtintreg postestimation** — Postestimation tools for xtintreg

Postestimation commands  
Methods and formulas

[predict](#)  
[Also see](#)

[margins](#)

Remarks and examples

## Postestimation commands

The following postestimation commands are available after `xtintreg`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions, standard errors, probabilities, and expected values.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

`predict [type] newvar [if] [in] [, statistic nooffset]`

statistic	Description
<hr/>	
Main	
<code>xb</code>	linear prediction; the default
<code>stdp</code>	standard error of the linear prediction
<code>stdf</code>	standard error of the linear forecast
<code>pr(a,b)</code>	$\Pr(a < y < b)$ , marginal with respect to the random effect
<code>e(a,b)</code>	$E(y   a < y < b)$ , marginal with respect to the random effect
<code>ystar(a,b)</code>	$E(y^*)$ , $y^* = \max\{a, \min(y, b)\}$ , marginal with respect to the random effect

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

where  $a$  and  $b$  may be numbers or variables;  $a$  missing ( $a \geq .$ ) means  $-\infty$ , and  $b$  missing ( $b \geq .$ ) means  $+\infty$ ; see [\[U\] 12.2.1 Missing values](#).

### Options for predict

Main

`xb`, the default, calculates the linear prediction  $\mathbf{x}_{it}\beta$  using the estimated fixed effects (coefficients) in the model. This is equivalent to fixing all random effects in the model to their theoretical (prior) mean value of zero.

`stdp` calculates the standard error of the linear prediction. It can be thought of as the standard error of the predicted expected value or mean for the observation's covariate pattern. The standard error of the prediction is also referred to as the standard error of the fitted value.

`stdf` calculates the standard error of the linear forecast. This is the standard error of the point prediction for 1 observation. It is commonly referred to as the standard error of the future or forecast value. By construction, the standard errors produced by `stdf` are always larger than those produced by `stdp`; see *Methods and formulas* in [\[R\] regress](#).

`pr(a,b)` calculates estimates of  $\Pr(a < y < b | \mathbf{x} = \mathbf{x}_{it})$ , which is the probability that  $y$  would be observed in the interval  $(a, b)$ , given the current values of the predictors,  $\mathbf{x}_{it}$ . The predictions are calculated marginally with respect to the random effect. That is, the random effect is integrated out of the prediction function. In the discussion that follows, these two conditions are implied.

$a$  and  $b$  may be specified as numbers or variable names;  $lb$  and  $ub$  are variable names;

`pr(20,30)` calculates  $\Pr(20 < y < 30)$ ;

`pr(lb,ub)` calculates  $\Pr(lb < y < ub)$ ; and

`pr(20,ub)` calculates  $\Pr(20 < y < ub)$ .

$a$  missing ( $a \geq .$ ) means  $-\infty$ ; `pr(.,30)` calculates  $\Pr(-\infty < y < 30)$ ;

`pr(lb,30)` calculates  $\Pr(-\infty < y < 30)$  in observations for which  $lb \geq .$

(and calculates  $\Pr(lb < y < 30)$  elsewhere).

$b$  missing ( $b \geq .$ ) means  $+\infty$ ; `pr(20,.)` calculates  $\Pr(+\infty > y > 20)$ ;

`pr(20,ub)` calculates  $\Pr(+\infty > y > 20)$  in observations for which  $ub \geq .$

(and calculates  $\Pr(20 < y < ub)$  elsewhere).

`e(a,b)` calculates estimates of  $E(y | a < y < b, \mathbf{x} = \mathbf{x}_{it})$ , which is the expected value of  $y$  conditional on  $y$  being in the interval  $(a, b)$ , meaning that  $y$  is truncated.  $a$  and  $b$  are specified as they are for `pr()`. The predictions are calculated marginally with respect to the random effect. That is, the random effect is integrated out of the prediction function.

`ystar(a,b)` calculates estimates of  $E(y^* | \mathbf{x} = \mathbf{x}_{it})$ , where  $y^* = a$  if  $y \leq a$ ,  $y^* = b$  if  $y \geq b$ , and  $y^* = y$  otherwise, meaning that  $y^*$  is the censored version of  $y$ .  $a$  and  $b$  are specified as they are for `pr()`. The predictions are calculated marginally with respect to the random effect. That is, the random effect is integrated out of the prediction function.

`nooffset` is relevant only if you specified `offset(varname)` for `xtintreg`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\beta$  rather than  $\mathbf{x}_{it}\beta + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions, probabilities, and expected values.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

`margins [marginlist] [, options]`

`margins [marginlist], predict(statistic ...) [predict(statistic ...) ...] [options]`

<i>statistic</i>	Description
<code>xb</code>	linear prediction; the default
<code>pr(a,b)</code>	$\Pr(a < y < b)$ , marginal with respect to the random effect
<code>e(a,b)</code>	$E(y   a < y < b)$ , marginal with respect to the random effect
<code>ystar(a,b)</code>	$E(y^*)$ , $y^* = \max\{a, \min(y, b)\}$ , marginal with respect to the random effect
<code>stdp</code>	not allowed with <code>margins</code>
<code>stdf</code>	not allowed with <code>margins</code>

---

<code>xb</code>	linear prediction; the default
<code>pr(a,b)</code>	$\Pr(a < y < b)$ , marginal with respect to the random effect
<code>e(a,b)</code>	$E(y   a < y < b)$ , marginal with respect to the random effect
<code>ystar(a,b)</code>	$E(y^*)$ , $y^* = \max\{a, \min(y, b)\}$ , marginal with respect to the random effect
<code>stdp</code>	not allowed with <code>margins</code>
<code>stdf</code>	not allowed with <code>margins</code>

---

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

## Remarks and examples

### ▷ Example 1: Average marginal probabilities at specified covariate values

In example 1 of [\[XT\] xtintreg](#), we fit a random-effects model of wages. Say that we want to know how union membership status affects the probability that a worker's wage will be "low", where low means a log wage that is less than the 20th percentile of all observations in our dataset. First, we use `centile` to find the 20th percentile of `ln_wage`:

```
. use https://www.stata-press.com/data/r16/nlswork5
(National Longitudinal Survey. Young Women 14–26 years of age in 1968)
. xtintreg ln_wage1 ln_wage2 i.union age grade not_smsa south##c.year, intreg
(output omitted)
. centile ln_wage, centile(20)
```

Variable	Obs	Percentile	Centile	— Binom. Interp. —	
				[95% Conf. Interval]	
ln_wage	28,534	20	1.301507	1.297063	1.308635

Now we use `margins` to obtain the effect of union status on the probability that the log of wages is in the bottom 20% of women. Given the results from `centile` that corresponds to the log of wages being below 1.30. We evaluate the effect for two groups: 1) women age 30 living in the south in 1988 who graduated high school, but had no more schooling, and 2) the same group of women, but who are instead college graduates (`grade=16`).

. margins, dydx(union) predict(pr(.,1.30))								
> at(age=30 south=1 year=88 grade=12 union=0)								
> at(age=30 south=1 year=88 grade=16 union=0)								
Average marginal effects	Number of obs = 19,224							
Model VCE : OIM								
Expression : Pr(ln_wage1<1.30), predict(pr(.,1.30))								
dy/dx w.r.t. : 1.union								
1._at : union = 0								
age = 30								
grade = 12								
south = 1								
year = 88								
2._at : union = 0								
age = 30								
grade = 16								
south = 1								
year = 88								
<hr/>								
	Delta-method							
	dy/dx	Std. Err.	z	P> z	[95% Conf. Interval]			
0.union	(base outcome)							
1.union								
_at								
1	-.0755536	.0058942	-12.82	0.000	-.0871059	-.0640012		
2	-.0368238	.0034632	-10.63	0.000	-.0436114	-.0300361		

Note: dy/dx for factor levels is the discrete change from the base level.

For the first group of women, according to our fitted model, being in a union lowers the probability of being classified as a low-wage worker by almost 7.6 percentage points. Being a college graduate attenuates this effect to just under 3.7 percentage points.



## Methods and formulas

Methods and formulas for calculating the available predictions are given in [Methods and formulas of \[XT\] xtbit postestimation](#).

## Also see

[\[XT\] xtintreg](#) — Random-effects interval-data regression models

[\[U\] 20 Estimation and postestimation commands](#)

**xtivreg** — Instrumental variables and two-stage least squares for panel-data models

Description	Quick start	Menu
Syntax	Options for RE model	Options for BE model
Options for FE model	Options for FD model	Remarks and examples
Stored results	Methods and formulas	Acknowledgment
References	Also see	

## Description

`xtivreg` offers five different estimators for fitting panel-data models in which some of the right-hand-side covariates are endogenous. These estimators are two-stage least-squares generalizations of simple panel-data estimators for exogenous variables. `xtivreg` with the `be` option uses the two-stage least-squares between estimator. `xtivreg` with the `fe` option uses the two-stage least-squares within estimator. `xtivreg` with the `re` option uses a two-stage least-squares random-effects estimator. There are two implementations: G2SLS from [Balestra and Varadharajan-Krishnakumar \(1987\)](#) and EC2SLS from Baltagi. The Balestra and Varadharajan-Krishnakumar G2SLS is the default because it is computationally less expensive. Baltagi's EC2SLS can be obtained by specifying the `ec2sls` option. `xtivreg` with the `fd` option requests the two-stage least-squares first-differenced estimator.

See [Baltagi \(2013\)](#) for an introduction to panel-data models with endogenous covariates. For the derivation and application of the first-differenced estimator, see [Anderson and Hsiao \(1981\)](#).

## Quick start

Random-effects linear panel-data model with outcome `y`, exogenous `x1`, and `x2` instrumented by `x3` using `xtset` data

```
xtivreg y x1 (x2 = x3)
```

Use fixed-effects estimator and include `indicators` for each level of categorical variable `a`

```
xtivreg y x1 i.a (x2 = x3), fe
```

Use between-effects estimator and include `indicators` for levels of `b` as instruments

```
xtivreg y x1 i.a (x2 = x3 i.b), be
```

First-differenced model of `y` as a function of `x1` and `x2` and the lag of `y` instrumented by its third lag

```
xtivreg y x1 x2 (L.y = L3.y), fd
```

## Menu

Statistics > Longitudinal/panel data > Endogenous covariates > Instrumental-variables regression (FE, RE, BE, FD)

## Syntax

*GLS random-effects (RE) model*

```
xtivreg depvar [varlist1] (varlist2 = varlistiv) [if] [in] [, re RE_options]
```

*Between-effects (BE) model*

```
xtivreg depvar [varlist1] (varlist2 = varlistiv) [if] [in], be BE_options
```

*Fixed-effects (FE) model*

```
xtivreg depvar [varlist1] (varlist2 = varlistiv) [if] [in], fe FE_options
```

*First-differenced (FD) estimator*

```
xtivreg depvar [varlist1] (varlist2 = varlistiv) [if] [in], fd FD_options
```

<i>RE_options</i>	Description
<hr/>	
Model	
<u>re</u>	use random-effects estimator; the default
<u>ec2sls</u>	use Baltagi's EC2SLS random-effects estimator
<u>nosa</u>	use the Baltagi–Chang estimators of the variance components
<u>regress</u>	treat covariates as exogenous and ignore instrumental variables
SE/Robust	
<u>vce(vcetype)</u>	<i>vcetype</i> may be conventional, <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level(#)</u>	set confidence level; default is <code>level(95)</code>
<u>first</u>	report first-stage estimates
<u>small</u>	report <i>t</i> and <i>F</i> statistics instead of <i>Z</i> and $\chi^2$ statistics
<u>theta</u>	report $\theta$
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<u>coeflegend</u>	display legend instead of statistics

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<i>BE_options</i>	Description
<hr/>	
Model	
<b>be</b>	use between-effects estimator
<b>regress</b>	treat covariates as exogenous and ignore instrumental variables
<hr/>	
SE/Robust	
<b>vce(vcetype)</b>	<i>vcetype</i> may be conventional, robust, cluster <i>clustvar</i> , bootstrap, or jackknife
<hr/>	
Reporting	
<b>level(#)</b>	set confidence level; default is <code>level(95)</code>
<b>first</b>	report first-stage estimates
<b>small</b>	report <i>t</i> and <i>F</i> statistics instead of <i>Z</i> and $\chi^2$ statistics
<i>display_options</i>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>coeflegend</b>	display legend instead of statistics
<hr/>	
<i>FE_options</i>	Description
<hr/>	
Model	
<b>fe</b>	use fixed-effects estimator
<b>regress</b>	treat covariates as exogenous and ignore instrumental variables
<hr/>	
SE/Robust	
<b>vce(vcetype)</b>	<i>vcetype</i> may be conventional, robust, cluster <i>clustvar</i> , bootstrap, or jackknife
<hr/>	
Reporting	
<b>level(#)</b>	set confidence level; default is <code>level(95)</code>
<b>first</b>	report first-stage estimates
<b>small</b>	report <i>t</i> and <i>F</i> statistics instead of <i>Z</i> and $\chi^2$ statistics
<i>display_options</i>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>coeflegend</b>	display legend instead of statistics

<i>FD_options</i>	Description
<hr/>	
Model	
<u>noconstant</u>	suppress constant term
<u>fd</u>	use first-differenced estimator
<u>regress</u>	treat covariates as exogenous and ignore instrumental variables
SE/Robust	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be conventional, robust, cluster <i>clustvar</i> , bootstrap, or jackknife
Reporting	
<u>level</u> (#)	set confidence level; default is level(95)
<u>first</u>	report first-stage estimates
<u>small</u>	report <i>t</i> and <i>F</i> statistics instead of <i>Z</i> and $\chi^2$ statistics
<i>display_options</i>	control columns and column formats, row spacing, line width, and display of omitted variables
<u>coeflegend</u>	display legend instead of statistics

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A panel variable must be specified. For *xtivreg*, *fd*, a time variable must also be specified. Use *xtset*; see [XT] *xtset*.

*varlist*<sub>1</sub> and *varlist*<sub>iv</sub> may contain factor variables, except for the *fd* estimator; see [U] 11.4.3 Factor variables. *depvar*, *varlist*<sub>1</sub>, *varlist*<sub>2</sub>, and *varlist*<sub>iv</sub> may contain time-series operators; see [U] 11.4.4 Time-series varlists. *by* and *statsby* are allowed; see [U] 11.1.10 Prefix commands.

*coeflegend* does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options for RE model

### Model

*re* requests the G2SLS random-effects estimator. *re* is the default.

*ec2sls* requests Baltagi's EC2SLS random-effects estimator instead of the default Balestra and Varadharajan-Krishnakumar estimator.

*nosa* specifies that the Baltagi–Chang estimators of the variance components be used instead of the default adapted Swamy–Arora estimators.

*regress* specifies that all the covariates be treated as exogenous and that the instrument list be ignored. Specifying *regress* causes *xtivreg* to fit the requested panel-data regression model of *depvar* on *varlist*<sub>1</sub> and *varlist*<sub>2</sub>, ignoring *varlist*<sub>iv</sub>.

### SE/Robust

*vce*(*vcetype*) specifies the type of standard error reported, which includes types that are derived from asymptotic theory (conventional), that are robust to some kinds of misspecification (robust), that allow for intragroup correlation (cluster *clustvar*), and that use bootstrap or jackknife methods (bootstrap, jackknife); see [XT] *vce\_options*.

*vce*(conventional), the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtreg](#), `re` in *Methods and formulas* of [\[XT\] xtreg](#).

#### Reporting

`level(#)`; see [\[R\] Estimation options](#).

`first` specifies that the first-stage regressions be displayed.

`small` specifies that  $t$  statistics be reported instead of  $Z$  statistics and that  $F$  statistics be reported instead of  $\chi^2$  statistics.

`theta` specifies that the output include the estimated value of  $\theta$  used in combining the between and fixed estimators. For balanced data, this is a constant, and for unbalanced data, a summary of the values is presented in the header of the output.

`display_options`: `noci`, `nocpvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [\[R\] Estimation options](#).

The following option is available with `xtivreg` but is not shown in the dialog box:

`coeflegend`; see [\[R\] Estimation options](#).

## Options for BE model

#### Model

`be` requests the between regression estimator.

`regress` specifies that all the covariates be treated as exogenous and that the instrument list be ignored. Specifying `regress` causes `xtivreg` to fit the requested panel-data regression model of `depvar` on `varlist1` and `varlist2`, ignoring `varlistiv`.

#### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [\[XT\] vce\\_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtreg](#), `fe` in *Methods and formulas* of [\[XT\] xtreg](#).

#### Reporting

`level(#)`; see [\[R\] Estimation options](#).

`first` specifies that the first-stage regressions be displayed.

`small` specifies that  $t$  statistics be reported instead of  $Z$  statistics and that  $F$  statistics be reported instead of  $\chi^2$  statistics.

`display_options`: `noci`, `nocpvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [\[R\] Estimation options](#).

The following option is available with `xtivreg` but is not shown in the dialog box:  
`coeflegend`; see [R] Estimation options.

## Options for FE model

### Model

`fe` requests the fixed-effects (within) regression estimator.

`regress` specifies that all the covariates be treated as exogenous and that the instrument list be ignored. Specifying `regress` causes `xtivreg` to fit the requested panel-data regression model of `depvar` on `varlist1` and `varlist2`, ignoring `varlistiv`.

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (conventional), that are robust to some kinds of misspecification (robust), that allow for intragroup correlation (cluster `clustvar`), and that use bootstrap or jackknife methods (bootstrap, jackknife); see [XT] vce\_options.

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see xtreg, fe in Methods and formulas of [XT] xtreg.

### Reporting

`level(#)`; see [R] Estimation options.

`first` specifies that the first-stage regressions be displayed.

`small` specifies that  $t$  statistics be reported instead of  $Z$  statistics and that  $F$  statistics be reported instead of  $\chi^2$  statistics.

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fvrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] Estimation options.

The following option is available with `xtivreg` but is not shown in the dialog box:  
`coeflegend`; see [R] Estimation options.

## Options for FD model

### Model

`noconstant`; see [R] Estimation options.

`fd` requests the first-differenced regression estimator.

`regress` specifies that all the covariates be treated as exogenous and that the instrument list be ignored. Specifying `regress` causes `xtivreg` to fit the requested panel-data regression model of `depvar` on `varlist1` and `varlist2`, ignoring `varlistiv`.

## SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] `vce_options`.

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see `xtreg, fe` in *Methods and formulas* of [XT] `xtreg`.

## Reporting

`level(#)`; see [R] `Estimation options`.

`first` specifies that the first-stage regressions be displayed.

`small` specifies that  $t$  statistics be reported instead of  $Z$  statistics and that  $F$  statistics be reported instead of  $\chi^2$  statistics.

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] `Estimation options`.

The following option is available with `xtivreg` but is not shown in the dialog box:

`coeflegend`; see [R] `Estimation options`.

## Remarks and examples

If you have not read [XT] `xt`, please do so.

Consider an equation of the form

$$y_{it} = \mathbf{Y}_{it}\boldsymbol{\gamma} + \mathbf{X}_{1it}\boldsymbol{\beta} + \mu_i + \nu_{it} = \mathbf{Z}_{it}\boldsymbol{\delta} + \mu_i + \nu_{it} \quad (1)$$

where

$y_{it}$  is the dependent variable;

$\mathbf{Y}_{it}$  is an  $1 \times g_2$  vector of observations on  $g_2$  endogenous variables included as covariates, and these variables are allowed to be correlated with the  $\nu_{it}$ ;

$\mathbf{X}_{1it}$  is an  $1 \times k_1$  vector of observations on the exogenous variables included as covariates;

$\mathbf{Z}_{it} = [\mathbf{Y}_{it} \ \mathbf{X}_{it}]$ ;

$\boldsymbol{\gamma}$  is a  $g_2 \times 1$  vector of coefficients;

$\boldsymbol{\beta}$  is a  $k_1 \times 1$  vector of coefficients; and

$\boldsymbol{\delta}$  is a  $K \times 1$  vector of coefficients, where  $K = g_2 + k_1$ .

Assume that there is a  $1 \times k_2$  vector of observations on the  $k_2$  instruments in  $\mathbf{X}_{2it}$ . The order condition is satisfied if  $k_2 \geq g_2$ . Let  $\mathbf{X}_{it} = [\mathbf{X}_{1it} \ \mathbf{X}_{2it}]$ . `xtivreg` handles exogenously unbalanced panel data. Thus define  $T_i$  to be the number of observations on panel  $i$ ,  $n$  to be the number of panels and  $N$  to be the total number of observations; that is,  $N = \sum_{i=1}^n T_i$ .

`xtivreg` offers five different estimators, which may be applied to models having the form of (1). The first-differenced estimator (FD2SLS) removes the  $\mu_i$  by fitting the model in first differences. The within estimator (FE2SLS) fits the model after sweeping out the  $\mu_i$  by removing the panel-level means from each variable. The between estimator (BE2SLS) models the panel averages. The two random-effects estimators, G2SLS and EC2SLS, treat the  $\mu_i$  as random variables that are independent and identically distributed (i.i.d.) over the panels. Except for (FD2SLS), all of these estimators are generalizations of estimators in `xtreg`. See [XT] `xtreg` for a discussion of these estimators for exogenous covariates.

Although the estimators allow for different assumptions about the  $\mu_i$ , all the estimators assume that the idiosyncratic error term  $\nu_{it}$  has zero mean and is uncorrelated with the variables in  $\mathbf{X}_{it}$ . Just as when there are no endogenous covariates, as discussed in [XT] `xtreg`, there are various perspectives on what assumptions should be placed on the  $\mu_i$ . If they are assumed to be fixed, the  $\mu_i$  may be correlated with the variables in  $\mathbf{X}_{it}$ , and the within estimator is efficient within a class of limited information estimators. Alternatively, if the  $\mu_i$  are assumed to be random, they are also assumed to be i.i.d. over the panels. If the  $\mu_i$  are assumed to be uncorrelated with the variables in  $\mathbf{X}_{it}$ , the GLS random-effects estimators are more efficient than the within estimator. However, if the  $\mu_i$  are correlated with the variables in  $\mathbf{X}_{it}$ , the random-effects estimators are inconsistent but the within estimator is consistent. The price of using the within estimator is that it is not possible to estimate coefficients on time-invariant variables, and all inference is conditional on the  $\mu_i$  in the sample. See Mundlak (1978) and Hsiao (2014) for discussions of this interpretation of the within estimator.

## ▷ Example 1: Fixed-effects model

For the within estimator, consider another version of the wage equation discussed in [XT] `xtreg`. The data for this example come from an extract of women from the National Longitudinal Survey of Youth that was described in detail in [XT] `xt`. Restricting ourselves to only time-varying covariates, we might suppose that the log of the real wage was a function of the individual's age,  $\text{age}^2$ , her tenure in the observed place of employment, whether she belonged to union, whether she lives in metropolitan area, and whether she lives in the south. The variables for these are, respectively, `age`, `c.age#c.age`, `tenure`, `union`, `not_smsa`, and `south`. If we treat all the variables as exogenous, we can use the one-stage within estimator from `xtreg`, yielding

```
. use https://www.stata-press.com/data/r16/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xtreg ln_w age c.age#c.age tenure not_smsa union south, fe
Fixed-effects (within) regression                               Number of obs     =    19,007
Group variable: idcode                                      Number of groups  =      4,134
R-sq:                                         Obs per group:
    within  = 0.1333                                         min =          1
    between = 0.2375                                         avg =        4.6
    overall = 0.2031                                         max =       12
                                                F(6,14867)      =   381.19
corr(u_i, Xb)  = 0.2074                                         Prob > F      = 0.0000
```

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
age	.0311984	.0033902	9.20	0.000	.0245533 .0378436
c.age#c.age	-.0003457	.0000543	-6.37	0.000	-.0004522 -.0002393
tenure	.0176205	.0008099	21.76	0.000	.0160331 .0192079
not_smsa	-.0972535	.0125377	-7.76	0.000	-.1218289 -.072678
union	.0975672	.0069844	13.97	0.000	.0838769 .1112576
south	-.0620932	.013327	-4.66	0.000	-.0882158 -.0359706
_cons	1.091612	.0523126	20.87	0.000	.9890729 1.194151
sigma_u	.3910683				
sigma_e	.25545969				
rho	.70091004				(fraction of variance due to u_i)

F test that all u\_i=0: F(4133, 14867) = 8.31

Prob > F = 0.0000

All the coefficients are statistically significant and have the expected signs.

Now suppose that we wish to model tenure as a function of union and south and that we believe that the errors in the two equations are correlated. Because we are still interested in the within estimates, we now need a two-stage least-squares estimator. The following output shows the command and the results from fitting this model:

. xtivreg ln_w age c.age#c.age not_smsa (tenure = union south), fe	Number of obs = 19,007					
Fixed-effects (within) IV regression	Number of groups = 4,134					
Group variable: idcode	Obs per group:					
R-sq:	min = 1					
within = .	avg = 4.6					
between = 0.1304	max = 12					
overall = 0.0897						
	Wald chi2(4) = 147926.58					
corr(u_i, Xb) = -0.6843	Prob > chi2 = 0.0000					
ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
tenure	.2403531	.0373419	6.44	0.000	.1671643	.3135419
age	.0118437	.0090032	1.32	0.188	-.0058023	.0294897
c.age#c.age	-.0012145	.0001968	-6.17	0.000	-.0016003	-.0008286
not_smsa	-.0167178	.0339236	-0.49	0.622	-.0832069	.0497713
_cons	1.678287	.1626657	10.32	0.000	1.359468	1.997106
sigma_u	.70661941					
sigma_e	.63029359					
rho	.55690561				(fraction of variance due to u_i)	
F test that all u_i=0:	F(4133,14869) = 1.44				Prob > F = 0.0000	
Instrumented:	tenure					
Instruments:	age c.age#c.age not_smsa union south					

Although all the coefficients still have the expected signs, the coefficients on `age` and `not_smsa` are no longer statistically significant. Given that these variables have been found to be important in many other studies, we might want to rethink our specification. ◁

If we are willing to assume that the  $\mu_i$  are uncorrelated with the other covariates, we can fit a random-effects model. The model is frequently known as the variance-components or error-components model. `xtivreg` has estimators for two-stage least-squares one-way error-components models. In the one-way framework, there are two variance components to estimate, the variance of the  $\mu_i$  and the variance of the  $\nu_{it}$ . Because the variance components are unknown, consistent estimates are required to implement feasible GLS. `xtivreg` offers two choices: a Swamy–Arora method and simple consistent estimators from Baltagi and Chang (2000).

Baltagi and Chang (1994) derived the Swamy–Arora estimators of the variance components for unbalanced panels. By default, `xtivreg` uses estimators that extend these unbalanced Swamy–Arora estimators to the case with instrumental variables. The default Swamy–Arora method contains a degree-of-freedom correction to improve its performance in small samples. Baltagi and Chang (2000) use variance-components estimators, which are based on the ideas of Amemiya (1971) and Swamy and Arora (1972), but they do not attempt to make small-sample adjustments. These consistent estimators of the variance components will be used if the `nosa` option is specified.

Using either estimator of the variance components, `xtivreg` offers two GLS estimators of the random-effects model. These two estimators differ only in how they construct the GLS instruments from the exogenous and instrumental variables contained in  $\mathbf{X}_{it} = [\mathbf{X}_{1it} \mathbf{X}_{2it}]$ . The default method, G2SLS, which is from Balestra and Varadharajan-Krishnakumar, uses the exogenous variables after they have been passed through the feasible GLS transform. In math, G2SLS uses  $\mathbf{X}_{it}^*$  for the GLS instruments, where  $\mathbf{X}_{it}^*$  is constructed by passing each variable in  $\mathbf{X}_{it}$  through the GLS transform in

(3) given in *Methods and formulas*. If the `ec2sls` option is specified, `xtivreg` performs Baltagi's EC2SLS. In EC2SLS, the instruments are  $\tilde{\mathbf{X}}_{it}$  and  $\bar{\mathbf{X}}_{it}$ , where  $\tilde{\mathbf{X}}_{it}$  is constructed by passing each of the variables in  $\mathbf{X}_{it}$  through the within transform, and  $\bar{\mathbf{X}}_{it}$  is constructed by passing each variable through the between transform. The within and between transforms are given in the *Methods and formulas* section. Baltagi and Li (1992) show that, although the G2SLS instruments are a subset of those contained in EC2SLS, the extra instruments in EC2SLS are redundant in the sense of White (2001). Given the extra computational cost, G2SLS is the default.

## ▷ Example 2: GLS random-effects model

Here is the output from applying the G2SLS estimator to this model:

<pre>. xtivreg ln_w age c.age#c.age not_smsa 2.race (tenure = union birth south), re</pre>								
G2SLS random-effects IV regression						Number of obs = 19,007		
Group variable: idcode						Number of groups = 4,134		
R-sq:						Obs per group:		
						min = 1		
						avg = 4.6		
						max = 12		
						Wald chi2(5) = 1446.37		
corr(u_i, X) = 0 (assumed)						Prob > chi2 = 0.0000		
<hr/>								
ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]			
tenure	.1391798	.0078756	17.67	0.000	.123744	.1546157		
age	.0279649	.0054182	5.16	0.000	.0173454	.0385843		
c.age#c.age	-.0008357	.0000871	-9.60	0.000	-.0010063	-.000665		
not_smsa	-.2235103	.0111371	-20.07	0.000	-.2453386	-.2016821		
race								
black	-.2078613	.0125803	-16.52	0.000	-.2325183	-.1832044		
_cons	1.337684	.0844988	15.83	0.000	1.172069	1.503299		
sigma_u	.36582493							
sigma_e	.63031479							
rho	.25197078				(fraction of variance due to u_i)			
<hr/>								
Instrumented:	tenure							
Instruments:	age c.age#c.age not_smsa 2.race union birth_yr south							
<hr/>								

We have included two time-invariant covariates, `birth_yr` and `2.race`. All the coefficients are statistically significant and are of the expected sign.

Applying the EC2SLS estimator yields similar results:

. xtivreg ln_w age c.age#c.age not_smsa 2.race (tenure = union birth south), re > ec2sls	
EC2SLS random-effects IV regression	Number of obs = 19,007
Group variable: idcode	Number of groups = 4,134
R-sq:	Obs per group:
within = 0.0898	min = 1
between = 0.2608	avg = 4.6
overall = 0.1926	max = 12
	Wald chi2(5) = 2721.92
corr(u_i, X) = 0 (assumed)	Prob > chi2 = 0.0000
<hr/>	
ln_wage	Coef. Std. Err. z P> z  [95% Conf. Interval]
tenure	.064822 .0025647 25.27 0.000 .0597953 .0698486
age	.0380048 .0039549 9.61 0.000 .0302534 .0457562
c.age#c.age	-.0006676 .0000632 -10.56 0.000 -.0007915 -.0005438
not_smsa	-.2298961 .0082993 -27.70 0.000 -.2461625 -.2136297
race	
black	-.1823627 .0092005 -19.82 0.000 -.2003954 -.16433
_cons	1.110564 .0606538 18.31 0.000 .9916849 1.229443
sigma_u	.36582493
sigma_e	.63031479
rho	.25197078 (fraction of variance due to u_i)
<hr/>	
Instrumented:	tenure
Instruments:	age c.age#c.age not_smsa 2.race union birth_yr south

Fitting the same model as above with the G2SLS estimator and the consistent variance components estimators yields

. xtivreg ln_w age c.age#c.age not_smsa 2.race (tenure = union birth south), > re nosa					
G2SLS random-effects IV regression	Number of obs = 19,007				
Group variable: idcode	Number of groups = 4,134				
R-sq:	Obs per group:				
within = 0.0664	min = 1				
between = 0.2098	avg = 4.6				
overall = 0.1463	max = 12				
	Wald chi2(5) = 1446.93				
corr(u_i, X) = 0 (assumed)	Prob > chi2 = 0.0000				
ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
tenure	.1391859	.007873	17.68	0.000	.1237552 .1546166
age	.0279697	.005419	5.16	0.000	.0173486 .0385909
c.age#c.age	-.0008357	.0000871	-9.60	0.000	-.0010064 -.000665
not_smsa	-.2235738	.0111344	-20.08	0.000	-.2453967 -.2017508
race					
black	-.2078733	.0125751	-16.53	0.000	-.2325201 -.1832265
_cons	1.337522	.0845083	15.83	0.000	1.171889 1.503155
sigma_u	.36535633				
sigma_e	.63020883				
rho	.2515512	(fraction of variance due to u_i)			
Instrumented:	tenure				
Instruments:	age c.age#c.age not_smsa 2.race union birth_yr south				



## ▷ Example 3: First-differenced estimator

The two-stage least-squares first-differenced estimator (FD2SLS) has been used to fit both fixed-effect and random-effect models. If the  $\mu_i$  are truly fixed-effects, the FD2SLS estimator is not as efficient as the two-stage least-squares within estimator for finite  $T_i$ . Similarly, if none of the endogenous variables are lagged dependent variables, the exogenous variables are all strictly exogenous, and the random effects are i.i.d. and independent of the  $\mathbf{X}_{it}$ , the two-stage GLS estimators are more efficient than the FD2SLS estimator. However, the FD2SLS estimator has been used to obtain consistent estimates when one of these conditions fails. [Anderson and Hsiao \(1981\)](#) used a version of the FD2SLS estimator to fit a panel-data model with a lagged dependent variable.

[Arellano and Bond \(1991\)](#) develop new one-step and two-step GMM estimators for dynamic panel data. See [\[XT\] xtabond](#) for a discussion of these estimators and Stata's implementation of them. In their article, [Arellano and Bond \(1991\)](#) apply their new estimators to a model of dynamic labor demand that had previously been considered by [Layard and Nickell \(1986\)](#). They also compare the results of their estimators with those from the Anderson–Hsiao estimator using data from an unbalanced panel of firms from the United Kingdom. As is conventional, all variables are indexed over the firm  $i$  and time  $t$ . In this dataset,  $n_{it}$  is the log of employment in firm  $i$  inside the United Kingdom at time  $t$ ,  $w_{it}$  is the natural log of the real product wage,  $k_{it}$  is the natural log of the gross capital stock, and  $y_{s,it}$  is the natural log of industry output. The model also includes time dummies  $yr1980$ ,  $yr1981$ ,  $yr1982$ ,  $yr1983$ , and  $yr1984$ . In [Arellano and Bond \(1991, table 5, column e\)](#), the authors present the results from applying one version of the Anderson–Hsiao estimator to these data. This example reproduces

their results for the coefficients, though standard errors are slightly different because Arellano and Bond are using robust standard errors from GMM while we obtain our robust standard errors from 2SLS.

```
. use https://www.stata-press.com/data/r16/abdata
. xtivreg n l2.n l(0/1).w l(0/2).(k ys) yr1981-yr1984 (l.n = 13.n), fd vce(robust)

First-differenced IV regression
Group variable: id Number of obs = 471
Time variable: year Number of groups = 140
R-sq: Obs per group:
      within = 0.0141 min = 3
      between = 0.9165 avg = 3.4
      overall = 0.9892 max = 5
corr(u_i, Xb) = 0.9239 Wald chi2(14) = 259.49
                                         Prob > chi2 = 0.0000
                                         (Std. Err. adjusted for 140 clusters in id)
```

D.n	Robust					
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
n	1.422765	1.019992	1.39	0.163	-.5763824	3.421913
	-.1645517	.1300598	-1.27	0.206	-.4194643	.0903609
w	-.7524675	.2341305	-3.21	0.001	-1.211355	-.29358
	.9627611	.7828358	1.23	0.219	-.5715688	2.497091
k	.3221686	.1066645	3.02	0.003	.1131099	.5312273
	-.3248778	.3933448	-0.83	0.409	-1.095819	.4460637
	-.0953947	.1257672	-0.76	0.448	-.3418938	.1511045
ys	.7660906	.3172664	2.41	0.016	.14426	1.387921
	-1.361881	.8980497	-1.52	0.129	-3.122026	.3982639
	.3212993	.4234835	0.76	0.448	-.508713	1.151312
yr1981						
D1.	-.0574197	.0323419	-1.78	0.076	-.1208088	.0059693
yr1982						
D1.	-.0882952	.0580339	-1.52	0.128	-.2020395	.0254491
yr1983						
D1.	-.1063153	.0934136	-1.14	0.255	-.2894026	.0767719
yr1984						
D1.	-.1172108	.1150944	-1.02	0.308	-.3427917	.1083701
_cons	.0161204	.025376	0.64	0.525	-.0336155	.0658564
sigma_u	.29069213					
sigma_e	.34152632					
rho	.42011045	(fraction of variance due to u_i)				

Instrumented: L.n  
 Instruments: L2.n w L.w k L.k L2.k ys L.y s L2.y s yr1981 yr1982 yr1983  
 yr1984 L3.n



## Stored results

**xtivreg, re** stores the following in **e()**:

### Scalars

<b>e(N)</b>	number of observations
<b>e(N_g)</b>	number of groups
<b>e(df_m)</b>	model degrees of freedom
<b>e(df_rz)</b>	residual degrees of freedom
<b>e(g_min)</b>	smallest group size
<b>e(g_avg)</b>	average group size
<b>e(g_max)</b>	largest group size
<b>e(Tcon)</b>	1 if panels balanced, 0 otherwise
<b>e(N_clust)</b>	number of clusters
<b>e(sigma)</b>	ancillary parameter ( <code>gamma</code> , <code>lnormal</code> )
<b>e(sigma_u)</b>	panel-level standard deviation
<b>e(sigma_e)</b>	standard deviation of $\epsilon_{it}$
<b>e(r2_w)</b>	$R^2$ -squared for within model
<b>e(r2_o)</b>	$R^2$ -squared for overall model
<b>e(r2_b)</b>	$R^2$ -squared for between model
<b>e(chi2)</b>	$\chi^2$
<b>e(rho)</b>	$\rho$
<b>e(F)</b>	model $F$ (small only)
<b>e(m_p)</b>	$p$ -value from model test
<b>e(thta_min)</b>	minimum $\theta$
<b>e(thta_5)</b>	$\theta$ , 5th percentile
<b>e(thta_50)</b>	$\theta$ , 50th percentile
<b>e(thta_95)</b>	$\theta$ , 95th percentile
<b>e(thta_max)</b>	maximum $\theta$
<b>e(rank)</b>	rank of <b>e(V)</b>

### Macros

<b>e(cmd)</b>	<b>xtivreg</b>
<b>e(cmdline)</b>	command as typed
<b>e(depyvar)</b>	name of dependent variable
<b>e(ivvar)</b>	variable denoting groups
<b>e(tvar)</b>	variable denoting time within groups
<b>e(insts)</b>	instruments
<b>e(instd)</b>	instrumented variables
<b>e(model)</b>	<code>g2s1s</code> or <code>ec2s1s</code>
<b>e(small)</b>	small, if specified
<b>e(clustvar)</b>	name of cluster variable
<b>e(chi2type)</b>	Wald; type of model $\chi^2$ test
<b>e(vce)</b>	<code>vcetype</code> specified in <code>vce()</code>
<b>e(vcetype)</b>	title used to label Std. Err.
<b>e(properties)</b>	b V
<b>e(predict)</b>	program used to implement predict
<b>e(marginsok)</b>	predictions allowed by <code>margins</code>
<b>e(marginsnotok)</b>	predictions disallowed by <code>margins</code>
<b>e(asbalanced)</b>	factor variables <code>fvset</code> as <code>asbalanced</code>
<b>e(asobserved)</b>	factor variables <code>fvset</code> as <code>asobserved</code>

### Matrices

<b>e(b)</b>	coefficient vector
<b>e(V)</b>	variance–covariance matrix of the estimators
<b>e(V_modelbased)</b>	model-based variance

### Functions

<b>e(sample)</b>	marks estimation sample
------------------	-------------------------

`xtivreg, be` stores the following in `e()`:

#### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(mss)</code>	model sum of squares
<code>e(df_m)</code>	model degrees of freedom
<code>e(rss)</code>	residual sum of squares
<code>e(df_r)</code>	residual degrees of freedom
<code>e(df_rz)</code>	residual degrees of freedom for the between-transformed regression
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rs_a)</code>	adjusted $R^2$
<code>e(r2_w)</code>	$R$ -squared for within model
<code>e(r2_o)</code>	$R$ -squared for overall model
<code>e(r2_b)</code>	$R$ -squared for between model
<code>e(N_clust)</code>	number of clusters
<code>e(chi2)</code>	model Wald
<code>e(chi2_p)</code>	$p$ -value for model $\chi^2$ test
<code>e(F)</code>	$F$ statistic (small only)
<code>e(rmse)</code>	root mean squared error
<code>e(rank)</code>	rank of <code>e(V)</code>

#### Macros

<code>e(cmd)</code>	<code>xtivreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(insts)</code>	instruments
<code>e(instd)</code>	instrumented variables
<code>e(model)</code>	be
<code>e(small)</code>	small, if specified
<code>e(clustvar)</code>	name of cluster variable
<code>e(vce)</code>	<code>vctype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

#### Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

#### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

**xtivreg, fe** stores the following in **e()**:

#### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(rss)</code>	residual sum of squares
<code>e(df_r)</code>	residual degrees of freedom (small only)
<code>e(df_rz)</code>	residual degrees of freedom for the within-transformed regression
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(N_clust)</code>	number of clusters
<code>e(sigma)</code>	ancillary parameter (gamma, lnormal)
<code>e(corr)</code>	$\text{corr}(u_i, Xb)$
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of $\epsilon_{it}$
<code>e(r2_w)</code>	$R^2$ -squared for within model
<code>e(r2_o)</code>	$R^2$ -squared for overall model
<code>e(r2_b)</code>	$R^2$ -squared for between model
<code>e(chi2)</code>	model Wald (not small)
<code>e(chi2_p)</code>	$p$ -value for model $\chi^2$ test
<code>e(rho)</code>	$\rho$
<code>e(F)</code>	$F$ statistic (small only)
<code>e(F_f)</code>	$F$ for $H_0: u_i=0$
<code>e(F_fp)</code>	$p$ -value for $F$ for $H_0: u_i=0$
<code>e(df_a)</code>	degrees of freedom for absorbed effect
<code>e(rank)</code>	rank of <code>e(V)</code>

#### Macros

<code>e(cmd)</code>	<b>xtivreg</b>
<code>e(cmdline)</code>	command as typed
<code>e(depyvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(insts)</code>	instruments
<code>e(instd)</code>	instrumented variables
<code>e(model)</code>	<code>fe</code>
<code>e(small)</code>	small, if specified
<code>e(clustvar)</code>	name of cluster variable
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(properties)</code>	title used to label Std. Err.
<code>e(predict)</code>	b V
<code>e(marginsok)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions allowed by <code>margins</code>
<code>e(asbalanced)</code>	predictions disallowed by <code>margins</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
	factor variables <code>fvset</code> as <code>asobserved</code>

#### Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

#### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

`xtivreg, fd` stores the following in `e()`:

#### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(rss)</code>	residual sum of squares
<code>e(df_r)</code>	residual degrees of freedom (small only)
<code>e(df_rz)</code>	residual degrees of freedom for first-differenced regression
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(N_clust)</code>	number of clusters
<code>e(sigma)</code>	ancillary parameter (gamma, lnormal)
<code>e(corr)</code>	$\text{corr}(u_i, Xb)$
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of $\epsilon_{it}$
<code>e(r2_w)</code>	$R^2$ -squared for within model
<code>e(r2_o)</code>	$R^2$ -squared for overall model
<code>e(r2_b)</code>	$R^2$ -squared for between model
<code>e(chi2)</code>	model Wald (not small)
<code>e(chi2_p)</code>	$p$ -value for model $\chi^2$ test
<code>e(rho)</code>	$\rho$
<code>e(F)</code>	$F$ statistic (small only)
<code>e(rank)</code>	rank of <code>e(V)</code>

#### Macros

<code>e(cmd)</code>	<code>xtivreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(tvars)</code>	variable denoting time within groups
<code>e(insts)</code>	instruments
<code>e(instd)</code>	instrumented variables
<code>e(model)</code>	<code>fd</code>
<code>e(small)</code>	small, if specified
<code>e(clustvar)</code>	name of cluster variable
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>

#### Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

#### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

Consider an equation of the form

$$y_{it} = \mathbf{Y}_{it}\boldsymbol{\gamma} + \mathbf{X}_{1it}\boldsymbol{\beta} + \mu_i + \nu_{it} = \mathbf{Z}_{it}\boldsymbol{\delta} + \mu_i + \nu_{it} \quad (2)$$

where

$y_{it}$  is the dependent variable;

$\mathbf{Y}_{it}$  is an  $1 \times g_2$  vector of observations on  $g_2$  endogenous variables included as covariates, and these variables are allowed to be correlated with the  $\nu_{it}$ ;

$\mathbf{X}_{1it}$  is an  $1 \times k_1$  vector of observations on the exogenous variables included as covariates;

$\mathbf{Z}_{it} = [\mathbf{Y}_{it} \ \mathbf{X}_{it}]$ ;

$\boldsymbol{\gamma}$  is a  $g_2 \times 1$  vector of coefficients;

$\boldsymbol{\beta}$  is a  $k_1 \times 1$  vector of coefficients; and

$\boldsymbol{\delta}$  is a  $K \times 1$  vector of coefficients, where  $K = g_2 + k_1$ .

Assume that there is a  $1 \times k_2$  vector of observations on the  $k_2$  instruments in  $\mathbf{X}_{2it}$ . The order condition is satisfied if  $k_2 \geq g_2$ . Let  $\mathbf{X}_{it} = [\mathbf{X}_{1it} \ \mathbf{X}_{2it}]$ . **xtivreg** handles exogenously unbalanced panel data. Thus define  $T_i$  to be the number of observations on panel  $i$ ,  $n$  to be the number of panels, and  $N$  to be the total number of observations; that is,  $N = \sum_{i=1}^n T_i$ .

Methods and formulas are presented under the following headings:

[xtivreg, fd](#)  
[xtivreg, fe](#)  
[xtivreg, be](#)  
[xtivreg, re](#)

### xtivreg, fd

As the name implies, this estimator obtains its estimates and conventional VCE from an instrumental-variables regression on the first-differenced data. Specifically, first differencing the data yields

$$y_{it} - y_{it-1} = (\mathbf{Z}_{it} - \mathbf{Z}_{i,t-1})\boldsymbol{\delta} + \nu_{it} - \nu_{i,t-1}$$

With the  $\mu_i$  removed by differencing, we can obtain the estimated coefficients and their estimated variance–covariance matrix from a two-stage least-squares regression of  $\Delta y_{it}$  on  $\Delta \mathbf{Z}_{it}$  with instruments  $\Delta \mathbf{X}_{it}$ .

$R^2$  within is reported as  $\left[ \text{corr}\{(\mathbf{Z}_{it} - \bar{\mathbf{Z}}_i)\hat{\boldsymbol{\delta}}, y_{it} - \bar{y}_i\} \right]^2$ .

$R^2$  between is reported as  $\left\{ \text{corr}(\bar{\mathbf{Z}}_i\hat{\boldsymbol{\delta}}, \bar{y}_i) \right\}^2$ .

$R^2$  overall is reported as  $\left\{ \text{corr}(\mathbf{Z}_{it}\hat{\boldsymbol{\delta}}, y_{it}) \right\}^2$ .

### xtivreg, fe

At the heart of this model is the within transformation. The within transform of a variable  $w$  is

$$\tilde{w}_{it} = w_{it} - \bar{w}_{i.} + \bar{w}$$

where

$$\bar{w}_{i\cdot} = \frac{1}{n} \sum_{t=1}^{T_i} w_{it}$$

$$\bar{w} = \frac{1}{N} \sum_{i=1}^n \sum_{t=1}^{T_i} w_{it}$$

and  $n$  is the number of groups and  $N$  is the total number of observations on the variable.

The within transform of (2) is

$$\tilde{y}_{it} = \tilde{\mathbf{Z}}_{it} + \tilde{\nu}_{it}$$

The within transform has removed the  $\mu_i$ . With the  $\mu_i$  gone, the within 2SLS estimator can be obtained from a two-stage least-squares regression of  $\tilde{y}_{it}$  on  $\tilde{\mathbf{Z}}_{it}$  with instruments  $\tilde{\mathbf{X}}_{it}$ .

Suppose that there are  $K$  variables in  $\mathbf{Z}_{it}$ , including the mandatory constant. There are  $K + n - 1$  parameters estimated in the model, and the conventional VCE for the within estimator is

$$\frac{N - K}{N - n - K + 1} V_{IV}$$

where  $V_{IV}$  is the VCE from the above two-stage least-squares regression. The robust and cluster-robust variance-covariance matrices are the robust and cluster-robust variance-covariance matrices from a two-stage least-squares regression of  $\tilde{y}_{it}$  on  $\tilde{\mathbf{Z}}_{it}$  with instruments  $\tilde{\mathbf{X}}_{it}$ .

From the estimate of  $\hat{\delta}$ , estimates  $\hat{\mu}_i$  of  $\mu_i$  are obtained as  $\hat{\mu}_i = \bar{y}_i - \bar{\mathbf{Z}}_i \hat{\delta}$ . Reported from the calculated  $\hat{\mu}_i$  is its standard deviation and its correlation with  $\bar{\mathbf{Z}}_i \hat{\delta}$ . Reported as the standard deviation of  $\nu_{it}$  is the regression's estimated root mean squared error,  $s^2$ , which is adjusted (as previously stated) for the  $n - 1$  estimated means.

$R^2$  within is reported as the  $R^2$  from the mean-deviated regression.

$$R^2 \text{ between is reported as } \left\{ \text{corr}(\bar{\mathbf{Z}}_i \hat{\delta}, \bar{y}_i) \right\}^2.$$

$$R^2 \text{ overall is reported as } \left\{ \text{corr}(\mathbf{Z}_{it} \hat{\delta}, y_{it}) \right\}^2.$$

At the bottom of the output, an  $F$  statistics against the null hypothesis that all the  $\mu_i$  are zero is reported. This  $F$  statistic is an application of the results in Wooldridge (1990).

## xtivreg, be

After passing (2) through the between transform, we are left with

$$\bar{y}_i = \alpha + \bar{\mathbf{Z}}_i \delta + \mu_i + \bar{\nu}_i \quad (3)$$

where

$$\bar{w}_i = \frac{1}{T_i} \sum_{t=1}^{T_i} w_{it} \quad \text{for } w \in \{y, \mathbf{Z}, \nu\}$$

Similarly, define  $\bar{\mathbf{X}}_i$  as the matrix of instruments  $\mathbf{X}_{it}$  after they have been passed through the between transform.

The BE2SLS estimator of (3) obtains its coefficient estimates and its VCE, a two-stage least-squares regression of  $\bar{y}_i$  on  $\bar{\mathbf{Z}}_i$  with instruments  $\bar{\mathbf{X}}_i$  in which each average appears  $T_i$  times.

$R^2$  between is reported as the  $R^2$  from the fitted regression.

$$R^2 \text{ within is reported as } \left[ \text{corr}\{(\mathbf{Z}_{it} - \bar{\mathbf{Z}}_i)\hat{\boldsymbol{\delta}}, y_{it} - \bar{y}_i\} \right]^2.$$

$$R^2 \text{ overall is reported as } \left\{ \text{corr}(\mathbf{Z}_{it}\hat{\boldsymbol{\delta}}, y_{it}) \right\}^2.$$

## xtivreg, re

Per Baltagi and Chang (2000), let

$$u = \mu_i + \nu_{it}$$

be the  $N \times 1$  vector of combined errors. Then under the assumptions of the random-effects model,

$$E(uu') = \sigma_\nu^2 \text{diag} \left[ I_{T_i} - \frac{1}{T_i} \boldsymbol{\iota}_{T_i} \boldsymbol{\iota}'_{T_i} \right] + \text{diag} \left[ w_i \frac{1}{T_i} \boldsymbol{\iota}_{T_i} \boldsymbol{\iota}'_{T_i} \right]$$

where

$$\omega_i = T_i \sigma_\mu^2 + \sigma_\nu^2$$

and  $\boldsymbol{\iota}_{T_i}$  is a vector of ones of dimension  $T_i$ .

Because the variance components are unknown, consistent estimates are required to implement feasible GLS. **xtivreg** offers two choices. The default is a simple extension of the Swamy–Arora method for unbalanced panels.

Let

$$u_{it}^w = \tilde{y}_{it} - \tilde{\mathbf{Z}}_{it}\hat{\boldsymbol{\delta}}_w$$

be the combined residuals from the within estimator. Let  $\tilde{u}_{it}$  be the within-transformed  $u_{it}$ . Then

$$\hat{\sigma}_\nu^2 = \frac{\sum_{i=1}^n \sum_{t=1}^{T_i} \tilde{u}_{it}^2}{N - n - K + 1}$$

Let

$$u_{it}^b = y_{it} - \mathbf{Z}_{it}\boldsymbol{\delta}_b$$

be the combined residual from the between estimator. Let  $\bar{u}_i^b$  be the between residuals after they have been passed through the between transform. Then

$$\hat{\sigma}_\mu^2 = \frac{\sum_{i=1}^n \sum_{t=1}^{T_i} \bar{u}_{it}^2 - (n - K)\hat{\sigma}_\nu^2}{N - r}$$

where

$$r = \text{trace} \left\{ \left( \bar{\mathbf{Z}}_i' \bar{\mathbf{Z}}_i \right)^{-1} \bar{\mathbf{Z}}_i' \mathbf{Z}_\mu \mathbf{Z}_\mu' \bar{\mathbf{Z}}_i \right\}$$

where

$$\mathbf{Z}_\mu = \text{diag} \left( \boldsymbol{\iota}_{T_i} \boldsymbol{\iota}'_{T_i} \right)$$

If the `nosa` option is specified, the consistent estimators described in [Baltagi and Chang \(2000\)](#) are used. These are given by

$$\hat{\sigma}_\nu = \frac{\sum_{i=1}^n \sum_{t=1}^{T_i} \tilde{u}_{it}^2}{N - n}$$

and

$$\hat{\sigma}_\mu^2 = \frac{\sum_{i=1}^n \sum_{t=1}^{T_i} \bar{u}_{it}^2 - n\hat{\sigma}_\nu^2}{N}$$

The default Swamy–Arora method contains a degree-of-freedom correction to improve its performance in small samples.

Given estimates of the variance components,  $\hat{\sigma}_\nu^2$  and  $\hat{\sigma}_\mu^2$ , the feasible GLS transform of a variable  $w$  is

$$w^* = w_{it} - \hat{\theta}_{it}\bar{w}_i. \quad (4)$$

where

$$\bar{w}_i = \frac{1}{T_i} \sum_{t=1}^{T_i} w_{it}$$

$$\hat{\theta}_{it} = 1 - \left( \frac{\hat{\sigma}_\nu^2}{\hat{\omega}_i} \right)^{-\frac{1}{2}}$$

and

$$\hat{\omega}_i = T_i \hat{\sigma}_\mu^2 + \hat{\sigma}_\nu^2$$

Using either estimator of the variance components, `xtivreg` contains two GLS estimators of the random-effects model. These two estimators differ only in how they construct the GLS instruments from the exogenous and instrumental variables contained in  $\mathbf{X}_{it} = [\mathbf{X}_{1it} \mathbf{X}_{2it}]$ . The default method, G2SLS, which is from Balestra and Varadharajan-Krishnakumar, uses the exogenous variables after they have been passed through the feasible GLS transform. Mathematically, G2SLS uses  $\mathbf{X}^*$  for the GLS instruments, where  $\mathbf{X}^*$  is constructed by passing each variable in  $\mathbf{X}$  through the GLS transform in (4). The G2SLS estimator obtains its coefficient estimates and VCE from an instrumental variable regression of  $y_{it}^*$  on  $\mathbf{Z}_{it}^*$  with instruments  $\mathbf{X}_{it}^*$ .

If the `ec2s1s` option is specified, `xtivreg` performs Baltagi's EC2SLS. In EC2SLS, the instruments are  $\tilde{\mathbf{X}}_{it}$  and  $\bar{\mathbf{X}}_{it}$ , where  $\tilde{\mathbf{X}}_{it}$  is constructed by each of the variables in  $\mathbf{X}_{it}$  throughout the GLS transform in (4), and  $\bar{\mathbf{X}}_{it}$  is made of the group means of each variable in  $\mathbf{X}_{it}$ . The EC2SLS estimator obtains its coefficient estimates and its VCE from an instrumental variables regression of  $y_{it}^*$  on  $\mathbf{Z}_{it}^*$  with instruments  $\tilde{\mathbf{X}}_{it}$  and  $\bar{\mathbf{X}}_{it}$ .

[Baltagi and Li \(1992\)](#) show that although the G2SLS instruments are a subset of those in EC2SLS, the extra instruments in EC2SLS are redundant in the sense of [White \(2001\)](#). Given the extra computational cost, G2SLS is the default.

The standard deviation of  $\mu_i + \nu_{it}$  is calculated as  $\sqrt{\hat{\sigma}_\mu^2 + \hat{\sigma}_\nu^2}$ .

$R^2$  between is reported as  $\left\{ \text{corr}(\bar{\mathbf{Z}}_i \hat{\boldsymbol{\delta}}, \bar{y}_i) \right\}^2$ .

$R^2$  within is reported as  $\left[ \text{corr}\{(\mathbf{Z}_{it} - \bar{\mathbf{Z}}_i)\hat{\boldsymbol{\delta}}, y_{it} - \bar{y}_i\} \right]^2$ .

$R^2$  overall is reported as  $\left\{ \text{corr}(\mathbf{Z}_{it} \hat{\boldsymbol{\delta}}, y_{it}) \right\}^2$ .

## Acknowledgment

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## Also see

- [XT] **xtivreg postestimation** — Postestimation tools for xtivreg
- [XT] **xtabond** — Arellano–Bond linear dynamic panel-data estimation
- [XT] **xteregress** — Extended random-effects linear regression
- [XT] **xhtaylor** — Hausman–Taylor estimator for error-components models
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtset** — Declare data to be panel data
- [R] **ivregress** — Single-equation instrumental-variables regression
- [U] **20 Estimation and postestimation commands**

**xtivreg postestimation** — Postestimation tools for xtivreg

[Postestimation commands](#)    [predict](#)    [margins](#)    [Also see](#)

## Postestimation commands

The following postestimation commands are available after `xtivreg`:

Command	Description
<code>* contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>* pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

\* `contrast` and `pwcompare` are not appropriate after `xtivreg, fd`.

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as fitted values and predictions.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

For all but the first-differenced estimator

```
predict [type] newvar [if] [in] [, statistic]
```

First-differenced estimator

```
predict [type] newvar [if] [in] [, FD_statistic]
```

statistic	Description
<hr/>	
Main	
xb	$\mathbf{Z}_{it}\hat{\delta}$ , fitted values; the default
ue	$\hat{\mu}_i + \hat{\nu}_{it}$ , the combined residual
* xbu	$\mathbf{Z}_{it}\hat{\delta} + \hat{\mu}_i$ , prediction including effect
* u	$\hat{\mu}_i$ , the fixed- or random-error component
* e	$\hat{\nu}_{it}$ , the overall error component

Unstarred statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample. Starred statistics are calculated only for the estimation sample, even when `if e(sample)` is not specified.

FD_statistic	Description
<hr/>	
Main	
xb	$\mathbf{x}_j\mathbf{b}$ , fitted values for the first-differenced model; the default
e	$e_{it} - e_{it-1}$ , the first-differenced overall error component

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

### Options for predict

Main

`xb`, the default, calculates the linear prediction, that is,  $\mathbf{Z}_{it}\hat{\delta}$ .

`ue` calculates the prediction of  $\hat{\mu}_i + \hat{\nu}_{it}$ . This is not available after the first-differenced model.

- xbu** calculates the prediction of  $\mathbf{Z}_{it}\hat{\delta} + \hat{\mu}_i$ , the prediction including the fixed or random component.  
 This is not available after the first-differenced model.
- u** calculates the prediction of  $\hat{\mu}_i$ , the estimated fixed or random effect. This is not available after the first-differenced model.
- e** calculates the prediction of  $\hat{\nu}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for fitted values.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist] , predict(statistic ...) [options]
```

For all but the first-differenced estimator

statistic	Description
-----------	-------------

<b>xb</b>	$\mathbf{Z}_{it}\hat{\delta}$ , fitted values; the default
<b>ue</b>	not allowed with <code>margins</code>
<b>xbu</b>	not allowed with <code>margins</code>
<b>u</b>	not allowed with <code>margins</code>
<b>e</b>	not allowed with <code>margins</code>

First-differenced estimator

statistic	Description
-----------	-------------

<b>xb</b>	$\mathbf{x}_j \mathbf{b}$ , fitted values for the first-differenced model; the default
<b>e</b>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

## Also see

[\[XT\] xtivreg](#) — Instrumental variables and two-stage least squares for panel-data models

[\[U\] 20 Estimation and postestimation commands](#)

## xtline — Panel-data line plots

Description

Syntax

Remarks and examples

Quick start

Options for graph by panel

Reference

Menu

Options for overlaid panels

Also see

## Description

`xtline` draws line plots for panel data.

## Quick start

Matrix of line plots of `y` against time variable `tvar` with panel identifier `pvar`

```
xtline y, i(pvar) t(tvar)
```

Same as above, but using `xtset` data

```
xtline y
```

As above, but overlay line plots for each panel identifier `pvar`

```
xtline y, overlay
```

Add “My Title” to graph showing a matrix of line plots

```
xtline y, byopts(title(My Title))
```

Add “My Title” to graph of overlaid line plots

```
xtline y, overlay title(My Title)
```

## Menu

Statistics > Longitudinal/panel data > Line plots

## Syntax

*Graph by panel*

`xtline varlist [if] [in] [, panel_options]`

*Overlaid panels*

`xtline varname [if] [in], overlay [overlaid_options]`

<i>panel_options</i>	Description
Main	
<code>i(varname<sub>i</sub>)</code>	use <i>varname<sub>i</sub></i> as the panel ID variable
<code>t(varname<sub>t</sub>)</code>	use <i>varname<sub>t</sub></i> as the time variable
Plot	
<code>cline_options</code>	affect rendition of the plotted points connected by lines
Add plots	
<code>addplot(plot)</code>	add other plots to the generated graph
Y axis, Time axis, Titles, Legend, Overall	
<code>twoway_options</code>	any options other than <code>by()</code> documented in [G-3] <i>twoway_options</i>
<code>byopts(byopts)</code>	affect appearance of the combined graph
<i>overlaid_options</i>	Description
Main	
<code>overlay</code>	overlay each panel on the same graph
<code>i(varname<sub>i</sub>)</code>	use <i>varname<sub>i</sub></i> as the panel ID variable
<code>t(varname<sub>t</sub>)</code>	use <i>varname<sub>t</sub></i> as the time variable
Plots	
<code>plot#opts(cline_options)</code>	affect rendition of the # panel line
Add plots	
<code>addplot(plot)</code>	add other plots to the generated graph
Y axis, Time axis, Titles, Legend, Overall	
<code>twoway_options</code>	any options other than <code>by()</code> documented in [G-3] <i>twoway_options</i>

A panel variable and a time variable must be specified. Use `xtset` (see [XT] `xtset`) or specify the `i()` and `t()` options. The `t()` option allows noninteger values for the time variable, whereas `xtset` does not.

## Options for graph by panel

### Main

`i(varnamei)` and `t(varnamet)` override the panel settings from `xtset`; see [XT] `xtset`. `varnamei` is allowed to be a string variable. `varnamet` can take on noninteger values and have repeated values within panel. That is to say, it can be any numeric variable that you would like to specify for the *x*-dimension of the graph. It is an error to specify `i()` without `t()` and vice versa.

### Plot

`cline_options` affect the rendition of the plotted points connected by lines; see [G-3] `cline_options`.

### Add plots

`addplot(plot)` provides a way to add other plots to the generated graph; see [G-3] `addplot_option`.

### Y axis, Time axis, Titles, Legend, Overall

`twoway_options` are any of the options documented in [G-3] `twoway_options`, excluding `by()`. These include options for titling the graph (see [G-3] `title_options`) and for saving the graph to disk (see [G-3] `saving_option`).

`byopts(byopts)` allows all the options documented in [G-3] `by_option`. These options affect the appearance of the by-graph. `byopts()` may not be combined with `overlay`.

## Options for overlaid panels

### Main

`overlay` causes the plot from each panel to be overlaid on the same graph. The default is to generate plots by panel. This option may not be combined with `byopts()` or be specified when there are multiple variables in `varlist`.

`i(varnamei)` and `t(varnamet)` override the panel settings from `xtset`; see [XT] `xtset`. `varnamei` is allowed to be a string variable. `varnamet` can take on noninteger values and have repeated values within panel. That is to say, it can be any numeric variable that you would like to specify for the *x*-dimension of the graph. It is an error to specify `i()` without `t()` and vice versa.

### Plots

`plot#opts(cline_options)` affect the rendition of the #th panel (in sorted order). The `cline_options` can affect whether and how the points are connected; see [G-3] `cline_options`.

### Add plots

`addplot(plot)` provides a way to add other plots to the generated graph; see [G-3] `addplot_option`.

### Y axis, Time axis, Titles, Legend, Overall

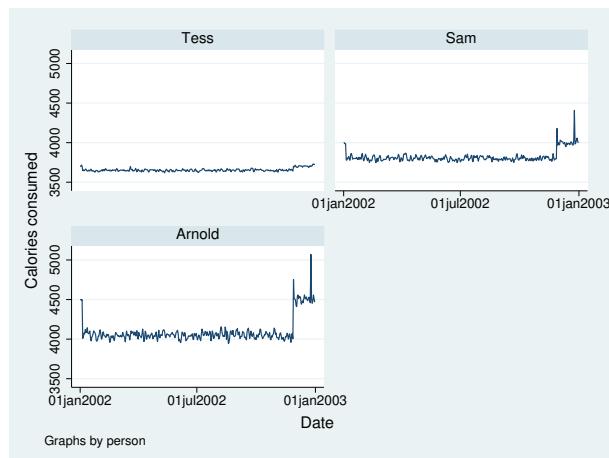
`twoway_options` are any of the options documented in [G-3] `twoway_options`, excluding `by()`. These include options for titling the graph (see [G-3] `title_options`) and for saving the graph to disk (see [G-3] `saving_option`).

## Remarks and examples

### ▷ Example 1

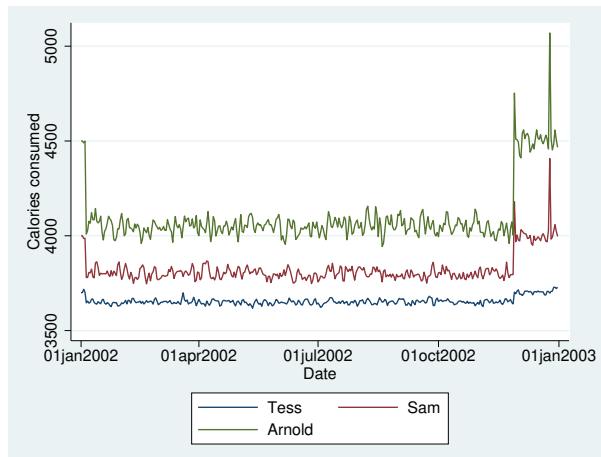
Suppose that Tess, Sam, and Arnold kept a calorie log for an entire calendar year. At the end of the year, if they pooled their data together, they would have a dataset (for example, *xtline1.dta*) that contains the number of calories each of them consumed for 365 days. They could then use *xtset* to identify the date variable and treat each person as a panel and use *xtline* to plot the calories versus time for each person separately.

```
. use https://www.stata-press.com/data/r16/xtline1
. xtset person day
    panel variable: person (strongly balanced)
    time variable: day, 01jan2002 to 31dec2002
    delta: 1 day
. xtline calories, tlabel(#3)
```



Specify the *overlay* option so that the values are plotted on the same graph to provide a better comparison among Tess, Sam, and Arnold.

```
. xtline calories, overlay
```



## Reference

Chatfield, M. D. 2018. Graphing each individual's data over time. *Stata Journal* 18: 503–516.

## Also see

[XT] **xtset** — Declare data to be panel data

[G-2] **graph twoway** — Twoway graphs

[TS] **tsline** — Time-series line plots

**xtlogit** — Fixed-effects, random-effects, and population-averaged logit models

Description	Quick start	Menu
Syntax	Options for RE model	Options for FE model
Options for PA model	Remarks and examples	Stored results
Methods and formulas	References	Also see

## Description

`xtlogit` fits random-effects, conditional fixed-effects, and population-averaged logit models for a binary dependent variable. The probability of a positive outcome is assumed to be determined by the logistic cumulative distribution function. Results may be reported as coefficients or odds ratios.

## Quick start

Random-effects model of `y` as a function of `x1`, `x2`, and `indicators` for levels of categorical variable `a` using `xtset` data

```
xtlogit y x1 x2 i.a
```

As above, but report odds ratios

```
xtlogit y x1 x2 i.a, or
```

Conditional fixed-effects model

```
xtlogit y x1 x2 i.a, fe
```

Population-averaged model with robust standard errors

```
xtlogit y x1 x2 i.a, pa vce(robust)
```

Random-effects model with cluster-robust standard errors for panels nested within `cvar`

```
xtlogit y x1 x2 i.a, vce(cluster cvar)
```

## Menu

Statistics > Longitudinal/panel data > Binary outcomes > Logistic regression (FE, RE, PA)

## Syntax

*Random-effects (RE) model*

```
xtlogit depvar [indepvars] [if] [in] [weight] [, re RE_options]
```

*Conditional fixed-effects (FE) model*

```
xtlogit depvar [indepvars] [if] [in] [weight], fe FE_options
```

*Population-averaged (PA) model*

```
xtlogit depvar [indepvars] [if] [in] [weight], pa PA_options
```

<i>RE_options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term
<u>re</u>	use random-effects estimator; the default
<u>offset(<i>varname</i>)</u>	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints(<i>constraints</i>)</u>	apply specified linear constraints
<u>asis</u>	retain perfect predictor variables
<b>SE/Robust</b>	
<u>vce(vcetype)</u>	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
<b>Reporting</b>	
<u>level(#)</u>	set confidence level; default is <u>level(95)</u>
<u>or</u>	report odds ratios
<u>lrmodel</u>	perform the likelihood-ratio model test instead of the default Wald test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Integration</b>	
<u>intmethod(<i>intmethod</i>)</u>	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints(#)</u>	use # quadrature points; default is <u>intpoints(12)</u>
<b>Maximization</b>	
<u>maximize_options</u>	control the maximization process; seldom used
<u>nodisplay</u>	suppress display of header and coefficients
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

<i>FE_options</i>	Description
Model	
<code>fe</code>	use fixed-effects estimator
<code>offset(<i>varname</i>)</code>	include <i>varname</i> in model with coefficient constrained to 1
<code>constraints(<i>constraints</i>)</code>	apply specified linear constraints
SE	
<code>vce(vcetype)</code>	<i>vcetype</i> may be <code>oim</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>or</code>	report odds ratios
<code>lrmodel</code>	perform the likelihood-ratio model test instead of the default Wald test
<code>nocnsreport</code>	do not display constraints
<code>display_options</code>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Maximization	
<code>maximize_options</code>	control the maximization process; seldom used
<code>nodisplay</code>	suppress display of header and coefficients
<code>collinear</code>	keep collinear variables
<code>coeflegend</code>	display legend instead of statistics

---

<i>PA_options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>pa</u>	use population-averaged estimator
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<u>asis</u>	retain perfect predictor variables
Correlation	
<u>corr</u> ( <i>correlation</i> )	within-panel correlation structure
<u>force</u>	estimate even if observations unequally spaced in time
SE/Robust	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be conventional, <u>robust</u> , <u>bootstrap</u> , or <u>jackknife</u>
<u>nmp</u>	use divisor $N - P$ instead of the default $N$
<u>scale</u> ( <i>parm</i> )	overrides the default scale parameter; <i>parm</i> may be <i>x2</i> , <i>dev</i> , <i>phi</i> , or <i>#</i>
Reporting	
<u>level</u> (#)	set confidence level; default is <i>level</i> (95)
<u>or</u>	report odds ratios
<i>display_options</i>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<i>optimize_options</i>	control the optimization process; seldom used
<u>nodisplay</u>	suppress display of header and coefficients
<u>coeflegend</u>	display legend instead of statistics

correlation	Description
<code>exchangeable</code>	exchangeable
<code>independent</code>	independent
<code>unstructured</code>	unstructured
<code>fixed matname</code>	user-specified
<code>ar #</code>	autoregressive of order #
<code>stationary #</code>	stationary of order #
<code>nonstationary #</code>	nonstationary of order #

A panel variable must be specified. For `xtlogit`, `pa`, correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] `xtset`.

`indepvars` may contain factor variables; see [U] 11.4.3 Factor variables.

`depvar` and `indepvars` may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by`, `mi estimate`, and `statsby` are allowed; see [U] 11.1.10 Prefix commands. `fp` is allowed for the random-effects and fixed-effects models.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] `mi estimate`.

`iweights`, `fweights`, and `pweights` are allowed for the population-averaged model, and `iweights` are allowed for the fixed-effects and random-effects models; see [U] 11.1.6 weight. Weights must be constant within panel.

`nodisplay`, `collinear`, and `coflegend` do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options for RE model

### Model

`noconstant`; see [R] Estimation options.

`re` requests the random-effects estimator, which is the default.

`offset(varname)` constraints(*constraints*); see [R] Estimation options.

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] `probit`.

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] `vce_options`.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see *xtlogit, re and the robust VCE estimator* in Methods and formulas.

### Reporting

`level(#)`; see [R] Estimation options.

`or` reports the estimated coefficients transformed to odds ratios, that is,  $e^b$  rather than  $b$ . Standard errors and confidence intervals are similarly transformed. This option affects how results are displayed, not how they are estimated. `or` may be specified at estimation or when replaying previously estimated results.

`lrmodel`, `nocnsreport`; see [R] Estimation options.

*display\_options*: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] **Estimation options**.

#### Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] **Estimation options**.

#### Maximization

*maximize\_options*: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] **Maximize**. These options are seldom used.

The following options are available with `xtlogit` but are not shown in the dialog box:

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.  
`collinear`, `coeflegend`; see [R] **Estimation options**.

## Options for FE model

#### Model

`fe` requests the fixed-effects estimator.

`offset(varname)`, `constraints(constraints)`; see [R] **Estimation options**.

#### SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] **vce\_options**.

#### Reporting

`level(#)`; see [R] **Estimation options**.

`or` reports the estimated coefficients transformed to odds ratios, that is,  $e^b$  rather than  $b$ . Standard errors and confidence intervals are similarly transformed. This option affects how results are displayed, not how they are estimated. `or` may be specified at estimation or when replaying previously estimated results.

`lrmodel`, `nocnsreport`; see [R] **Estimation options**.

*display\_options*: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] **Estimation options**.

---

Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, [no] `log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] **Maximize**. These options are seldom used.

The following options are available with `xtlogit` but are not shown in the dialog box:

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.  
`collinear`, `coeflegend`; see [R] **Estimation options**.

## Options for PA model

---

Model

`noconstant`; see [R] **Estimation options**.

`pa` requests the population-averaged estimator.

`offset(varname)`; see [R] **Estimation options**.

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] **probit**.

---

Correlation

`corr(correlation)` specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

`force` specifies that estimation be forced even though the time variable is not equally spaced. This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

---

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] **vce\_options**.

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`nmp`, `scale(x2 | dev | phi | #)`; see [XT] **vce\_options**.

---

Reporting

`level(#)`; see [R] **Estimation options**.

`or` reports the estimated coefficients transformed to odds ratios, that is,  $e^b$  rather than  $b$ . Standard errors and confidence intervals are similarly transformed. This option affects how results are displayed, not how they are estimated. `or` may be specified at estimation or when replaying previously estimated results.

`display_options`: `noci`, `nocvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] **Estimation options**.

#### Optimization

`optimize_options` control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`log` and `nolog` specify whether to display the iteration log. The iteration log is displayed by default unless you used `set iterlog off` to suppress it; see `set iterlog` in [R] **set iter**.

`trace` specifies that the current estimates be printed at each iteration.

The following options are available with `xtlogit` but are not shown in the dialog box:

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.

`coeflegend`; see [R] **Estimation options**.

## Remarks and examples

`xtlogit` fits random-effects, conditional fixed-effects, and population-averaged logit models. Whenever we refer to a fixed-effects model, we mean the conditional fixed-effects model. `depvar` equal to nonzero and nonmissing (typically `depvar` equal to one) indicates a positive outcome, whereas `depvar` equal to zero indicates a negative outcome.

By default, the population-averaged model is an equal-correlation model; that is `xtlogit`, `pa` assumes `corr(exchangeable)`. Thus, `xtlogit` is a convenience command for fitting the population-averaged model using `xtgee`; see [XT] **xtgee**. Typing

```
. xtlogit ..., pa ...
```

is equivalent to typing

```
. xtgee ..., ... family(binomial) link(logit) corr(exchangeable)
```

It is also a convenience command if you want the fixed-effects model. Typing

```
. xtlogit ..., fe ...
```

is equivalent to typing

```
. clogit ..., group(varname_i) ...
```

See also [XT] **xtgee** and [R] **clogit** for information about `xtlogit`.

By default or when `re` is specified, `xtlogit` fits via maximum likelihood the random-effects model

$$\Pr(y_{it} \neq 0 | \mathbf{x}_{it}) = P(\mathbf{x}_{it}\beta + \nu_i)$$

for  $i = 1, \dots, n$  panels, where  $t = 1, \dots, n_i$ ,  $\nu_i$  are i.i.d.,  $N(0, \sigma_\nu^2)$ , and  $P(z) = \{1 + \exp(-z)\}^{-1}$ .

Underlying this model is the variance components model

$$y_{it} \neq 0 \iff \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it} > 0$$

where  $\epsilon_{it}$  are i.i.d. logistic distributed with mean zero and variance  $\sigma_\epsilon^2 = \pi^2/3$ , independently of  $\nu_i$ .

## ▷ Example 1

We are studying unionization of women in the United States and are using the `union` dataset; see [XT] `xt`. We wish to fit a random-effects model of union membership:

```
. use https://www.stata-press.com/data/r16/union
(NLS Women 14-24 in 1968)

. xtlogit union age grade not_smsa south##c.year
  (output omitted)

Random-effects logistic regression
Group variable: idcode
Random effects u_i ~ Gaussian

Number of obs      =     26,200
Number of groups   =      4,434
Obs per group:
    min =          1
    avg =      5.9
    max =      12

Integration method: mvaghermite
Integration pts.   =       12
Wald chi2(6)      =     227.46
Prob > chi2        =     0.0000

Log likelihood = -10540.274


```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
age	.0156732	.0149895	1.05	0.296	-.0137056 .045052
grade	.0870851	.0176476	4.93	0.000	.0524965 .1216738
not_smsa	-.2511884	.0823508	-3.05	0.002	-.4125929 -.0897839
1.south	-2.839112	.6413116	-4.43	0.000	-4.096059 -1.582164
year	-.0068604	.0156575	-0.44	0.661	-.0375486 .0238277
south##c.year					
1	.0238506	.0079732	2.99	0.003	.0082235 .0394777
_cons	-3.009365	.8414963	-3.58	0.000	-4.658667 -1.360062
/lnsig2u	1.749366	.0470017			1.657245 1.841488
sigma_u	2.398116	.0563577			2.290162 2.511158
rho	.6361098	.0108797			.6145307 .6571548

LR test of rho=0: chibar2(01) = 6004.43

Prob >= chibar2 = 0.000

The output includes the additional panel-level variance component. This is parameterized as the log of the variance  $\ln(\sigma_\nu^2)$  (labeled `lnsig2u` in the output). The standard deviation  $\sigma_\nu$  is also included in the output and labeled `sigma_u` together with  $\rho$  (labeled `rho`),

$$\rho = \frac{\sigma_\nu^2}{\sigma_\nu^2 + \sigma_\epsilon^2}$$

which is the proportion of the total variance contributed by the panel-level variance component.

When rho is zero, the panel-level variance component is unimportant, and the panel estimator is no different from the pooled estimator. A likelihood-ratio test of this is included at the bottom of the output. This test formally compares the pooled estimator (logit) with the panel estimator.

As an alternative to the random-effects specification, we might want to fit an equal-correlation logit model:

. xtlogit union age grade not_smsa south##c.year, pa						
Iteration 1: tolerance = .14878775						
Iteration 2: tolerance = .00949339						
Iteration 3: tolerance = .00040606						
Iteration 4: tolerance = .00001602						
Iteration 5: tolerance = 6.628e-07						
GEE population-averaged model					Number of obs	= 26,200
Group variable: idcode					Number of groups	= 4,434
Link: logit					Obs per group:	
Family: binomial					min =	1
Correlation: exchangeable					avg =	5.9
					max =	12
					Wald chi2(6)	= 235.08
Scale parameter:	1				Prob > chi2	= 0.0000
union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0165893	.0092229	1.80	0.072	-.0014873	.0346659
grade	.0600669	.0108343	5.54	0.000	.0388321	.0813016
not_smsa	-.1215445	.0483713	-2.51	0.012	-.2163505	-.0267384
1.south	-1.857094	.372967	-4.98	0.000	-2.588096	-1.126092
year	-.0121168	.0095707	-1.27	0.205	-.030875	.0066413
south##c.year						
1	.0160193	.0046076	3.48	0.001	.0069886	.0250501
_cons	-1.39755	.5089508	-2.75	0.006	-2.395075	-.4000247



## ► Example 2

`xtlogit` with the `pa` option allows a `vce(robust)` option, so we can obtain the population-averaged logit estimator with the robust variance calculation by typing

```
. xtlogit union age grade not_smsa south##c.year, pa vce(robust) nolog
GEE population-averaged model
Group variable: idcode      Number of obs = 26,200
Link:          logit        Number of groups = 4,434
Family:         binomial    Obs per group:
Correlation:   exchangeable           min = 1
                Scale parameter: 1           avg = 5.9
                                         max = 12
                                         Wald chi2(6) = 154.88
                                         Prob > chi2 = 0.0000
                                         (Std. Err. adjusted for clustering on idcode)
```

union	Robust				
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
age	.0165893	.008951	1.85	0.064	-.0009543 .0341329
grade	.0600669	.0133193	4.51	0.000	.0339616 .0861722
not_smsa	-.1215445	.0613803	-1.98	0.048	-.2418477 -.0012412
1.south	-1.857094	.5389238	-3.45	0.001	-2.913366 -.8008231
year	-.0121168	.0096998	-1.25	0.212	-.0311282 .0068945
south##c.year					
1	.0160193	.0067217	2.38	0.017	.002845 .0291937
_cons	-1.39755	.5603767	-2.49	0.013	-2.495868 -.2992317

These standard errors are somewhat larger than those obtained without the `vce(robust)` option.

Finally, we can also fit a fixed-effects model to these data (see also [R] **clogit** for details):

```
. xtlogit union age grade not_smsa south##c.year, fe
note: multiple positive outcomes within groups encountered.
note: 2,744 groups (14,165 obs) dropped because of all positive or
      all negative outcomes.

Iteration 0:  log likelihood = -4516.5881
Iteration 1:  log likelihood = -4510.8906
Iteration 2:  log likelihood = -4510.888
Iteration 3:  log likelihood = -4510.888

Conditional fixed-effects logistic regression  Number of obs      =    12,035
Group variable: idcode                      Number of groups   =     1,690
                                                       Obs per group:
                                                       min =          2
                                                       avg =         7.1
                                                       max =        12
                                                       LR chi2(6)       =     78.60
Log likelihood = -4510.888                     Prob > chi2      = 0.0000
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
age	.0710973	.0960536	0.74	0.459	-.1171643 .2593589
grade	.0816111	.0419074	1.95	0.051	-.0005259 .163748
not_smsa	.0224809	.1131786	0.20	0.843	-.199345 .2443069
1.south	-2.856488	.6765694	-4.22	0.000	-4.182539 -1.530436
year	-.0636853	.0967747	-0.66	0.510	-.2533602 .1259896
south#c.year					
1	.0264136	.0083216	3.17	0.002	.0101036 .0427235



## □ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the **quadchk** command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the **intpoints()** option and run **quadchk** again. Do not attempt to interpret the results of estimates when the coefficients reported by **quadchk** differ substantially. See [XT] **quadchk** for details and [XT] **xtprobit** for an example.

Because the **xtlogit** likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.



## Stored results

**xtlogit, re** stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(l1_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	$\chi^2$
<code>e(chi2_c)</code>	$\chi^2$ for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(rho)</code>	$\rho$
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

### Macros

<code>e(cmd)</code>	<code>xtlogit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(model)</code>	<code>re</code>
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(clustvar)</code>	name of cluster variable
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald or LR; type of model $\chi^2$ test
<code>e(chi2_ct)</code>	Wald or LR; type of model $\chi^2$ test corresponding to <code>e(chi2_c)</code>
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsdefault)</code>	default <code>predict()</code> specification for <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

## Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(log)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

## Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

`xtlogit, fe` stores the following in `e()`:

## Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_drop)</code>	number of observations dropped because of all positive or all negative outcomes
<code>e(N_group_drop)</code>	number of groups dropped because of all positive or all negative outcomes
<code>e(k)</code>	number of parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(r2_p)</code>	pseudo <i>R</i> -squared
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(chi2)</code>	$\chi^2$
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

## Macros

<code>e(cmd)</code>	<code>clogit</code>
<code>e(cmd2)</code>	<code>xtlogit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(model)</code>	<code>fe</code>
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	LR; type of model $\chi^2$ test
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(group)</code>	name of <code>group()</code> variable
<code>e(multiple)</code>	<code>multiple</code> if multiple positive outcomes within groups
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	<code>max</code> or <code>min</code> ; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of <code>ml</code> method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(marginsdefault)</code>	default <code>predict()</code> specification for <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

## Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(log)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimators

## Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

**xtlogit, pa** stores the following in `e()`:

## Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(chi2)</code>	$\chi^2$
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(df_pear)</code>	degrees of freedom for Pearson $\chi^2$
<code>e(chi2_dev)</code>	$\chi^2$ test of deviance
<code>e(chi2_dis)</code>	$\chi^2$ test of deviance dispersion
<code>e(deviance)</code>	deviance
<code>e(dispers)</code>	deviance dispersion
<code>e(phi)</code>	scale parameter
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(tol)</code>	target tolerance
<code>e(dif)</code>	achieved tolerance
<code>e(rc)</code>	return code

## Macros

<code>e(cmd)</code>	<code>xtgee</code>
<code>e(cmd2)</code>	<code>xtlogit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(model)</code>	<code>pa</code>
<code>e(family)</code>	<code>binomial</code>
<code>e(link)</code>	<code>logit</code> ; link function
<code>e(corr)</code>	correlation structure
<code>e(scale)</code>	<code>x2, dev, phi, or #, scale</code> parameter
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	<code>Wald</code> ; type of model $\chi^2$ test
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(nmp)</code>	<code>nmp</code> , if specified
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

## Matrices

<code>e(b)</code>	coefficient vector
<code>e(R)</code>	estimated working correlation matrix
<code>e(V)</code>	variance-covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

## Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

`xtlogit` reports the population-averaged results obtained using `xtgee`, `family(binomial)` `link(logit)` to obtain estimates. The fixed-effects results are obtained using `clogit`. See [XT] `xtgee` and [R] `clogit` for details on the methods and formulas.

If we assume a normal distribution,  $N(0, \sigma_\nu^2)$ , for the random effects  $\nu_i$ ,

$$\Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i$$

where

$$F(y, z) = \begin{cases} \frac{1}{1 + \exp(-z)} & \text{if } y \neq 0 \\ \frac{1}{1 + \exp(z)} & \text{otherwise} \end{cases}$$

The panel-level likelihood  $l_i$  is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, \mathbf{x}_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with  $M$ -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the  $w_m^*$  denote the quadrature weights and the  $a_m^*$  denote the quadrature abscissas. The log likelihood,  $L$ , is the sum of the logs of the panel-level likelihoods  $l_i$ .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{it}, \mathbf{x}_{it}, \sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i)$$

where  $\widehat{\sigma}_i$  and  $\widehat{\mu}_i$  are the adaptive parameters for panel  $i$ . Therefore, with the definition of  $g(y_{it}, x_{it}, \nu_i)$ , the total log likelihood is approximated by

$$L \approx \sum_{i=1}^n w_i \log \left[ \sqrt{2\widehat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2}\widehat{\sigma}_i a_m^* + \widehat{\mu}_i)^2/2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \right] \\ \prod_{t=1}^{n_i} F(y_{it}, x_{it}\beta + \sqrt{2\widehat{\sigma}_i a_m^* + \widehat{\mu}_i}) \right]$$

where  $w_i$  is the user-specified weight for panel  $i$ ; if no weights are specified,  $w_i = 1$ .

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for  $\widehat{\mu}_i$  and  $\widehat{\sigma}_i$  by following the method of [Naylor and Smith \(1982\)](#), further discussed in [Skrondal and Rabe-Hesketh \(2004\)](#). We start with  $\widehat{\sigma}_{i,0} = 1$  and  $\widehat{\mu}_{i,0} = 0$ , and the posterior means and variances are updated in the  $k$ th iteration. That is, at the  $k$ th iteration of the optimization for  $l_i$ , we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2\widehat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2\widehat{\sigma}_{i,k-1}} a_m^* + \widehat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2\widehat{\sigma}_{i,k-1}} a_m^* + \widehat{\mu}_{i,k-1}$$

$$\widehat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2\widehat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\widehat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2\widehat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\widehat{\mu}_{i,k})^2$$

and this is repeated until  $\widehat{\mu}_{i,k}$  and  $\widehat{\sigma}_{i,k}$  have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of  $1e-6$ ; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature, the `int-method(ghermite)` option, where  $\rho = \sigma_\nu^2 / (\sigma_\nu^2 + 1)$ :

$$L = \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ \approx \sum_{i=1}^n w_i \log \left[ \frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left\{ y_{it}, \mathbf{x}_{it}\beta + a_m^* \left( \frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right]$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i)$$

is well approximated by a polynomial. As panel size and  $\rho$  increase, the quadrature approximation can become less accurate. For large  $\rho$ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] `quadchk`) to verify the quadrature approximation used in this command, whichever approximation you choose.

## xtlogit, re and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] `_robust`, particularly *Introduction* and *Methods and formulas*. Wooldridge (2020) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2020), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in  $\epsilon_{it}$ .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

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## Also see

- [XT] **xtlogit postestimation** — Postestimation tools for xtlogit
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtcloglog** — Random-effects and population-averaged cloglog models
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtprobit** — Random-effects and population-averaged probit models
- [XT] **xtset** — Declare data to be panel data
- [ME] **melogit** — Multilevel mixed-effects logistic regression
- [MI] **Estimation** — Estimation commands for use with mi estimate
- [R] **clogit** — Conditional (fixed-effects) logistic regression
- [R] **logistic** — Logistic regression, reporting odds ratios
- [R] **logit** — Logistic regression, reporting coefficients
- [U] **20 Estimation and postestimation commands**

**xtlogit postestimation** — Postestimation tools for xtlogit

Postestimation commands predict margins Remarks and examples  
Also see

## Postestimation commands

The following postestimation commands are available after `xtlogit`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
* <code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
† <code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
* <code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from <code>margins</code> (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

\* `estat ic` and `lrtest` are not appropriate after `xtlogit, pa`.

† `forecast` is not appropriate with `mi` estimation results or after `xtlogit, fe`.

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions, probabilities, standard errors, and equation-level scores.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

*Random-effects model*

```
predict [type] newvar [if] [in] [, RE_statistic nooffset]
```

*Fixed-effects model*

```
predict [type] newvar [if] [in] [, FE_statistic nooffset]
```

*Population-averaged model*

```
predict [type] newvar [if] [in] [, PA_statistic nooffset]
```

*RE\_statistic*      Description

---

Main

<code>xb</code>	linear prediction; the default
<code>pr</code>	marginal probability of a positive outcome
<code>pu0</code>	probability of a positive outcome assuming that the random effect is zero
<code>stdp</code>	standard error of the linear prediction

---

*FE\_statistic*      Description

---

Main

<code>pc1</code>	predicted probability of a positive outcome conditional on one positive outcome within group; the default
<code>pu0</code>	probability of a positive outcome assuming that the fixed effect is zero
<code>xb</code>	linear prediction
<code>stdp</code>	standard error of the linear prediction

---

The predicted probability for the fixed-effects model is conditional on there being only one outcome per group. See [\[R\] clogit](#) for details.

*PA\_statistic*      Description

---

Main

<code>mu</code>	predicted probability of <code>depvar</code> ; considers the <code>offset()</code>
<code>rate</code>	predicted probability of <code>depvar</code>
<code>xb</code>	linear prediction
<code>stdp</code>	standard error of the linear prediction
<code>score</code>	first derivative of the log likelihood with respect to $\mathbf{x}_{it}\beta$

---

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

## Options for predict

### Main

`xb` calculates the linear prediction. This is the default for the random-effects model.

`pc1` calculates the predicted probability of a positive outcome conditional on one positive outcome within group. This is the default for the fixed-effects model.

`mu` and `rate` both calculate the predicted probability of `depvar`. `mu` takes into account the `offset()`, and `rate` ignores those adjustments. `mu` and `rate` are equivalent if you did not specify `offset()`. `mu` is the default for the population-averaged model.

`pr` calculates the probability of a positive outcome that is marginal with respect to the random effect, which means that the probability is calculated by integrating the prediction function with respect to the random effect over its entire support.

`pu0` calculates the probability of a positive outcome, assuming that the fixed or random effect for that observation's panel is zero ( $\nu_i = 0$ ). This may not be similar to the proportion of observed outcomes in the group.

`stdp` calculates the standard error of the linear prediction.

`score` calculates the equation-level score,  $u_{it} = \partial \ln L(\mathbf{x}_{it}\boldsymbol{\beta}) / \partial (\mathbf{x}_{it}\boldsymbol{\beta})$ .

`nooffset` is relevant only if you specified `offset(varname)` for `xtlogit`. This option modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\boldsymbol{\beta}$  rather than  $\mathbf{x}_{it}\boldsymbol{\beta} + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions and probabilities.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist] , predict(statistic ...) [predict(statistic ...) ...] [options]
```

#### Random-effects model

<i>statistic</i>	Description
<code>pr</code>	marginal probability of a positive outcome; the default
<code>pu0</code>	probability of a positive outcome assuming that the random effect is zero
<code>xb</code>	linear prediction
<code>stdp</code>	not allowed with <code>margins</code>

#### Fixed-effects model

<i>statistic</i>	Description
<code>pu0</code>	probability of a positive outcome assuming that the fixed effect is zero; the default
<code>xb</code>	linear prediction
<code>pc1</code>	not allowed with <code>margins</code>
<code>stdp</code>	not allowed with <code>margins</code>

#### Population-averaged model

<i>statistic</i>	Description
<code>mu</code>	probability of <code>depvar</code> ; considers the <code>offset()</code>
<code>rate</code>	probability of <code>depvar</code>
<code>xb</code>	linear prediction
<code>stdp</code>	not allowed with <code>margins</code>
<code>score</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] **margins**.

## Remarks and examples

### ▷ Example 1: Conducting hypothesis tests

In example 1 of [XT] **xtlogit**, we fit a random-effects model of union status on the person's age and level of schooling, whether she lived in an urban area, and whether she lived in the south. In fact, we included the full interaction between `south` and `year` to capture both the overall effect of residing in the south and a separate time-trend for southerners. To test whether residing in the south affects union status, we must determine whether `1.south` and `south#c.year` are jointly significant. First, we refit our model, store the estimation results for later use, and use `test` to conduct a Wald test of the joint significance of those two variables' parameters:

```
. use https://www.stata-press.com/data/r16/union
(NLS Women 14-24 in 1968)
. xtlogit union age grade not_smsa south##c.year
(output omitted)
. estimates store fullmodel
. test 1.south 1.south#c.year
( 1) [union]1.south = 0
( 2) [union]1.south#c.year = 0
      chi2( 2) = 143.93
      Prob > chi2 = 0.0000
```

The test statistic is clearly significant, so we reject the null hypothesis that the coefficients are jointly zero and conclude that living in the south does significantly affect union status.

We can also test our hypothesis with a likelihood-ratio test. Here we fit the model without `south##c.year` and then call `lrtest` to compare this restricted model to the full model:

```
. xtlogit union age grade not_smsa
(output omitted)
. lrtest fullmodel .
Likelihood-ratio test                               LR chi2(3) =    146.55
(Assumption: . nested in fullmodel)               Prob > chi2 = 0.0000
```

These results confirm our finding that living in the south affects union status.



## Also see

[XT] **xtlogit** — Fixed-effects, random-effects, and population-averaged logit models

[U] **20 Estimation and postestimation commands**

Description	Quick start	Menu
Syntax	Options for RE/FE models	Options for PA model
Remarks and examples	Stored results	Methods and formulas
References	Also see	

## Description

**xtnbreg** fits random-effects and conditional fixed-effects overdispersion models where the random effects or fixed effects apply to the distribution of the dispersion parameter. The dispersion is the same for all observations in the same panel. In the random-effects model, the dispersion varies randomly from group to group, such that the inverse of one plus the dispersion follows a Beta distribution. In the fixed-effects model, the dispersion parameter in a group can take on any value.

**xtnbreg** also fits a population-averaged negative binomial model for a nonnegative count dependent variable with overdispersion.

## Quick start

Random-effects negative-binomial regression of *y* on *x* and indicators for levels of categorical variable *a* using `xtset` data

```
xtnbreg y x i.a
```

As above, but report incidence-rate ratios

```
xtnbreg y x i.a, irr
```

Conditional fixed-effects model with exposure variable *evar*

```
xtnbreg y x i.a, fe exposure(evar)
```

Population-averaged model with robust standard errors

```
xtnbreg y x i.a, pa vce(robust)
```

## Menu

Statistics > Longitudinal/panel data > Count outcomes > Negative binomial regression (FE, RE, PA)

## Syntax

*Random-effects (RE) and conditional fixed-effects (FE) overdispersion models*

`xtnbreg depvar [indepvars] [if] [in] [weight] [, [re|fe] RE/FE_options]`

*Population-averaged (PA) model*

`xtnbreg depvar [indepvars] [if] [in] [weight] , pa PA_options`

<i>RE/FE_options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term; not available with <code>fe</code>
<code>re</code>	use random-effects estimator; the default
<code>fe</code>	use fixed-effects estimator
<code>exposure(varname)</code>	include <code>ln(varname)</code> in model with coefficient constrained to 1
<code>offset(varname)</code>	include <code>varname</code> in model with coefficient constrained to 1
<u>constraints(constraints)</u>	apply specified linear constraints
<b>SE</b>	
<code>vce(vcetype)</code>	<code>vcetype</code> may be <code>oim</code> , <code>bootstrap</code> , or <code>jackknife</code>
<b>Reporting</b>	
<u>level(#)</u>	set confidence level; default is <code>level(95)</code>
<code>irr</code>	report incidence-rate ratios
<code>lrmodel</code>	perform the likelihood-ratio model test instead of the default Wald test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Maximization</b>	
<u>maximize_options</u>	control the maximization process; seldom used
<u>collinear</u>	keep collinear variables
<u>coflegend</u>	display legend instead of statistics

<i>PA_options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term
<u>pa</u>	use population-averaged estimator
<u>exposure</u> ( <i>varname</i> )	include <i>ln(varname)</i> in model with coefficient constrained to 1
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<b>Correlation</b>	
<u>corr</u> ( <i>correlation</i> )	within-panel correlation structure
<u>force</u>	estimate even if observations unequally spaced in time
<b>SE/Robust</b>	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be conventional, <u>robust</u> , <u>bootstrap</u> , or <u>jackknife</u>
<u>nmp</u>	use divisor $N - P$ instead of the default $N$
<u>scale</u> ( <i>parm</i> )	overrides the default scale parameter; <i>parm</i> may be <i>x2</i> , <i>dev</i> , <i>phi</i> , or <i>#</i>
<b>Reporting</b>	
<u>level</u> (#)	set confidence level; default is <b>level(95)</b>
<u>irr</u>	report incidence-rate ratios
<i>display_options</i>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Optimization</b>	
<u>optimize_options</u>	control the optimization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>correlation</i>	Description
<u>exchangeable</u>	exchangeable
<u>independent</u>	independent
<u>unstructured</u>	unstructured
<u>fixed</u> <i>matname</i>	user-specified
<u>ar</u> #	autoregressive of order #
<u>stationary</u> #	stationary of order #
<u>nonstationary</u> #	nonstationary of order #

A panel variable must be specified. For **xtnbreg**, *pa*, correlation structures other than **exchangeable** and **independent** require that a time variable also be specified. Use **xtset**; see [XT] **xtset**.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

*depvar* and *indepvars* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

*by*, *mi estimate*, and *statsby* are allowed; see [U] 11.1.10 Prefix commands. *fp* is allowed for the random-effects and fixed-effects models.

*vce(bootstrap)* and *vce(jackknife)* are not allowed with the *mi estimate* prefix; see [MI] **mi estimate**.

*iweights*, *fweights*, and *pweights* are allowed for the population-averaged model, and *iweights* are allowed in the random-effects and fixed-effects models; see [U] 11.1.6 weight. Weights must be constant within panel.

*collinear* and *coeflegend* do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options for RE/FE models

### Model

`noconstant`; see [R] [Estimation options](#).

`re` requests the random-effects estimator, which is the default.

`fe` requests the conditional fixed-effects estimator.

`exposure(varname)`, `offset(varname)`, `constraints(constraints)`; see [R] [Estimation options](#).

### SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

### Reporting

`level(#)`; see [R] [Estimation options](#).

`irr` reports exponentiated coefficients  $e^b$  rather than coefficients  $b$ . For the negative binomial model, exponentiated coefficients have the interpretation of incidence-rate ratios.

`lrmodel`, `nocnsreport`; see [R] [Estimation options](#).

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

### Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] [Maximize](#). These options are seldom used.

The following options are available with `xtnbreg` but are not shown in the dialog box:

`collinear`, `coeflegend`; see [R] [Estimation options](#).

## Options for PA model

### Model

`noconstant`; see [R] [Estimation options](#).

`pa` requests the population-averaged estimator.

`exposure(varname)`, `offset(varname)`; see [R] [Estimation options](#).

### Correlation

`corr(correlation)` specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

`force` specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

#### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`nmp`, `scale(x2 | dev | phi | #)`; see [XT] [vce\\_options](#).

#### Reporting

`level(#)`; see [R] [Estimation options](#).

`irr` reports exponentiated coefficients  $e^b$  rather than coefficients  $b$ . For the negative binomial model, exponentiated coefficients have the interpretation of incidence-rate ratios.

`display_options`: `noci`, `notvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

#### Optimization

`optimize_options` control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`log` and `nolog` specify whether to display the iteration log. The iteration log is displayed by default unless you used `set iterlog off` to suppress it; see `set iterlog` in [R] [set iter](#).

`trace` specifies that the current estimates be printed at each iteration.

The following option is available with `xtnbreg` but is not shown in the dialog box:

`coeflegend`; see [R] [Estimation options](#).

## Remarks and examples

xtnbreg fits random-effects overdispersion models, conditional fixed-effects overdispersion models, and population-averaged negative binomial models. Here “random effects” and “fixed effects” apply to the distribution of the dispersion parameter, not to the  $\mathbf{x}\beta$  term in the model. In the random-effects and fixed-effects overdispersion models, the dispersion is the same for all elements in the same group (that is, elements with the same value of the panel variable). In the random-effects model, the dispersion varies randomly from group to group, such that the inverse of one plus the dispersion follows a Beta( $r, s$ ) distribution. In the fixed-effects model, the dispersion parameter in a group can take on any value, because a conditional likelihood is used in which the dispersion parameter drops out of the estimation.

By default, the population-averaged model is an equal-correlation model; xtnbreg, pa assumes corr(exchangeable). Thus, xtnbreg is a convenience command for fitting the population-averaged using xtgee; see [XT] xtgee. Typing

```
. xtnbreg ..., ... pa exposure(time)
```

is equivalent to typing

```
. xtgee ..., ... family(nbinomial) link(log) corr(exchangeable) exposure(time)
```

See also [XT] xtgee for information about xtnbreg.

By default, or when re is specified, xtnbreg fits a maximum-likelihood random-effects overdispersion model.

### ▷ Example 1

You have (fictional) data on injury “incidents” incurred among 20 airlines in each of 4 years. (Incidents range from major injuries to exceedingly minor ones.) The government agency in charge of regulating airlines has run an experimental safety training program, and, in each of the years, some airlines have participated and some have not. You now wish to analyze whether the “incident” rate is affected by the program. You choose to estimate using random-effects negative binomial regression, as the dispersion might vary across the airlines for unidentified airline-specific reasons. Your measure of exposure is passenger miles for each airline in each year.

```
. use https://www.stata-press.com/data/r16/airacc
. xtnbreg i_cnt inprog, exposure(pmiles) irr
Fitting negative binomial (constant dispersion) model:
Iteration 0: log likelihood = -293.57997
Iteration 1: log likelihood = -293.57997
(output omitted)
Fitting full model:
Iteration 0: log likelihood = -295.72633
Iteration 1: log likelihood = -270.49929 (not concave)
(output omitted)

Random-effects negative binomial regression      Number of obs     =      80
Group variable: airline                         Number of groups  =      20
Random effects u_i ~ Beta                      Obs per group:
                                                min =          4
                                                avg =         4.0
                                                max =         4
Wald chi2(1) =                               2.04
Prob > chi2 =                               0.1532
Log likelihood = -265.38202
```

i_cnt	IRR	Std. Err.	z	P> z	[95% Conf. Interval]
inprog	.911673	.0590277	-1.43	0.153	.8030206 1.035027
_cons	.0367524	.0407032	-2.98	0.003	.0041936 .3220983
ln(pmiles)	1	(exposure)			
/ln_r	4.794991	.951781		2.929535	6.660448
/ln_s	3.268052	.4709033		2.345098	4.191005
r	120.9033	115.0735		18.71892	780.9007
s	26.26013	12.36598		10.4343	66.08918

Note: Estimates are transformed only in the first equation.

Note: \_cons estimates baseline incidence rate (conditional on zero random effects).

LR test vs. pooled: chibar2(01) = 19.03

Prob >= chibar2 = 0.000

In the output above, the /ln\_r and /ln\_s lines refer to  $\ln(r)$  and  $\ln(s)$ , where the inverse of one plus the dispersion is assumed to follow a Beta( $r, s$ ) distribution. The output also includes a likelihood-ratio test, which compares the panel estimator with the pooled estimator (that is, a negative binomial estimator with constant dispersion).

You find that the incidence rate for accidents is not significantly different for participation in the program and that the panel estimator is significantly different from the pooled estimator.

We may alternatively fit a fixed-effects overdispersion model:

xtnbreg i_cnt inprog, exposure(pmiles) irr fe nolog					
Conditional FE negative binomial regression			Number of obs = 80		
Group variable: airline			Number of groups = 20		
Obs per group:					
			min =	4	
			avg =	4.0	
			max =	4	
			Wald chi2(1)	= 2.11	
Log likelihood	-174.25143		Prob > chi2	= 0.1463	
i_cnt	IRR	Std. Err.	z	P> z	[95% Conf. Interval]
inprog	.9062669	.0613917	-1.45	0.146	.793587 1.034946
_cons	.0329025	.0331262	-3.39	0.001	.0045734 .2367111
ln(pmiles)	1	(exposure)			

Note: \_cons estimates baseline incidence rate (conditional on zero random effects).



## ▷ Example 2

We rerun our previous example, but this time we fit a robust equal-correlation population-averaged model:

xtnbreg i_cnt inprog, exposure(pmiles) irr vce(robust) pa					
Iteration 1: tolerance = .02499392					
Iteration 2: tolerance = .0000482					
Iteration 3: tolerance = 2.929e-07					
GEE population-averaged model			Number of obs = 80		
Group variable:	airline		Number of groups = 20		
Link:	log		Obs per group:		
Family:	negative binomial(k=1)		min = 4		
Correlation:	exchangeable		avg = 4.0		
			max = 4		
			Wald chi2(1) = 1.28		
Scale parameter:	1		Prob > chi2 = 0.2571		
(Std. Err. adjusted for clustering on airline)					
i_cnt	IRR	Semirobust Std. Err.	z	P> z	[95% Conf. Interval]
inprog	.927275	.0617857	-1.13	0.257	.8137513 1.056636
_cons	.0080211	.0004117	-94.02	0.000	.0072535 .00887
ln(pmiles)	1	(exposure)			

Note: \_cons estimates baseline incidence rate (conditional on zero random effects).

We compare this with a pooled estimator with clustered robust-variance estimates:

```
. nbreg i_cnt inprog, exposure(pmiles) irr vce(cluster airline)
```

Fitting Poisson model:

```
Iteration 0: log pseudolikelihood = -293.57997
Iteration 1: log pseudolikelihood = -293.57997
```

Fitting constant-only model:

```
Iteration 0: log pseudolikelihood = -335.13615
Iteration 1: log pseudolikelihood = -279.43327
Iteration 2: log pseudolikelihood = -276.09296
Iteration 3: log pseudolikelihood = -274.84036
Iteration 4: log pseudolikelihood = -274.81076
Iteration 5: log pseudolikelihood = -274.81075
```

Fitting full model:

```
Iteration 0: log pseudolikelihood = -274.56985
Iteration 1: log pseudolikelihood = -274.55077
Iteration 2: log pseudolikelihood = -274.55077
```

Negative binomial regression	Number of obs	=	80
	Wald chi2(1)	=	0.60
Dispersion = mean	Prob > chi2	=	0.4369
Log pseudolikelihood = -274.55077	Pseudo R2	=	0.0009

(Std. Err. adjusted for 20 clusters in airline)

i_cnt	Robust					[95% Conf. Interval]
	IRR	Std. Err.	z	P> z		
inprog	.9429015	.0713091	-0.78	0.437	.8130032	1.093555
_cons	.007956	.0004237	-90.77	0.000	.0071674	.0088314
ln(pmiles)	1	(exposure)				
/lnalpha	-2.835089	.3351784			-3.492027	-2.178151
alpha	.0587133	.0196794			.0304391	.1132507

Note: Estimates are transformed only in the first equation.

Note: \_cons estimates baseline incidence rate.



## Stored results

xtnbreg, re stores the following in e():

### Scalars

e(N)	number of observations
e(N_g)	number of groups
e(k)	number of parameters
e(k_aux)	number of auxiliary parameters
e(k_eq)	number of equations in e(b)
e(k_eq_model)	number of equations in overall model test
e(k_dv)	number of dependent variables
e(df_m)	model degrees of freedom
e(l1)	log likelihood
e(l1_0)	log likelihood, constant-only model
e(l1_c)	log likelihood, comparison model
e(chi2)	$\chi^2$
e(chi2_c)	$\chi^2$ for comparison test
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(r)	value of $r$ in Beta( $r, s$ )
e(s)	value of $s$ in Beta( $r, s$ )
e(p)	p-value for model test
e(rank)	rank of e(V)
e(rank0)	rank of e(V) for constant-only model
e(ic)	number of iterations
e(rc)	return code
e(converged)	1 if converged, 0 otherwise

### Macros

e(cmd)	xtnbreg
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivars)	variable denoting groups
e(model)	re
e(wtype)	weight type
e(wexp)	weight expression
e(title)	title in estimation output
e(offset)	linear offset variable
e(chi2type)	Wald or LR; type of model $\chi^2$ test
e(chi2_ct)	Wald or LR; type of model $\chi^2$ test corresponding to e(chi2_c)
e(vce)	vcetype specified in vce()
e(method)	estimation method
e(distrib)	Beta; the distribution of the random effect
e(opt)	type of optimization
e(which)	max or min; whether optimizer is to perform maximization or minimization
e(ml_method)	type of ml method
e(user)	name of likelihood-evaluator program
e(technique)	maximization technique
e(properties)	b V
e(predict)	program used to implement predict
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

### Matrices

e(b)	coefficient vector
e(Cns)	constraints matrix
e(iolog)	iteration log
e(gradient)	gradient vector
e(V)	variance-covariance matrix of the estimators

### Functions

e(sample)	marks estimation sample
-----------	-------------------------

**xtnbreg, fe** stores the following in **e()**:

#### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(chi2)</code>	$\chi^2$
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

#### Macros

<code>e(cmd)</code>	<code>xtnbreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	<code>fe</code>
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	LR; type of model $\chi^2$ test
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(method)</code>	requested estimation method
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	<code>max</code> or <code>min</code> ; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of <code>ml</code> method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

#### Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimators

#### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

`xtnbreg, pa` stores the following in `e()`:

#### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(chi2)</code>	$\chi^2$
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(df_pear)</code>	degrees of freedom for Pearson $\chi^2$
<code>e(chi2_dev)</code>	$\chi^2$ test of deviance
<code>e(chi2_dis)</code>	$\chi^2$ test of deviance dispersion
<code>e(deviance)</code>	deviance
<code>e(dispers)</code>	deviance dispersion
<code>e(phi)</code>	scale parameter
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(tol)</code>	target tolerance
<code>e(dif)</code>	achieved tolerance
<code>e(rc)</code>	return code

#### Macros

<code>e(cmd)</code>	<code>xtgee</code>
<code>e(cmd2)</code>	<code>xtnbreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(model)</code>	<code>pa</code>
<code>e(family)</code>	<code>negative binomial(k=1)</code>
<code>e(link)</code>	<code>log</code> ; link function
<code>e(corr)</code>	correlation structure
<code>e(scale)</code>	<code>x2, dev, phi, or #</code> ; scale parameter
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald; type of model $\chi^2$ test
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(nmp)</code>	<code>nmp</code> , if specified
<code>e(nbalpha)</code>	$\alpha$
<code>e(properties)</code>	$b$
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

#### Matrices

<code>e(b)</code>	coefficient vector
<code>e(R)</code>	estimated working correlation matrix
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

#### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

`xtnbreg`, `pa` reports the population-averaged results obtained by using `xtgee`, `family(nbinomial)` `link(log)` to obtain estimates. See [XT] `xtgee` for details on the methods and formulas.

For the random-effects and fixed-effects overdispersion models, let  $y_{it}$  be the count for the  $t$ th observation in the  $i$ th group. We begin with the model  $y_{it} | \gamma_{it} \sim \text{Poisson}(\gamma_{it})$ , where  $\gamma_{it} | \delta_i \sim \text{gamma}(\lambda_{it}, \delta_i)$  with  $\lambda_{it} = \exp(\mathbf{x}_{it}\beta + \text{offset}_{it})$  and  $\delta_i$  is the dispersion parameter. This yields the model

$$\Pr(Y_{it} = y_{it} | \mathbf{x}_{it}, \delta_i) = \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \left( \frac{1}{1 + \delta_i} \right)^{\lambda_{it}} \left( \frac{\delta_i}{1 + \delta_i} \right)^{y_{it}}$$

(See Hausman, Hall, and Griliches [1984, eq. 3.1, 922]; our  $\delta$  is the inverse of their  $\delta$ .) Looking at within-panel effects only, we find that this specification yields a negative binomial model for the  $i$ th group with dispersion (variance divided by the mean) equal to  $1 + \delta_i$ , that is, constant dispersion within group. This parameterization of the negative binomial model differs from the default parameterization of `nbreg`, which has dispersion equal to  $1 + \alpha \exp(\mathbf{x}\beta + \text{offset})$ ; see [R] `nbreg`.

For a random-effects overdispersion model, we allow  $\delta_i$  to vary randomly across groups; namely, we assume that  $1/(1 + \delta_i) \sim \text{Beta}(r, s)$ . The joint probability of the counts for the  $i$ th group is

$$\begin{aligned} \Pr(Y_{i1} = y_{i1}, \dots, Y_{in_i} = y_{in_i} | \mathbf{X}_i) &= \int_0^\infty \prod_{t=1}^{n_i} \Pr(Y_{it} = y_{it} | \mathbf{x}_{it}, \delta_i) f(\delta_i) d\delta_i \\ &= \frac{\Gamma(r+s)\Gamma(r + \sum_{t=1}^{n_i} \lambda_{it})\Gamma(s + \sum_{t=1}^{n_i} y_{it})}{\Gamma(r)\Gamma(s)\Gamma(r+s + \sum_{t=1}^{n_i} \lambda_{it} + \sum_{t=1}^{n_i} y_{it})} \prod_{t=1}^{n_i} \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \end{aligned}$$

for  $\mathbf{X}_i = (\mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i})$  and where  $f$  is the probability density function for  $\delta_i$ . The resulting log likelihood is

$$\begin{aligned} \ln L &= \sum_{i=1}^n w_i \left[ \ln \Gamma(r+s) + \ln \Gamma\left(r + \sum_{k=1}^{n_i} \lambda_{ik}\right) + \ln \Gamma\left(s + \sum_{k=1}^{n_i} y_{ik}\right) - \ln \Gamma(r) - \ln \Gamma(s) \right. \\ &\quad \left. - \ln \Gamma\left(r+s + \sum_{k=1}^{n_i} \lambda_{ik} + \sum_{k=1}^{n_i} y_{ik}\right) + \sum_{t=1}^{n_i} \left\{ \ln \Gamma(\lambda_{it} + y_{it}) - \ln \Gamma(\lambda_{it}) - \ln \Gamma(y_{it} + 1) \right\} \right] \end{aligned}$$

where  $\lambda_{it} = \exp(\mathbf{x}_{it}\beta + \text{offset}_{it})$  and  $w_i$  is the weight for the  $i$ th group (Hausman, Hall, and Griliches 1984, eq. 3.5, 927).

For the fixed-effects overdispersion model, we condition the joint probability of the counts for each group on the sum of the counts for the group (that is, the observed  $\sum_{t=1}^{n_i} y_{it}$ ). This yields

$$\begin{aligned} \Pr(Y_{i1} = y_{i1}, \dots, Y_{in_i} = y_{in_i} | \mathbf{X}_i, \sum_{t=1}^{n_i} Y_{it} = \sum_{t=1}^{n_i} y_{it}) \\ = \frac{\Gamma(\sum_{t=1}^{n_i} \lambda_{it})\Gamma(\sum_{t=1}^{n_i} y_{it} + 1)}{\Gamma(\sum_{t=1}^{n_i} \lambda_{it} + \sum_{t=1}^{n_i} y_{it})} \prod_{t=1}^{n_i} \frac{\Gamma(\lambda_{it} + y_{it})}{\Gamma(\lambda_{it})\Gamma(y_{it} + 1)} \end{aligned}$$

The conditional log likelihood is

$$\ln L = \sum_{i=1}^n w_i \left[ \ln \Gamma \left( \sum_{t=1}^{n_i} \lambda_{it} \right) + \ln \Gamma \left( \sum_{t=1}^{n_i} y_{it} + 1 \right) - \ln \Gamma \left( \sum_{t=1}^{n_i} \lambda_{it} + \sum_{t=1}^{n_i} y_{it} \right) \right. \\ \left. + \sum_{t=1}^{n_i} \left\{ \ln \Gamma(\lambda_{it} + y_{it}) - \ln \Gamma(\lambda_{it}) - \ln \Gamma(y_{it} + 1) \right\} \right]$$

See [Hausman, Hall, and Griliches \(1984\)](#) for a more thorough development of the random-effects and fixed-effects models. Also see [Cameron and Trivedi \(2013\)](#) for a good textbook treatment of this model.

## References

- Cameron, A. C., and P. K. Trivedi. 2013. *Regression Analysis of Count Data*. 2nd ed. New York: Cambridge University Press.
- Guimarães, P. 2005. A simple approach to fit the beta-binomial model. *Stata Journal* 5: 385–394.
- Hausman, J. A., B. H. Hall, and Z. Griliches. 1984. Econometric models for count data with an application to the patents-R & D relationship. *Econometrica* 52: 909–938.
- Liang, K.-Y., and S. L. Zeger. 1986. Longitudinal data analysis using generalized linear models. *Biometrika* 73: 13–22.

## Also see

- [XT] **xtnbreg postestimation** — Postestimation tools for xtnbreg
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtpoisson** — Fixed-effects, random-effects, and population-averaged Poisson models
- [XT] **xtset** — Declare data to be panel data
- [ME] **menbreg** — Multilevel mixed-effects negative binomial regression
- [MI] **Estimation** — Estimation commands for use with mi estimate
- [R] **nbreg** — Negative binomial regression
- [U] **20 Estimation and postestimation commands**

Postestimation commands

predict

margins

Methods and formulas

Also see

## Postestimation commands

The following postestimation commands are available after `xtnbreg`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
* <code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
† <code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
* <code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

\* `estat ic` and `lrtest` are not appropriate after `xtnbreg`, pa.

† `forecast` is not appropriate with `mi` estimation results.

# **predict**

## Description for predict

`predict` creates a new variable containing predictions such as linear predictions, standard errors, numbers of events, incidence rates, probabilities, and equation-level scores.

## Menu for predict

Statistics > Postestimation

## Syntax for predict

*Random-effects (RE) and conditional fixed-effects (FE) overdispersion models*

```
predict [type] newvar [if] [in] [, RE/FE_statistic nooffset]
```

*Population-averaged (PA) model*

```
predict [type] newvar [if] [in] [, PA_statistic nooffset]
```

---

<i>RE/FE_statistic</i>	Description
------------------------	-------------

Main

<code>xb</code>	linear prediction; the default
<code>stdp</code>	standard error of the linear prediction
<code>nu0</code>	predicted number of events; assumes fixed or random effect is zero
<code>iru0</code>	predicted incidence rate; assumes fixed or random effect is zero
<code>pr0(n)</code>	probability $\Pr(y = n)$ assuming the random effect is zero; only allowed after <code>xtnbreg, re</code>
<code>pr0(a,b)</code>	probability $\Pr(a \leq y \leq b)$ assuming the random effect is zero; only allowed after <code>xtnbreg, re</code>

---

<i>PA_statistic</i>	Description
---------------------	-------------

Main

<code>mu</code>	predicted number of events; considers the <code>offset()</code> ; the default
<code>rate</code>	predicted number of events
<code>xb</code>	linear prediction
<code>stdp</code>	standard error of the linear prediction
<code>score</code>	first derivative of the log likelihood with respect to $\mathbf{x}_{it}\beta$

---

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

## Options for predict

### Main

**xb** calculates the linear prediction. This is the default for the random-effects and fixed-effects models. **mu** and **rate** both calculate the predicted number of events. **mu** takes into account the **offset()**, and **rate** ignores those adjustments. **mu** and **rate** are equivalent if you did not specify **offset()**. **mu** is the default for the population-averaged model.

**stdp** calculates the standard error of the linear prediction.

**nu0** calculates the predicted number of events, assuming a zero random or fixed effect.

**iru0** calculates the predicted incidence rate, assuming a zero random or fixed effect.

**pr0(*n*)** calculates the probability  $\Pr(y = n)$  assuming the random effect is zero, where *n* is a nonnegative integer that may be specified as a number or a variable (only allowed after **xtnbreg, re**).

**pr0(*a*,*b*)** calculates the probability  $\Pr(a \leq y \leq b)$  assuming the random effect is zero, where *a* and *b* are nonnegative integers that may be specified as numbers or variables (only allowed after **xtnbreg, re**);

*b* missing ( $b \geq .$ ) means  $+\infty$ ;

**pr0(20,.)** calculates  $\Pr(y \geq 20)$ ;

**pr0(20,*b*)** calculates  $\Pr(y \geq 20)$  in observations for which  $b \geq .$  and calculates  $\Pr(20 \leq y \leq b)$  elsewhere.

**pr0(. ,*b*)** produces a syntax error. A missing value in an observation on the variable *a* causes a missing value in that observation for **pr0(*a*,*b*)**.

**score** calculates the equation-level score,  $u_{it} = \partial \ln L(\mathbf{x}_{it}\boldsymbol{\beta}) / \partial (\mathbf{x}_{it}\boldsymbol{\beta})$ .

**nooffset** is relevant only if you specified **offset(*varname*)** for **xtnbreg**. It modifies the calculations made by **predict** so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\boldsymbol{\beta}$  rather than  $\mathbf{x}_{it}\boldsymbol{\beta} + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions, numbers of events, incidence rates, and probabilities.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist], predict(statistic ...) [predict(statistic ...) ...] [options]
```

*Random-effects (RE) and conditional fixed-effects (FE) overdispersion models*

statistic	Description
xb	linear prediction; the default
nu0	predicted number of events; assumes fixed or random effect is zero
iru0	predicted incidence rate; assumes fixed or random effect is zero
pr0( <i>n</i> )	probability $\Pr(y = n)$ assuming the random effect is zero; only allowed after <code>xtnbreg, re</code>
pr0( <i>a,b</i> )	probability $\Pr(a \leq y \leq b)$ assuming the random effect is zero; only allowed after <code>xtnbreg, re</code>
stdp	not allowed with <code>margins</code>

*Population-averaged (PA) model*

statistic	Description
mu	predicted number of events; considers the <code>offset()</code> ; the default
rate	predicted number of events
xb	linear prediction
stdp	not allowed with <code>margins</code>
score	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

## Methods and formulas

The probabilities calculated using the `pr0(n)` option are the probability  $\Pr(y_{it} = n)$  for a RE model assuming the random effect is zero. A negative binomial model is an overdispersed Poisson model, and the nominal overdispersion can be calculated as  $\delta = s/(r - 1)$ , where  $r$  and  $s$  are as given in the estimation results. Define  $\mu_{it} = \exp(\mathbf{x}_{it}\boldsymbol{\beta} + \text{offset}_{it})$ . Then the probabilities in `pr0(n)` are calculated as the probability that  $y_{it} = n$ , where  $y_{it}$  has a negative binomial distribution with mean  $\delta\mu_{it}$  and variance  $\delta(1 + \delta)\mu_{it}$ .

## Also see

[XT] **xtnbreg** — Fixed-effects, random-effects, & population-averaged negative binomial models

[U] **20 Estimation and postestimation commands**

**xtologit** — Random-effects ordered logistic models

Description  
Options  
References

Quick start  
Remarks and examples  
Also see

Menu  
Stored results

Syntax  
Methods and formulas

## Description

**xtologit** fits random-effects ordered logistic models. The actual values taken on by the dependent variable are irrelevant, although larger values are assumed to correspond to “higher” outcomes. The conditional distribution of the dependent variable given the random effects is assumed to be multinomial with success probability determined by the logistic cumulative distribution function.

## Quick start

Random-effects ordered logistic model of *y* as a function of *x* using `xtset` data

```
xtologit y x
```

Add `indicators` for levels of categorical variable *a*

```
xtologit y x i.a
```

As above, but report odds ratios

```
xtologit y x i.a, or
```

With cluster-robust standard errors for panels nested within *cvar*

```
xtologit y x i.a, vce(cluster cvar)
```

## Menu

Statistics > Longitudinal/panel data > Ordinal outcomes > Logistic regression (RE)

## Syntax

**xtologit** *depvar* [*indepvars*] [*if*] [*in*] [*weight*] [, *options*]

<i>options</i>	Description
Model	
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> ( <i>constraints</i> )	apply specified linear constraints
SE/Robust	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>or</u>	report odds ratios
<u>lrmodel</u>	perform the likelihood-ratio model test instead of the default Wald test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> ( <i>intmethod</i> )	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is <u>intpoints</u> (12)
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>startgrid</u> ( <i>numlist</i> )	improve starting value of the random-intercept parameter by performing a grid search
<u>nodisplay</u>	suppress display of header and coefficients
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

A panel variable must be specified; see [XT] xtset.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

*depvar* and *indepvars* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

*by*, *fp*, and *statsby* are allowed; see [U] 11.1.10 Prefix commands.

*fweights*, *iweights*, and *pweights* are allowed; see [U] 11.1.6 weight.

*startgrid()*, *nodisplay*, and *coeflegend* do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

`offset(varname)`, `constraints(constraints)`; see [R] [Estimation options](#).

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtologit and the robust VCE estimator](#) in *Methods and formulas*.

### Reporting

`level(#)`; see [R] [Estimation options](#).

`or` reports the estimated coefficients transformed to odds ratios, that is,  $e^b$  rather than  $b$ . Standard errors and confidence intervals are similarly transformed. This option affects how results are displayed, not how they are estimated. `or` may be specified at estimation or when replaying previously estimated results.

`lrmodel`, `nocnsreport`; see [R] [Estimation options](#).

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

### Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] [Estimation options](#).

### Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] [Maximize](#). These options are seldom used.

The following options are available with `xtologit` but are not shown in the dialog box:

`startgrid(numlist)` performs a grid search to improve the starting value of the random-intercept parameter. No grid search is performed by default unless the starting value is found to not be feasible; in this case, `xtologit` runs `startgrid(0.1 1 10)` and chooses the value that works best. You may already be using a default form of `startgrid()` without knowing it. If you see `xtologit` displaying Grid node 1, Grid node 2, ... following Grid node 0 in the iteration log, that is `xtologit` doing a default search because the original starting value was not feasible.

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.

`collinear`, `coeflegend`; see [R] [Estimation options](#).

## Remarks and examples

Remarks are presented under the following headings:

[Overview](#)

[Video example](#)

### Overview

**xtologit** fits random-effects ordered logistic models. Ordered logistic models are used to estimate relationships between an ordinal dependent variable and a set of independent variables. An *ordinal* variable is a variable that is categorical and ordered, for instance, “poor”, “good”, and “excellent”, which might indicate a person’s current health status or the repair record of a car. If there are only two outcomes, see [XT] **xtlogit**, [XT] **xtprobit**, and [XT] **xtcloglog**. This entry is concerned only with more than two outcomes.

### ▷ Example 1

We use the data from the “Television, School, and Family Smoking Prevention and Cessation Project” (Flay et al. 1988; Rabe-Hesketh and Skrondal 2012, chap. 11), where schools were randomly assigned into one of four groups defined by two treatment variables. Students within each school are nested in classes, and classes are nested in schools. In this example, we ignore the variability of classes within schools; see [example 2](#) of [ME] **meologit** for a model that incorporates the additional class-level variance component. The dependent variable is the tobacco and health knowledge score (thk) collapsed into four ordered categories. We regress the outcome on the treatment variables and their interaction and control for the pretreatment score.

```
. use https://www.stata-press.com/data/r16/tvsfpors
. xtset school
    panel variable: school (unbalanced)
. xtologit thk prethk cc##tv
```

Fitting comparison model:

```
Iteration 0:  log likelihood = -2212.775
Iteration 1:  log likelihood = -2125.509
Iteration 2:  log likelihood = -2125.1034
Iteration 3:  log likelihood = -2125.1032
```

Refining starting values:

```
Grid node 0:  log likelihood = -2136.2426
```

Fitting full model:

```
Iteration 0:  log likelihood = -2136.2426 (not concave)
Iteration 1:  log likelihood = -2120.2577
Iteration 2:  log likelihood = -2119.7574
Iteration 3:  log likelihood = -2119.7428
Iteration 4:  log likelihood = -2119.7428
```

```
Random-effects ordered logistic regression          Number of obs      =     1,600
Group variable: school                          Number of groups   =       28
Random effects u_i ~ Gaussian                  Obs per group:
                                                min =           18
                                                avg =         57.1
                                                max =        137
```

```
Integration method: mvaghermite                Integration pts. =       12
                                                Wald chi2(4) =     128.06
                                                Prob > chi2 =     0.0000
```

Log likelihood = -2119.7428

thk	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
prethk	.4032892	.03886	10.38	0.000	.327125 .4794534
1.cc	.9237904	.204074	4.53	0.000	.5238127 1.323768
1.tv	.2749937	.1977424	1.39	0.164	-.1125744 .6625618
cc##tv					
1 1	-.4659256	.2845963	-1.64	0.102	-1.023724 .0918728
/cut1	-.0884493	.1641062			-.4100916 .233193
/cut2	1.153364	.165616			.8287625 1.477965
/cut3	2.33195	.1734199			1.992053 2.671846
/sigma2_u	.0735112	.0383106			.0264695 .2041551

LR test vs. ologit model: chibar2(01) = 10.72                          Prob >= chibar2 = 0.0005

The estimation table reports the parameter estimates, the estimated cutpoints ( $\kappa_1, \kappa_2, \kappa_3$ ), and the estimated panel-level variance component labeled `sigma2_u`. The parameter estimates can be interpreted just as the output from a standard ordered logistic regression would be interpreted; see [R] `ologit`. For example, we find that students with higher preintervention scores tend to have higher postintervention scores.

Underneath the parameter estimates and the cutpoints, the table shows the estimated variance component. The estimate of  $\sigma_u^2$  is 0.074 with standard error 0.038. The reported likelihood-ratio test shows that there is enough variability between schools to favor a random-effects ordered logistic regression over a standard ordered logistic regression.



## □ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [XT] `quadchk` for details and [XT] `xtprobit` for an example.

Because the `xtologit` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature. □

## Video example

Ordered logistic and probit for panel data

## Stored results

`xtologit` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(k_cat)</code>	number of categories
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(l1_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	$\chi^2$
<code>e(chi2_c)</code>	$\chi^2$ for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

Macros

<code>e(cmd)</code>	<code>meglm</code>
<code>e(cmd2)</code>	<code>xtologit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(covariates)</code>	list of covariates
<code>e(ivar)</code>	variable denoting groups

<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(clustvar)</code>	name of cluster variable
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald or LR; type of model $\chi^2$ test
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of <code>ml</code> method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginswtype)</code>	weight type for <code>margins</code>
<code>e(marginswexp)</code>	weight expression for <code>margins</code>
<code>e(marginsdefault)</code>	default <code>predict()</code> specification for <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>
Matrices	
<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(iolog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(cat)</code>	category values
<code>e(V)</code>	variance-covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance
Functions	
<code>e(sample)</code>	marks estimation sample

## Methods and formulas

`xtologit` fits via maximum likelihood the random-effects model

$$\Pr(y_{it} > k | \boldsymbol{\kappa}, \mathbf{x}_{it}, \nu_i) = H(\mathbf{x}_{it}\boldsymbol{\beta} + \nu_i - \kappa_k)$$

for  $i = 1, \dots, n$  panels, where  $t = 1, \dots, n_i$ ,  $\nu_i$  are independent and identically distributed  $N(0, \sigma_\nu^2)$ , and  $\boldsymbol{\kappa}$  is a set of cutpoints  $\kappa_1, \kappa_2, \dots, \kappa_{K-1}$ , where  $K$  is the number of possible outcomes; and  $H(\cdot)$  is the logistic cumulative distribution function.

From the above, we can derive the probability of observing outcome  $k$  for response  $y_{it}$  as

$$\begin{aligned} p_{itk} &\equiv \Pr(y_{it} = k | \boldsymbol{\kappa}, \mathbf{x}_{it}, \nu_i) = \Pr(\kappa_{k-1} < \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} \leq \kappa_k) \\ &= \Pr(\kappa_{k-1} - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i < \epsilon_{it} \leq \kappa_k - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) \\ &= H(\kappa_k - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) - H(\kappa_{k-1} - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) \\ &= \frac{1}{1 + \exp(-\kappa_k + \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)} - \frac{1}{1 + \exp(-\kappa_{k-1} + \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)} \end{aligned}$$

where  $\kappa_0$  is taken as  $-\infty$  and  $\kappa_K$  is taken as  $+\infty$ . Here  $\mathbf{x}_{it}$  does not contain a constant term, because its effect is absorbed into the cutpoints.

We may also express this model in terms of a latent linear response, where observed ordinal responses  $y_{it}$  are generated from the latent continuous responses, such that

$$y_{it}^* = \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it}$$

and

$$y_{it} = \begin{cases} 1 & \text{if } y_{it}^* \leq \kappa_1 \\ 2 & \text{if } \kappa_1 < y_{it}^* \leq \kappa_2 \\ \vdots & \\ K & \text{if } \kappa_{K-1} < y_{it}^* \end{cases}$$

The errors  $\epsilon_{it}$  are distributed as logistic with mean zero and variance  $\pi^2/3$  and are independent of  $\nu_i$ .

Given a set of panel-level random effects  $\nu_i$ , we can define the conditional distribution for response  $y_{it}$  as

$$\begin{aligned} f(y_{it}, \kappa, \mathbf{x}_{it}\beta + \nu_i) &= \prod_{k=1}^K p_{itk}^{I_k(y_{it})} \\ &= \exp \sum_{k=1}^K \left\{ I_k(y_{it}) \log(p_{itk}) \right\} \end{aligned}$$

where

$$I_k(y_{it}) = \begin{cases} 1 & \text{if } y_{it} = k \\ 0 & \text{otherwise} \end{cases}$$

For panel  $i$ ,  $i = 1, \dots, M$ , the conditional distribution of  $\mathbf{y}_i = (y_{i1}, \dots, y_{in_i})'$  is

$$\prod_{t=1}^{n_i} f(y_{it}, \kappa, \mathbf{x}_{it}\beta + \nu_i)$$

and the panel-level likelihood  $l_i$  is given by

$$\begin{aligned} l_i(\beta, \kappa, \sigma_\nu^2) &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} f(y_{it}, \kappa, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, \kappa, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with  $M$ -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp \{(a_m^*)^2\} f(a_m^*)$$

where the  $w_m^*$  denote the quadrature weights and the  $a_m^*$  denote the quadrature abscissas. The log likelihood,  $L$ , is the sum of the logs of the panel-level likelihoods  $l_i$ .

The default approximation of the log likelihood is by mean–variance adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{it}, \kappa, x_{it}, \sqrt{2\hat{\sigma}_i} a_m^* + \hat{\mu}_i)$$

where  $\hat{\sigma}_i$  and  $\hat{\mu}_i$  are the adaptive parameters for panel  $i$ . The method of calculating the posterior mean and variance and using those parameters for  $\hat{\mu}_i$  and  $\hat{\sigma}_i$  is described in detail in Naylor and Smith (1982) and Skrondal and Rabe-Hesketh (2004). We start with  $\hat{\sigma}_{i,0} = 1$  and  $\hat{\mu}_{i,0} = 0$ , and the posterior means and variances are updated in the  $j$ th iteration. That is, at the  $j$ th iteration of the optimization for  $l_i$ , we use

$$l_{i,j} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,j-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, \kappa, x_{it}, \sqrt{2\hat{\sigma}_{i,j-1}} a_m^* + \hat{\mu}_{i,j-1})$$

Letting

$$\tau_{i,m,j-1} = \sqrt{2\hat{\sigma}_{i,j-1}} a_m^* + \hat{\mu}_{i,j-1}$$

$$\hat{\mu}_{i,j} = \sum_{m=1}^M (\tau_{i,m,j-1}) \frac{\sqrt{2\hat{\sigma}_{i,j-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, \kappa, x_{it}, \tau_{i,m,j-1})}{l_{i,j}}$$

and

$$\hat{\sigma}_{i,j} = \sum_{m=1}^M (\tau_{i,m,j-1})^2 \frac{\sqrt{2\hat{\sigma}_{i,j-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, \kappa, x_{it}, \tau_{i,m,j-1})}{l_{i,j}} - (\hat{\mu}_{i,j})^2$$

This is repeated until  $\hat{\mu}_{i,j}$  and  $\hat{\sigma}_{i,j}$  have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature with the option `intmethod(ghermite)`, where  $\rho = \sigma_\nu^2 / (\sigma_\nu^2 + 1)$ :

$$\begin{aligned} L &= \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \kappa, \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ &\approx \sum_{i=1}^n w_i \log \left[ \frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} f \left\{ y_{it}, \kappa, \mathbf{x}_{it} \beta + a_m^* \left( \frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right] \end{aligned}$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} f(y_{it}, \kappa, \mathbf{x}_{it} \beta + \nu_i)$$

is well approximated by a polynomial. As panel size and  $\rho$  increase, the quadrature approximation can become less accurate. For large  $\rho$ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] `quadchk`) to verify the quadrature approximation used in this command, whichever approximation you choose.

## xtologit and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] **\_robust**, particularly *Introduction* and *Methods and formulas*. Wooldridge (2020) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2020), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in  $\epsilon_{it}$ .

The cluster–robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

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## Also see

- [XT] **xtologit postestimation** — Postestimation tools for xtologit
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtoprobit** — Random-effects ordered probit models
- [XT] **xtset** — Declare data to be panel data
- [ME] **meologit** — Multilevel mixed-effects ordered logistic regression
- [R] **logistic** — Logistic regression, reporting odds ratios
- [R] **logit** — Logistic regression, reporting coefficients
- [U] **20 Estimation and postestimation commands**

**xtologit postestimation** — Postestimation tools for xtologit

Postestimation commands predict margins Remarks and examples  
 Also see

## Postestimation commands

The following postestimation commands are available after `xtologit`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

# predict

## Description for predict

`predict` creates a new variable containing predictions such as linear predictions, probabilities, and standard errors.

## Menu for predict

Statistics > Postestimation

## Syntax for predict

```
predict [ type ] { stub* | newvar | newvarlist } [ if ] [ in ] [ , statistic
outcome(outcome) nooffset ]
```

<i>statistic</i>	Description
<hr/>	
Main	
<i>xb</i>	linear prediction; the default
<i>pr</i>	marginal probability of the specified outcome ( <i>outcome()</i> )
<i>pu0</i>	probability of the specified outcome ( <i>outcome()</i> ) assuming that the random effect is zero
<i>stdp</i>	standard error of the linear prediction

If you do not specify *outcome()*, *pr* and *pu0* (with one new variable specified) assume *outcome(#1)*.

You specify one or *k* new variables with *pr* and *pu0*, where *k* is the number of outcomes.

You specify one new variable with *xb* and *stdp*.

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

## Options for predict

### Main

*xb*, the default, calculates the linear prediction.

*pr* calculates predicted probabilities that are marginal with respect to the random effect, which means that the probabilities are calculated by integrating the prediction function with respect to the random effect over its entire support. Unless otherwise specified, *pr* defaults to the first outcome.

*pu0* calculates predicted probabilities, assuming that the random effect for that observation's panel is zero ( $\nu_i = 0$ ). Unless otherwise specified, *pu0* defaults to the first outcome.

*stdp* calculates the standard error of the linear prediction.

*outcome*(*outcome*) specifies the outcome for which the predicted probabilities are to be calculated. *outcome()* should contain either one value of the dependent variable or one of #1, #2, ..., with #1 meaning the first category of the dependent variable, #2 meaning the second category, etc.

*nooffset* is relevant only if you specified *offset(varname)* for `xtologit`. This option modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\beta$  rather than  $\mathbf{x}_{it}\beta + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions and probabilities.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

`margins [marginlist] [, options]`  
`margins [marginlist] , predict(statistic ...) [predict(statistic ...) ...] [options]`

statistic	Description
default	marginal probability for each outcome
pr	marginal probability of the specified outcome ( <code>outcome()</code> )
pu0	probability of the specified outcome ( <code>outcome()</code> ) assuming that the random effect is zero
xb	linear prediction
stdp	not allowed with <code>margins</code>

`pr` and `pu0` default to the first outcome.

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

### Remarks and examples

#### ▷ Example 1: Predicted marginal probabilities

In example 1 of [\[XT\] xtlogit](#), we modeled the tobacco and health knowledge score (`thk`)—coded 1, 2, 3, 4—among students as a function of two treatments (`cc` and `tv`) using a random-effects ordered logistic model. Here we refit the model, obtain the predicted probabilities for all 4 outcomes, and list the first 10 observations.

```
. use https://www.stata-press.com/data/r16/tvsfpors
. xtset school
    panel variable: school (unbalanced)
. xtologit thk prethk cc##tv
(output omitted)
. predict pr*, pr
(using 12 quadrature points)
. list thk pr1-pr4 in 1/10
```

	thk	pr1	pr2	pr3	pr4
1.	3	.1427312	.2191935	.281714	.3563613
2.	4	.0695318	.1343722	.2459221	.5501739
3.	3	.0695318	.1343722	.2459221	.5501739
4.	4	.1003876	.1756773	.2724781	.4514571
5.	4	.1003876	.1756773	.2724781	.4514571
6.	3	.0695318	.1343722	.2459221	.5501739
7.	2	.1427312	.2191935	.281714	.3563613
8.	4	.0695318	.1343722	.2459221	.5501739
9.	4	.0476276	.0990209	.2082012	.6451503
10.	4	.1003876	.1756773	.2724781	.4514571

For each observation, our best guess for the predicted outcome is the one with the highest predicted probability. For example, for the very first observation in the table above, we would choose outcome 4 as the most likely to occur.



## Also see

[XT] **xtologit** — Random-effects ordered logistic models

[U] **20 Estimation and postestimation commands**

**xtpoprobit** — Random-effects ordered probit models

Description  
Options  
References

Quick start  
Remarks and examples  
Also see

Menu  
Stored results

Syntax  
Methods and formulas

## Description

**xtpoprobit** fits random-effects ordered probit models. The actual values taken on by the dependent variable are irrelevant, although larger values are assumed to correspond to “higher” outcomes. The conditional distribution of the dependent variable given the random effects is assumed to be multinomial, with success probability determined by the standard normal cumulative distribution function.

## Quick start

Random-effects ordered probit model of *y* as a function of *x* using *xtset* data

```
xtpoprobit y x
```

Add indicators for levels of categorical variable *a*

```
xtpoprobit y x i.a
```

With cluster–robust standard errors for panels nested within *cvar*

```
xtpoprobit y x i.a, vce(cluster cvar)
```

## Menu

Statistics > Longitudinal/panel data > Ordinal outcomes > Probit regression (RE)

## Syntax

`xtprobit depvar [indepvars] [if] [in] [weight] [, options]`

<i>options</i>	Description
<hr/>	
Model	
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> ( <i>constraints</i> )	apply specified linear constraints
SE/Robust	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>lrmodel</u>	perform the likelihood-ratio model test instead of the default Wald test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> ( <i>intmethod</i> )	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is <u>intpoints</u> (12)
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>startgrid</u> ( <i>numlist</i> )	improve starting value of the random-intercept parameter by performing a grid search
<u>nodisplay</u>	suppress display of header and coefficients
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

A panel variable must be specified; see [XT] `xtset`.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

*depvar* and *indepvars* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

*by*, *fp*, and *statsby* are allowed; see [U] 11.1.10 Prefix commands.

*fweights*, *iweights*, and *pweights* are allowed; see [U] 11.1.6 weight.

`startgrid()`, `nodisplay`, `collinear`, and `coeflegend` do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

`offset`(*varname*), `constraints`(*constraints*); see [R] Estimation options.

---

**SE/Robust**

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtpoprobit and the robust VCE estimator](#) in *Methods and formulas*.

---

**Reporting**

`level(#)`; see [R] [Estimation options](#).

`lrmodel`, `nocnsreport`; see [R] [Estimation options](#).

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

---

**Integration**

`intmethod(intmethod)`, `intpoints(#)`; see [R] [Estimation options](#).

---

**Maximization**

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `rtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] [Maximize](#). These options are seldom used.

The following options are available with `xtpoprobit` but are not shown in the dialog box:

`startgrid(numlist)` performs a grid search to improve the starting value of the random-intercept parameter. No grid search is performed by default unless the starting value is found to not be feasible; in this case, `xtpoprobit` runs `startgrid(0.1 1 10)` and chooses the value that works best. You may already be using a default form of `startgrid()` without knowing it. If you see `xtpoprobit` displaying Grid node 1, Grid node 2, ... following Grid node 0 in the iteration log, that is `xtpoprobit` doing a default search because the original starting value was not feasible.

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.

`collinear`, `coeflegend`; see [R] [Estimation options](#).

## Remarks and examples

Remarks are presented under the following headings:

[Overview](#)

[Video example](#)

## Overview

`xtpoprobit` fits random-effects ordered probit models. Ordered probit models are used to estimate relationships between an ordinal dependent variable and a set of independent variables. An *ordinal* variable is a variable that is categorical and ordered, for instance, “poor”, “good”, and “excellent”, which might indicate a person’s current health status or the repair record of a car. If there are only two outcomes, see [XT] [xtprobit](#), [XT] [xtlogit](#), and [XT] [xtcloglog](#). This entry is concerned only with more than two outcomes.

## ► Example 1

We use the data from the “Television, School, and Family Smoking Prevention and Cessation Project” (Flay et al. 1988; Rabe-Hesketh and Skrondal 2012, chap. 11), where schools were randomly assigned into one of four groups defined by two treatment variables. Students within each school are nested in classes, and classes are nested in schools. In this example, we ignore the variability of classes within schools; see [example 2](#) of [ME] **meoprobit** for a model that incorporates the additional class-level variance component. The dependent variable is the tobacco and health knowledge score (thk) collapsed into four ordered categories. We regress the outcome on the treatment variables and their interaction and control for the pretreatment score.

```
. use https://www.stata-press.com/data/r16/tvsfpors
```

```
. xtset school  
    panel variable: school (unbalanced)
```

```
. xtpoprobit thk prethk cc##tv
```

```
Fitting comparison model:  
Iteration 0: log likelihood = -2212.775  
Iteration 1: log likelihood = -2127.8111  
Iteration 2: log likelihood = -2127.7612  
Iteration 3: log likelihood = -2127.7612
```

Refining starting values:

Grid node 0: log likelihood = -2149.7302

Fitting full model:

```
Iteration 0: log likelihood = -2149.7302 (not concave)
Iteration 1: log likelihood = -2129.6838 (not concave)
Iteration 2: log likelihood = -2123.5143
Iteration 3: log likelihood = -2122.2896
Iteration 4: log likelihood = -2121.7949
Iteration 5: log likelihood = -2121.7716
Iteration 6: log likelihood = -2121.7715
```

Random-effects ordered probit regression Number of obs = 1,600  
Group variable: school Number of groups = 28

Random effects u\_i ~ Gaussian Obs per group:  
min = 18  
avg = 57.1  
sd = 137

Integration method: myagromrite Integration pts = 12

Integration pts = 12

Wald chi2(4) = 128.05

Prob > chi2 = 0.0000

Log likelihood = -2121.7715

Prob > chi<sup>2</sup> = 0.0000

thk	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
prethk	.2369804	.0227739	10.41	0.000	.1923444 .2816164
1.cc	.5490957	.1255108	4.37	0.000	.303099 .7950923
1.tv	.1695405	.1215889	1.39	0.163	-.0687693 .4078504
cc#tv					
1 1	-.2951837	.1751969	-1.68	0.092	-.6385634 .0481959
/cut1	-.0682011	.1003374			-.2648587 .1284565
/cut2	.67681	.1008836			.4790817 .8745382
/cut3	1.390649	.1037494			1.187304 1.593995
/sigma2_u	.0288527	.0146201			.0106874 .0778937

LR test vs. oprobit model: chibar2(01) = 11.98

Prob >= chibar2 = 0.0003

The estimation table reports the parameter estimates, the estimated cutpoints ( $\kappa_1, \kappa_2, \kappa_3$ ), and the estimated panel-level variance component labeled `sigma2_u`. The parameter estimates can be interpreted just as the output from a standard ordered probit regression would be interpreted; see [R] **oprobit**. For example, we find that students with higher preintervention scores tend to have higher postintervention scores.

Underneath the parameter estimates and the cutpoints, the table shows the estimated variance component. The estimate of  $\sigma_u^2$  is 0.029 with standard error 0.015. The reported likelihood-ratio test shows that there is enough variability between schools to favor a random-effects ordered probit regression over a standard ordered probit regression.



## □ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [XT] **quadchk** for details and [XT] **xtpoprobit** for an example.

Because the `xtpoprobit` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.



## Video example

[Ordered logistic and probit for panel data](#)

## Stored results

`xtpoprobit` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(k_cat)</code>	number of categories
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(l1_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	$\chi^2$
<code>e(chi2_c)</code>	$\chi^2$ for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size

<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise
<b>Macros</b>	
<code>e(cmd)</code>	<code>meglm</code>
<code>e(cmd2)</code>	<code>xtoprobit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(covariates)</code>	list of covariates
<code>e(ivar)</code>	variable denoting groups
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(clustvar)</code>	name of cluster variable
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald or LR; type of model $\chi^2$ test
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(intmethod)</code>	integration method
<code>e(distrib)</code>	Gaussian; the distribution of the random effect
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	max or min; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of ml method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginswtype)</code>	weight type for <code>margins</code>
<code>e(marginswexp)</code>	weight expression for <code>margins</code>
<code>e(marginsdefault)</code>	default <code>predict()</code> specification for <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>
<b>Matrices</b>	
<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(cat)</code>	category values
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance
<b>Functions</b>	
<code>e(sample)</code>	marks estimation sample

## Methods and formulas

`xtoprobit` fits via maximum likelihood the random-effects model

$$\Pr(y_{it} > k | \boldsymbol{\kappa}, \mathbf{x}_{it}, \nu_i) = \Phi(\mathbf{x}_{it}\boldsymbol{\beta} + \nu_i - \kappa_k)$$

for  $i = 1, \dots, n$  panels, where  $t = 1, \dots, n_i$ ,  $\nu_i$  are independent and identically distributed  $N(0, \sigma_\nu^2)$ , and  $\boldsymbol{\kappa}$  is a set of cutpoints  $\kappa_1, \kappa_2, \dots, \kappa_{K-1}$ , where  $K$  is the number of possible outcomes; and  $\Phi(\cdot)$  is the standard normal cumulative distribution function.

From the above, we can derive the probability of observing outcome  $k$  for response  $y_{it}$  as

$$\begin{aligned} p_{itk} &\equiv \Pr(y_{it} = k | \boldsymbol{\kappa}, \mathbf{x}_{it}, \nu_i) = \Pr(\kappa_{k-1} < \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} \leq \kappa_k) \\ &= \Pr(\kappa_{k-1} - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i < \epsilon_{it} \leq \kappa_k - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) \\ &= \Phi(\kappa_k - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) - \Phi(\kappa_{k-1} - \mathbf{x}_{it}\boldsymbol{\beta} - \nu_i) \end{aligned}$$

where  $\kappa_0$  is taken as  $-\infty$ , and  $\kappa_K$  is taken as  $+\infty$ . Here  $\mathbf{x}_{it}$  does not contain a constant term, because its effect is absorbed into the cutpoints.

We may also express this model in terms of a latent linear response, where observed ordinal responses  $y_{it}$  are generated from the latent continuous responses, such that

$$y_{it}^* = \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it}$$

and

$$y_{it} = \begin{cases} 1 & \text{if } y_{it}^* \leq \kappa_1 \\ 2 & \text{if } \kappa_1 < y_{it}^* \leq \kappa_2 \\ \vdots & \\ K & \text{if } \kappa_{K-1} < y_{it}^* \end{cases}$$

The errors  $\epsilon_{it}$  are distributed as standard normal with mean zero and variance one and are independent of  $\nu_i$ .

Given a set of panel-level random effects  $\nu_i$ , we can define the conditional distribution for response  $y_{it}$  as

$$\begin{aligned} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) &= \prod_{k=1}^K p_{itk}^{I_k(y_{it})} \\ &= \exp \sum_{k=1}^K \left\{ I_k(y_{it}) \log(p_{itk}) \right\} \end{aligned}$$

where

$$I_k(y_{it}) = \begin{cases} 1 & \text{if } y_{it} = k \\ 0 & \text{otherwise} \end{cases}$$

For panel  $i$ ,  $i = 1, \dots, M$ , the conditional distribution of  $\mathbf{y}_i = (y_{i1}, \dots, y_{in_i})'$  is

$$\prod_{t=1}^{n_i} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

and the panel-level likelihood  $l_i$  is given by

$$\begin{aligned} l_i(\boldsymbol{\beta}, \boldsymbol{\kappa}, \sigma_\nu^2) &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} f(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, \boldsymbol{\kappa}, \mathbf{x}_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with  $M$ -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the  $w_m^*$  denote the quadrature weights and the  $a_m^*$  denote the quadrature abscissas. The log likelihood,  $L$ , is the sum of the logs of the panel-level likelihoods  $l_i$ .

The default approximation of the log likelihood is by mean–variance adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{it}, \kappa, x_{it}, \sqrt{2\hat{\sigma}_i} a_m^* + \hat{\mu}_i)$$

where  $\hat{\sigma}_i$  and  $\hat{\mu}_i$  are the adaptive parameters for panel  $i$ . The method of calculating the posterior mean and variance and using those parameters for  $\hat{\mu}_i$  and  $\hat{\sigma}_i$  is described in detail in [Naylor and Smith \(1982\)](#) and [Skrondal and Rabe-Hesketh \(2004\)](#). We start with  $\hat{\sigma}_{i,0} = 1$  and  $\hat{\mu}_{i,0} = 0$ , and the posterior means and variances are updated in the  $j$ th iteration. That is, at the  $j$ th iteration of the optimization for  $l_i$ , we use

$$l_{i,j} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,j-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, \kappa, x_{it}, \sqrt{2\hat{\sigma}_{i,j-1}} a_m^* + \hat{\mu}_{i,j-1})$$

Letting

$$\tau_{i,m,j-1} = \sqrt{2\hat{\sigma}_{i,j-1}} a_m^* + \hat{\mu}_{i,j-1}$$

$$\hat{\mu}_{i,j} = \sum_{m=1}^M (\tau_{i,m,j-1}) \frac{\sqrt{2\hat{\sigma}_{i,j-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, \kappa, x_{it}, \tau_{i,m,j-1})}{l_{i,j}}$$

and

$$\hat{\sigma}_{i,j} = \sum_{m=1}^M (\tau_{i,m,j-1})^2 \frac{\sqrt{2\hat{\sigma}_{i,j-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, \kappa, x_{it}, \tau_{i,m,j-1})}{l_{i,j}} - (\hat{\mu}_{i,j})^2$$

This is repeated until  $\hat{\mu}_{i,j}$  and  $\hat{\sigma}_{i,j}$  have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature with the option `intmethod(ghermite)`, where  $\rho = \sigma_\nu^2 / (\sigma_\nu^2 + 1)$ :

$$\begin{aligned} L &= \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \kappa, \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ &\approx \sum_{i=1}^n w_i \log \left[ \frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} f \left\{ y_{it}, \kappa, \mathbf{x}_{it} \beta + a_m^* \left( \frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right] \end{aligned}$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} f(y_{it}, \kappa, \mathbf{x}_{it}\beta + \nu_i)$$

is well approximated by a polynomial. As panel size and  $\rho$  increase, the quadrature approximation can become less accurate. For large  $\rho$ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] `quadchk`) to verify the quadrature approximation used in this command, whichever approximation you choose.

## xtporbit and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] `robust`, particularly *Introduction* and *Methods and formulas*. Wooldridge (2020) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2020), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in  $\epsilon_{it}$ .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

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## Also see

- [XT] **xtpoprobit** — Postestimation tools for xtpoprobit
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xteoprobit** — Extended random-effects ordered probit regression
- [XT] **xtologit** — Random-effects ordered logistic models
- [XT] **xtset** — Declare data to be panel data
- [ME] **meoprobit** — Multilevel mixed-effects ordered probit regression
- [R] **probit** — Probit regression
- [U] **20 Estimation and postestimation commands**

## Postestimation commands

The following postestimation commands are available after `xtpoprobit`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions, probabilities, and standard errors.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

```
predict [ type ] { stub* | newvar | newvarlist } [ if ] [ in ] [ , statistic
outcome(outcome) nooffset ]
```

<i>statistic</i>	Description
<hr/>	
Main	
<i>xb</i>	linear prediction; the default
<i>pr</i>	marginal probability of the specified outcome ( <i>outcome()</i> )
<i>pu0</i>	probability of the specified outcome ( <i>outcome()</i> ) assuming that the random effect is zero
<i>stdp</i>	standard error of the linear prediction

If you do not specify *outcome()*, *pr* and *pu0* (with one new variable specified) assume *outcome(#1)*.

You specify one or *k* new variables with *pr* and *pu0*, where *k* is the number of outcomes.

You specify one new variable with *xb* and *stdp*.

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

### Options for predict

#### Main

*xb*, the default, calculates the linear prediction.

*pr* calculates predicted probabilities that are marginal with respect to the random effect, which means that the probabilities are calculated by integrating the prediction function with respect to the random effect over its entire support. Unless otherwise specified, *pr* defaults to the first outcome.

*pu0* calculates predicted probabilities, assuming that the random effect for that observation's panel is zero ( $\nu_i = 0$ ). Unless otherwise specified, *pu0* defaults to the first outcome.

*stdp* calculates the standard error of the linear prediction.

*outcome*(*outcome*) specifies the outcome for which the predicted probabilities are to be calculated. *outcome()* should contain either one value of the dependent variable or one of #1, #2, ..., with #1 meaning the first category of the dependent variable, #2 meaning the second category, etc.

*nooffset* is relevant only if you specified *offset(varname)* for `xtoprobit`. This option modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\beta$  rather than  $\mathbf{x}_{it}\beta + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions and probabilities.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]  
margins [marginlist] , predict(statistic ...) [predict(statistic ...) ...] [options]
```

<i>statistic</i>	Description
default	marginal probability for each outcome
pr	marginal probability of the specified outcome ( <code>outcome()</code> )
pu0	probability of the specified outcome ( <code>outcome()</code> ) assuming that the random effect is zero
xb	linear prediction
stdp	not allowed with <code>margins</code>

`pr` and `pu0` default to the first outcome.

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] **margins**.

## Remarks and examples

### ▷ Example 1: Predicted marginal probabilities

In example 1 of [XT] **xtpoprobit**, we modeled the tobacco and health knowledge score (`thk`)—coded 1, 2, 3, 4—among students as a function of two treatments (`cc` and `tv`) using a random-effects ordered probit model. Here we refit the model, obtain the predicted probabilities for all 4 outcomes, and list the first 10 observations.

```
. use https://www.stata-press.com/data/r16/tvsfpors
. xtset school
    panel variable: school (unbalanced)
. xtoprobit thk prethk cc##tv
(output omitted)
. predict pr*, pr
(using 12 quadrature points)
. list thk pr1-pr4 in 1/10
```

	thk	pr1	pr2	pr3	pr4
1.	3	.1409978	.2254197	.2750568	.3585258
2.	4	.0614014	.1479641	.2488757	.5417588
3.	3	.0614014	.1479641	.2488757	.5417588
4.	4	.0951857	.187463	.2685807	.4487706
5.	4	.0951857	.187463	.2685807	.4487706
6.	3	.0614014	.1479641	.2488757	.5417588
7.	2	.1409978	.2254197	.2750568	.3585258
8.	4	.0614014	.1479641	.2488757	.5417588
9.	4	.0378048	.1108411	.2188475	.6325067
10.	4	.0951857	.187463	.2685807	.4487706

For each observation, our best guess for the predicted outcome is the one with the highest predicted probability. For example, for the very first observation in the table above, we would choose outcome 4 as the most likely to occur.



## Also see

[XT] **xtprobit** — Random-effects ordered probit models

[U] **20 Estimation and postestimation commands**

**xtpcse** — Linear regression with panel-corrected standard errors

Description

Options

Acknowledgments

Quick start

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Menu

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Also see

Syntax

Methods and formulas

## Description

**xtpcse** calculates panel-corrected standard error (PCSE) estimates for linear cross-sectional time-series models where the parameters are estimated by either OLS or Prais–Winsten regression. When computing the standard errors and the variance–covariance estimates, **xtpcse** assumes that the disturbances are, by default, heteroskedastic and contemporaneously correlated across panels.

See [XT] **xtgls** for the generalized least-squares estimator for these models.

## Quick start

Linear regression of *y* on *x1* and *x2* with panel-corrected standard errors and assuming no within-panel autocorrelation using **xtset** data

```
xtpcse y x1 x2
```

As above, but specify a common first-order autocorrelation within panels

```
xtpcse y x1 x2, correlation(ar1)
```

Within-panel heteroskedastic errors but no contemporaneous correlation between panels

```
xtpcse y x1 x2, hetonly
```

Let autocorrelation structure be panel-specific estimated by time-series methods

```
xtpcse y x1 x2, correlation(psar1) rhotype(tscorr)
```

## Menu

Statistics > Longitudinal/panel data > Contemporaneous correlation > Regression with panel-corrected standard errors (PCSE)

## Syntax

`xtpcse depvar [indepvars] [if] [in] [weight] [, options]`

<i>options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term
<u>correlation(independent)</u>	use independent autocorrelation structure
<u>correlation(ar1)</u>	use AR1 autocorrelation structure
<u>correlation(psar1)</u>	use panel-specific AR1 autocorrelation structure
<u>rhototype(calc)</u>	specify method to compute autocorrelation parameter; seldom used
<u>np1</u>	weight panel-specific autocorrelations by panel sizes
<u>hetonly</u>	assume panel-level heteroskedastic errors
<u>independent</u>	assume independent errors across panels
<b>by/if/in</b>	
<u>casewise</u>	include only observations with complete cases
<u>pairwise</u>	include all available observations with nonmissing pairs
<b>SE</b>	
<u>nmk</u>	normalize standard errors by $N - k$ instead of $N$
<b>Reporting</b>	
<u>level(#)</u>	set confidence level; default is <code>level(95)</code>
<u>detail</u>	report list of gaps in time series
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<u>coeflegend</u>	display legend instead of statistics

A panel variable and a time variable must be specified; use `xtset`; see [XT] `xtset`.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

*depvar* and *indepvars* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by` and `statsby` are allowed; see [U] 11.1.10 Prefix commands.

`iweights` and `aweights` are allowed; see [U] 11.1.6 weight.

`coeflegend` does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

`noconstant`; see [R] Estimation options.

`correlation(corr)` specifies the form of assumed autocorrelation within panels.

`correlation(independent)`, the default, specifies that there is no autocorrelation.

`correlation(ar1)` specifies that, within panels, there is first-order autocorrelation AR(1) and that the coefficient of the AR(1) process is common to all the panels.

`correlation(psar1)` specifies that, within panels, there is first-order autocorrelation and that the coefficient of the AR(1) process is specific to each panel. `psar1` stands for panel-specific AR(1).

`rhototype(calc)` specifies the method to be used to calculate the autocorrelation parameter. Allowed strings for `calc` are

<code>regress</code>	regression using lags; the default
<code>freg</code>	regression using leads
<code>tscorr</code>	time-series autocorrelation calculation
<code>dw</code>	Durbin–Watson calculation

All the above methods are consistent and asymptotically equivalent; this is a rarely used option.

`np1` specifies that the panel-specific autocorrelations be weighted by  $T_i$  rather than by the default  $T_i - 1$  when estimating a common  $\rho$  for all panels, where  $T_i$  is the number of observations in panel  $i$ . This option has an effect only when panels are unbalanced and the `correlation(ar1)` option is specified.

`hetonly` and `independent` specify alternative forms for the assumed covariance of the disturbances across the panels. If neither is specified, the disturbances are assumed to be heteroskedastic (each panel has its own variance) and contemporaneously correlated across the panels (each pair of panels has its own covariance). This is the standard PCSE model.

`hetonly` specifies that the disturbances are assumed to be panel-level heteroskedastic only with no contemporaneous correlation across panels.

`independent` specifies that the disturbances are assumed to be independent across panels; that is, there is one disturbance variance common to all observations.

by/if/in

`casewise` and `pairwise` specify how missing observations in unbalanced panels are to be treated when estimating the interpanel covariance matrix of the disturbances. The default is `casewise` selection.

`casewise` specifies that the entire covariance matrix be computed only on the observations (periods) that are available for all panels. If an observation has missing data, all observations of that period are excluded when estimating the covariance matrix of disturbances. Specifying `casewise` ensures that the estimated covariance matrix will be of full rank and will be positive definite.

`pairwise` specifies that, for each element in the covariance matrix, all available observations (periods) that are common to the two panels contributing to the covariance be used to compute the covariance.

The `casewise` and `pairwise` options have an effect only when the panels are unbalanced and neither `hetonly` nor `independent` is specified.

SE

`nmk` specifies that standard errors be normalized by  $N - k$ , where  $k$  is the number of parameters estimated, rather than  $N$ , the number of observations. Different authors have used one or the other normalization. Greene (2018, 313) remarks that whether a degree-of-freedom correction improves the small-sample properties is an open question.

Reporting

`level(#); see [R] Estimation options.`

`detail` specifies that a detailed list of any gaps in the series be reported.

*display\_options:* `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] **Estimation options**.

The following option is available with `xtpcse` but is not shown in the dialog box:  
`coeflegend`; see [R] **Estimation options**.

## Remarks and examples

`xtpcse` is an alternative to feasible generalized least squares (FGLS)—see [XT] **xtgls**—for fitting linear cross-sectional time-series models when the disturbances are not assumed to be independent and identically distributed (i.i.d.). Instead, the disturbances are assumed to be either heteroskedastic across panels or heteroskedastic and contemporaneously correlated across panels. The disturbances may also be assumed to be autocorrelated within panel, and the autocorrelation parameter may be constant across panels or different for each panel.

We can write such models as

$$y_{it} = \mathbf{x}_{it}\beta + \epsilon_{it}$$

where  $i = 1, \dots, m$  is the number of units (or panels);  $t = 1, \dots, T_i$ ;  $T_i$  is the number of periods in panel  $i$ ; and  $\epsilon_{it}$  is a disturbance that may be autocorrelated along  $t$  or contemporaneously correlated across  $i$ .

This model can also be written panel by panel as

$$\begin{bmatrix} \mathbf{y}_1 \\ \mathbf{y}_2 \\ \vdots \\ \mathbf{y}_m \end{bmatrix} = \begin{bmatrix} \mathbf{X}_1 \\ \mathbf{X}_2 \\ \vdots \\ \mathbf{X}_m \end{bmatrix} \beta + \begin{bmatrix} \epsilon_1 \\ \epsilon_2 \\ \vdots \\ \epsilon_m \end{bmatrix}$$

For a model with heteroskedastic disturbances and contemporaneous correlation but with no autocorrelation, the disturbance covariance matrix is assumed to be

$$E[\boldsymbol{\epsilon}\boldsymbol{\epsilon}'] = \boldsymbol{\Omega} = \begin{bmatrix} \sigma_{11}\mathbf{I}_{11} & \sigma_{12}\mathbf{I}_{12} & \cdots & \sigma_{1m}\mathbf{I}_{1m} \\ \sigma_{21}\mathbf{I}_{21} & \sigma_{22}\mathbf{I}_{22} & \cdots & \sigma_{2m}\mathbf{I}_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{m1}\mathbf{I}_{m1} & \sigma_{m2}\mathbf{I}_{m2} & \cdots & \sigma_{mm}\mathbf{I}_{mm} \end{bmatrix}$$

where  $\sigma_{ii}$  is the variance of the disturbances for panel  $i$ ,  $\sigma_{ij}$  is the covariance of the disturbances between panel  $i$  and panel  $j$  when the panels' periods are matched, and  $\mathbf{I}$  is a  $T_i$  by  $T_i$  identity matrix with balanced panels. The panels need not be balanced for `xtpcse`, but the expression for the covariance of the disturbances will be more general if they are unbalanced.

This could also be written as

$$E[\boldsymbol{\epsilon}\boldsymbol{\epsilon}'] = \boldsymbol{\Sigma}_{m \times m} \otimes \mathbf{I}_{T_i \times T_i}$$

where  $\boldsymbol{\Sigma}$  is the panel-by-panel covariance matrix and  $\mathbf{I}$  is an identity matrix.

See [XT] **xtgls** for a full taxonomy and description of possible disturbance covariance structures.

**xtpcse** and **xtgls** follow two different estimation schemes for this family of models. **xtpcse** produces OLS estimates of the parameters when no autocorrelation is specified, or Prais–Winsten (see [TS] **prais**) estimates when autocorrelation is specified. If autocorrelation is specified, the estimates of the parameters are conditional on the estimates of the autocorrelation parameter(s). The estimate of the variance–covariance matrix of the parameters is asymptotically efficient under the assumed covariance structure of the disturbances and uses the FGLS estimate of the disturbance covariance matrix; see Kmenta (1997, 121).

**xtgls** produces full FGLS parameter and variance–covariance estimates. These estimates are conditional on the estimates of the disturbance covariance matrix and are conditional on any autocorrelation parameters that are estimated; see Kmenta (1997), Greene (2018), Davidson and MacKinnon (1993), or Judge et al. (1985).

Both estimators are consistent, as long as the conditional mean ( $x_{it}\beta$ ) is correctly specified. If the assumed covariance structure is correct, FGLS estimates produced by **xtgls** are more efficient. Beck and Katz (1995) have shown, however, that the full FGLS variance–covariance estimates are typically unacceptably optimistic (anticonservative) when used with the type of data analyzed by most social scientists—10–20 panels with 10–40 periods per panel. They show that the OLS or Prais–Winsten estimates with PCSEs have coverage probabilities that are closer to nominal.

Because the covariance matrix elements,  $\sigma_{ij}$ , are estimated from panels  $i$  and  $j$ , using those observations that have common time periods, estimators for this model achieve their asymptotic behavior as the  $T_i$ s approach infinity. In contrast, the random- and fixed-effects estimators assume a different model and are asymptotic in the number of panels  $m$ ; see [XT] **xtreg** for details of the random- and fixed-effects estimators.

Although **xtpcse** allows other disturbance covariance structures, the term PCSE, as used in the literature, refers specifically to models that are both heteroskedastic and contemporaneously correlated across panels, with or without autocorrelation.

## ▷ Example 1: Controlling for heteroskedasticity and cross-panel correlation

Grunfeld and Griliches (1960) analyzed a company’s current-year gross investment (**invest**) as determined by the company’s prior year market value (**mvalue**) and the prior year’s value of the company’s plant and equipment (**kstock**). The dataset includes 10 companies over 20 years, from 1935 through 1954, and is a classic dataset for demonstrating cross-sectional time-series analysis. Greene (2012, 1112) reproduces the dataset.

To use **xtpcse**, the data must be organized in “long form”; that is, each observation must represent a record for a specific company at a specific time; see [D] **reshape**. In the Grunfeld data, **company** is a categorical variable identifying the company, and **year** is a variable recording the year. Here are the first few records:

```
. use https://www.stata-press.com/data/r16/grunfeld
. list in 1/5
```

	company	year	invest	mvalue	kstock	time
1.	1	1935	317.6	3078.5	2.8	1
2.	1	1936	391.8	4661.7	52.6	2
3.	1	1937	410.6	5387.1	156.9	3
4.	1	1938	257.7	2792.2	209.2	4
5.	1	1939	330.8	4313.2	203.4	5

To compute PCSEs, Stata must be able to identify the panel to which each observation belongs and be able to match the periods across the panels. We tell Stata how to do this matching by specifying

the panel and time variables with `xtset`; see [XT] `xtset`. Because the data are annual, we specify the `yearly` option.

```
. xtset company year, yearly
      panel variable: company (strongly balanced)
      time variable: year, 1935 to 1954
                  delta: 1 year
```

We can obtain OLS parameter estimates for a linear model of `invest` on `mvalue` and `kstock` while allowing the standard errors (and variance–covariance matrix of the estimates) to be consistent when the disturbances from each observation are not independent. Specifically, we want the standard errors to be robust to each company having a different variance of the disturbances and to each company's observations being correlated with those of the other companies through time.

This model is fit in Stata by typing

```
. xtpcse invest mvalue kstock
      Linear regression, correlated panels corrected standard errors (PCSEs)
      Group variable: company                               Number of obs     =      200
      Time variable: year                                 Number of groups  =       10
      Panels: correlated (balanced)                      Obs per group:
      Autocorrelation: no autocorrelation                min =        20
                                                               avg =        20
                                                               max =        20
      Estimated covariances     =      55          R-squared        =    0.8124
      Estimated autocorrelations =      0          Wald chi2(2)     =   637.41
      Estimated coefficients    =      3          Prob > chi2     =    0.0000
```

invest	Panel-corrected					[95% Conf. Interval]
	Coef.	Std. Err.	z	P> z		
mvalue	.1155622	.0072124	16.02	0.000	.101426	.1296983
kstock	.2306785	.0278862	8.27	0.000	.1760225	.2853345
_cons	-42.71437	6.780965	-6.30	0.000	-56.00482	-29.42392



## ▷ Example 2: Comparing the FGLS and PCSE approaches

`xtgls` will produce more efficient FGLS estimates of the models' parameters, but with the disadvantage that the standard error estimates are conditional on the estimated disturbance covariance. Beck and Katz (1995) argue that the improvement in power using FGLS with such data is small and that the standard error estimates from FGLS are unacceptably optimistic (anticonservative).

The FGLS model is fit by typing

```
. xtgls invest mvalue kstock, panels(correlated)
Cross-sectional time-series FGLS regression
Coefficients: generalized least squares
Panels: heteroskedastic with cross-sectional correlation
Correlation: no autocorrelation

Estimated covariances      =      55          Number of obs      =      200
Estimated autocorrelations =      0          Number of groups   =       10
Estimated coefficients     =      3          Time periods     =       20
                                         Wald chi2(2)    =    3738.07
                                         Prob > chi2    =    0.0000
```

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
mvalue	.1127515	.0022364	50.42	0.000	.1083683 .1171347
kstock	.2231176	.0057363	38.90	0.000	.2118746 .2343605
_cons	-39.84382	1.717563	-23.20	0.000	-43.21018 -36.47746

The coefficients between the two models are close; the constants differ substantially, but we are generally not interested in the constant. As Beck and Katz observed, the standard errors for the FGLS model are 50%–100% smaller than those for the OLS model with PCSE.

If we were also concerned about autocorrelation of the disturbances, we could obtain a model with a common AR(1) parameter by specifying `correlation(ar1)`.

```
. xtpcse invest mvalue kstock, correlation(ar1)
(note: estimates of rho outside [-1,1] bounded to be in the range [-1,1])

Prais-Winsten regression, correlated panels corrected standard errors (PCSEs)

Group variable: company          Number of obs      =      200
Time variable: year              Number of groups   =       10
Panels: correlated (balanced)   Obs per group:
Autocorrelation: common AR(1)    min =        20
                                         avg =        20
                                         max =        20
Estimated covariances      =      55          R-squared      =    0.5468
Estimated autocorrelations =      1          Wald chi2(2)    =    93.71
Estimated coefficients     =      3          Prob > chi2    =    0.0000
```

invest	Panel-corrected				
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
mvalue	.0950157	.0129934	7.31	0.000	.0695492 .1204822
kstock	.306005	.0603718	5.07	0.000	.1876784 .4243317
_cons	-39.12569	30.50355	-1.28	0.200	-98.91154 20.66016
rho	.9059774				

The estimate of the autocorrelation parameter is high (0.906), and the standard errors are larger than for the model without autocorrelation, which is to be expected if there is autocorrelation.



## ▷ Example 3: Controlling for cross-panel correlation and autocorrelation

Let's estimate panel-specific autocorrelation parameters and change the method of estimating the autocorrelation parameter to the one typically used to estimate autocorrelation in time-series analysis.

. xtpcse invest mvalue kstock, correlation(psar1) rhotype(tscorr)						
Prais-Winsten regression, correlated panels corrected standard errors (PCSEs)						
Group variable:	company	Number of obs	=	200		
Time variable:	year	Number of groups	=	10		
Panels:	correlated (balanced)	Obs per group:				
Autocorrelation:	panel-specific AR(1)	min	=	20		
		avg	=	20		
		max	=	20		
Estimated covariances	= 55	R-squared	=	0.8670		
Estimated autocorrelations	= 10	Wald chi2(2)	=	444.53		
Estimated coefficients	= 3	Prob > chi2	=	0.0000		
<hr/>						
invest	Panel-corrected					
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
mvalue	.1052613	.0086018	12.24	0.000	.0884021	.1221205
kstock	.3386743	.0367568	9.21	0.000	.2666322	.4107163
_cons	-58.18714	12.63687	-4.60	0.000	-82.95496	-33.41933
<hr/>						
rhos = .5135627	.87017	.9023497	.63368	.8571502	...	.8752707

Beck and Katz (1995, 121) make a case against estimating panel-specific AR parameters, as opposed to one AR parameter for all panels.



## ▷ Example 4: Controlling for heteroskedasticity only; not quite PCSEs

We can also diverge from PCSEs to estimate standard errors that are panel corrected, but only for panel-level heteroskedasticity; that is, each company has a different variance of the disturbances. Allowing also for autocorrelation, we would type

. xtpcse invest mvalue kstock, correlation(ar1) hetonly						
(note: estimates of rho outside [-1,1] bounded to be in the range [-1,1])						
Prais-Winsten regression, heteroskedastic panels corrected standard errors						
Group variable:	company	Number of obs	=	200		
Time variable:	year	Number of groups	=	10		
Panels:	heteroskedastic (balanced)	Obs per group:				
Autocorrelation:	common AR(1)	min	=	20		
		avg	=	20		
		max	=	20		
Estimated covariances	= 10	R-squared	=	0.5468		
Estimated autocorrelations	= 1	Wald chi2(2)	=	91.72		
Estimated coefficients	= 3	Prob > chi2	=	0.0000		
<hr/>						
invest	Het-corrected					
	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
mvalue	.0950157	.0130872	7.26	0.000	.0693653	.1206661
kstock	.306005	.061432	4.98	0.000	.1856006	.4264095
_cons	-39.12569	26.16935	-1.50	0.135	-90.41666	12.16529
<hr/>						
rho	.9059774					

With this specification, we do not obtain what are referred to in the literature as PCSEs. These standard errors are in the same spirit as PCSEs but are from the asymptotic covariance estimates of OLS without allowing for contemporaneous correlation.



## Stored results

**xtpcse** stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_gaps)</code>	number of gaps
<code>e(n_cf)</code>	number of estimated coefficients
<code>e(n_cv)</code>	number of estimated covariances
<code>e(n_cr)</code>	number of estimated correlations
<code>e(n_sigma)</code>	observations used to estimate elements of <code>Sigma</code>
<code>e(mss)</code>	model sum of squares
<code>e(df)</code>	degrees of freedom
<code>e(df_m)</code>	model degrees of freedom
<code>e(rss)</code>	residual sum of squares
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(r2)</code>	<i>R</i> -squared
<code>e(chi2)</code>	$\chi^2$
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rmse)</code>	root mean squared error
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rc)</code>	return code

Macros

<code>e(cmd)</code>	<code>xtpcse</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(tvars)</code>	variable denoting time within groups
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(panels)</code>	contemporaneous covariance structure
<code>e(corr)</code>	correlation structure
<code>e(rhotype)</code>	type of estimated correlation
<code>e(rho)</code>	$\rho$
<code>e(cons)</code>	noconstant or ""
<code>e(missmeth)</code>	casewise or pairwise
<code>e(balance)</code>	balanced or unbalanced
<code>e(chi2type)</code>	Wald; type of model $\chi^2$ test
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement predict
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables fvset as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables fvset as <code>asobserved</code>

Matrices

<code>e(b)</code>	coefficient vector
<code>e(Sigma)</code>	$\Sigma$ matrix
<code>e(rhomat)</code>	vector of autocorrelation parameter estimates
<code>e(V)</code>	variance–covariance matrix of the estimators

Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

If no autocorrelation is specified, the parameters  $\beta$  are estimated by OLS; see [R] regress. If autocorrelation is specified, the parameters  $\beta$  are estimated by Prais–Winsten; see [TS] prais.

When autocorrelation with panel-specific coefficients of correlation is specified (by using option correlation(psar1)), each panel-level  $\rho_i$  is computed from the residuals of an OLS regression across all panels; see [TS] prais. When autocorrelation with a common coefficient of correlation is specified (by using option correlation(ar1)), the common correlation coefficient is computed as

$$\rho = \frac{\rho_1 + \rho_2 + \cdots + \rho_m}{m}$$

where  $\rho_i$  is the estimated autocorrelation coefficient for panel  $i$  and  $m$  is the number of panels.

The covariance of the OLS or Prais–Winsten coefficients is

$$\text{Var}(\beta) = (\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'\Omega\mathbf{X}(\mathbf{X}'\mathbf{X})^{-1}$$

where  $\Omega$  is the full covariance matrix of the disturbances.

When the panels are balanced, we can write  $\Omega$  as

$$\Omega = \Sigma_{m \times m} \otimes \mathbf{I}_{T_i \times T_i}$$

where  $\Sigma$  is the  $m$  by  $m$  panel-by-panel covariance matrix of the disturbances; see Remarks and examples.

xtpcse estimates the elements of  $\Sigma$  as

$$\widehat{\Sigma}_{ij} = \frac{\epsilon_i' \epsilon_j}{T_{ij}}$$

where  $\epsilon_i$  and  $\epsilon_j$  are the residuals for panels  $i$  and  $j$ , respectively, that can be matched by period, and where  $T_{ij}$  is the number of residuals between the panels  $i$  and  $j$  that can be matched by time period.

When the panels are balanced (each panel has the same number of observations and all periods are common to all panels),  $T_{ij} = T$ , where  $T$  is the number of observations per panel.

When panels are unbalanced, xtpcse by default uses casewise selection, in which only those residuals from periods that are common to all panels are used to compute  $\widehat{S}_{ij}$ . Here  $T_{ij} = T^*$ , where  $T^*$  is the number of periods common to all panels. When pairwise is specified, each  $\widehat{S}_{ij}$  is computed using all observations that can be matched by period between the panels  $i$  and  $j$ .

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## Also see

- [XT] **xtpcse postestimation** — Postestimation tools for xtpcse
- [XT] **xtgls** — Fit panel-data models by using GLS
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance
- [XT] **xtset** — Declare data to be panel data
- [R] **regress** — Linear regression
- [TS] **newey** — Regression with Newey–West standard errors
- [TS] **prais** — Prais–Winsten and Cochrane–Orcutt regression
- [U] **20 Estimation and postestimation commands**

## Postestimation commands

The following postestimation commands are available after `xtpcse`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from <code>margins</code> (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions and standard errors.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

```
predict [type] newvar [if] [in] [, xb stdp]
```

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

### Options for predict

Main

`xb`, the default, calculates the linear prediction.

`stdp` calculates the standard error of the linear prediction.

## margins

### Description for margins

`margins` estimates margins of response for linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist] , predict(statistic ...) [options]
```

<i>statistic</i>	Description
<code>xb</code>	linear prediction, the default
<code>stdp</code>	not allowed with <code>margins</code>

<code>xb</code>	linear prediction, the default
<code>stdp</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] **margins**.

### Also see

[XT] **xtpcse** — Linear regression with panel-corrected standard errors

[U] **20 Estimation and postestimation commands**

**xtpoisson** — Fixed-effects, random-effects, and population-averaged Poisson models

Description	Quick start	Menu
Syntax	Options for RE model	Options for FE model
Options for PA model	Remarks and examples	Stored results
Methods and formulas	References	Also see

## Description

`xtpoisson` fits random-effects, conditional fixed-effects, and population-averaged Poisson models. These models are typically used for a nonnegative count dependent variable.

## Quick start

Random-effects Poisson regression of `y` on `x` and `indicators` for levels of categorical variable `a` using `xtset` data

```
xtpoisson y x i.a
```

Conditional fixed-effects model with exposure variable `evar`

```
xtpoisson y x i.a, fe exposure(evar)
```

Population-averaged model with robust standard errors

```
xtpoisson y x i.a, pa vce(robust)
```

As above, but report incidence-rate ratios

```
xtpoisson y x i.a, pa vce(robust) irr
```

## Menu

Statistics > Longitudinal/panel data > Count outcomes > Poisson regression (FE, RE, PA)

## Syntax

*Random-effects (RE) model*

```
xtpoisson depvar [indepvars] [if] [in] [weight] [, re RE_options]
```

*Conditional fixed-effects (FE) model*

```
xtpoisson depvar [indepvars] [if] [in] [weight], fe FE_options
```

*Population-averaged (PA) model*

```
xtpoisson depvar [indepvars] [if] [in] [weight], pa PA_options
```

<i>RE_options</i>	Description
<hr/>	
Model	
<u>noconstant</u>	suppress constant term
<u>re</u>	use random-effects estimator; the default
<u>exposure(varname)</u>	include <i>ln(varname)</i> in model with coefficient constrained to 1
<u>offset(varname)</u>	include <i>varname</i> in model with coefficient constrained to 1
<u>normal</u>	use a normal distribution for random effects instead of gamma
<u>constraints(constraints)</u>	apply specified linear constraints
SE/Robust	
<u>vce(vcetype)</u>	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster clustvar</u> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level(#)</u>	set confidence level; default is <i>level(95)</i>
<u>irr</u>	report incidence-rate ratios
<u>lrmodel</u>	perform the likelihood-ratio model test instead of the default Wald test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod(intmethod)</u>	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints(#)</u>	use # quadrature points; default is <i>intpoints(12)</i>
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

<i>FE_options</i>	Description
<hr/>	
Model	
<u>fe</u>	use fixed-effects estimator
<u>exposure</u> ( <i>varname</i> )	include $\ln(\text{varname})$ in model with coefficient constrained to 1
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> ( <i>constraints</i> )	apply specified linear constraints
SE/Robust	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>irr</u>	report incidence-rate ratios
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

---

<i>PA_options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>pa</u>	use population-averaged estimator
<u>exposure</u> ( <i>varname</i> )	include $\ln(varname)$ in model with coefficient constrained to 1
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
Correlation	
<u>corr</u> ( <i>correlation</i> )	within-panel correlation structure
<u>force</u>	estimate even if observations unequally spaced in time
SE/Robust	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be conventional, <u>robust</u> , <u>bootstrap</u> , or <u>jackknife</u>
<u>nmp</u>	use divisor $N - P$ instead of the default $N$
<u>scale</u> ( <i>parm</i> )	overrides the default scale parameter; <i>parm</i> may be x2, dev, phi, or #
Reporting	
<u>level</u> (#)	set confidence level; default is <code>level(95)</code>
<u>irr</u>	report incidence-rate ratios
<i>display_options</i>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Optimization	
<u>optimize_options</u>	control the optimization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>correlation</i>	Description
<u>exchangeable</u>	exchangeable
<u>independent</u>	independent
<u>unstructured</u>	unstructured
<u>fixed</u> <i>matname</i>	user-specified
<u>ar</u> #	autoregressive of order #
<u>stationary</u> #	stationary of order #
<u>nonstationary</u> #	nonstationary of order #

A panel variable must be specified. For `xtpoisson`, `pa`, correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] `xtset`.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

*depvar* and *indepvars* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by`, `mi estimate`, and `statsby` are allowed; see [U] 11.1.10 Prefix commands. `fp` is allowed for the random-effects and fixed-effects models.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] `mi estimate`.

`iweights`, `fweights`, and `pweights` are allowed for the population-averaged model, and `iweights` are allowed for the random-effects and fixed-effects models; see [U] 11.1.6 weight. Weights must be constant within panel.

`coeflegend` does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options for RE model

### Model

`noconstant`; see [R] [Estimation options](#).

`re`, the default, requests the random-effects estimator.

`exposure(varname)`, `offset(varname)`; see [R] [Estimation options](#).

`normal` specifies that the random effects follow a normal distribution instead of a gamma distribution.

`constraints(constraints)`; see [R] [Estimation options](#).

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtpoisson, re and the robust VCE estimator](#) in *Methods and formulas*.

### Reporting

`level(#)`; see [R] [Estimation options](#).

`irr` reports exponentiated coefficients  $e^b$  rather than coefficients  $b$ . For the Poisson model, exponentiated coefficients are interpreted as incidence-rate ratios.

`lrmodel`, `nocnsreport`; see [R] [Estimation options](#).

`display_options`: `noci`, `nocvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

### Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] [Estimation options](#). `normal` must also be specified.

### Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] [Maximize](#). These options are seldom used.

The following options are available with `xtpoisson` but are not shown in the dialog box:

`collinear`, `coeflegend`; see [R] [Estimation options](#).

## Options for FE model

### Model

`fe` requests the fixed-effects estimator.

`exposure(varname)`, `offset(varname)`, `constraints(constraints)`; see [R] Estimation options.

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] vce\_options.

`vce(robust)` invokes a cluster-robust estimate of the VCE in which the ID variable specifies the clusters.

### Reporting

`level(#)`; see [R] Estimation options.

`irr` reports exponentiated coefficients  $e^b$  rather than coefficients  $b$ . For the Poisson model, exponentiated coefficients are interpreted as incidence-rate ratios.

`nocnsreport`; see [R] Estimation options.

`display_options`: `noci`, `novalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] Estimation options.

### Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, [`no`] `log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] Maximize. These options are seldom used.

The following options are available with `xtpoisson` but are not shown in the dialog box:  
`collinear`, `coeflegend`; see [R] Estimation options.

## Options for PA model

### Model

`noconstant`; see [R] Estimation options.

`pa` requests the population-averaged estimator.

`exposure(varname)`, `offset(varname)`; see [R] Estimation options.

### Correlation

`corr(correlation)` specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

`force` specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

---

SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`nmp`, `scale(x2 | dev | phi | #)`; see [XT] [vce\\_options](#).

---

Reporting

`level(#)`; see [R] [Estimation options](#).

`irr` reports exponentiated coefficients  $e^b$  rather than coefficients  $b$ . For the Poisson model, exponentiated coefficients are interpreted as incidence-rate ratios.

`display_options`: `noci`, `novalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

---

Optimization

`optimize_options` control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`log` and `nolog` specify whether to display the iteration log. The iteration log is displayed by default unless you used `set iterlog off` to suppress it; see `set iterlog` in [R] [set iter](#).

`trace` specifies that the current estimates be printed at each iteration.

The following option is available with `xtpoisson` but is not shown in the dialog box:

`coeflegend`; see [R] [Estimation options](#).

## Remarks and examples

`xtpoisson` fits random-effects, conditional fixed-effects, and population-averaged Poisson models. Whenever we refer to a fixed-effects model, we mean the conditional fixed-effects model. These models are typically used for a nonnegative count dependent variable but may be used for any dependent variable in natural logs. For more information about the assumptions of the Poisson model, see [R] `poisson`.

By default, the population-averaged model is an equal-correlation model; `xtpoisson`, `pa` assumes `corr(exchangeable)`. Thus, `xtpoisson` is a convenience command for fitting the population-averaged model using `xtgee`; see [XT] `xtgee`. Typing

```
. xtpoisson ..., ... pa exposure(time)
```

is equivalent to typing

```
. xtgee ..., ... family(poisson) link(log) corr(exchangeable) exposure(time)
```

Also see [XT] `xtgee` for information about `xtpoisson`.

By default or when `re` is specified, `xtpoisson` fits via maximum likelihood the random-effects model

$$\Pr(Y_{it} = y_{it} | \mathbf{x}_{it}) = F(y_{it}, \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

for  $i = 1, \dots, n$  panels, where  $t = 1, \dots, n_i$ , and  $F(x, z) = \Pr(X = x)$ , where  $X$  is Poisson distributed with mean  $\exp(z)$ . In the standard random-effects model,  $\nu_i$  is assumed to be i.i.d. such that  $\exp(\nu_i)$  is gamma with mean one and variance  $\alpha$ , which is estimated from the data. If `normal` is specified,  $\nu_i$  is assumed to be i.i.d.  $N(0, \sigma_\nu^2)$ .

### ▷ Example 1

We have data on the number of ship accidents for five different types of ships (McCullagh and Nelder 1989, 205). We wish to analyze whether the “incident” rate is affected by the period in which the ship was constructed and operated. Our measure of exposure is months of service for the ship, and in this model, we assume that the exponentiated random effects are distributed as gamma with mean one and variance  $\alpha$ .

```
. use https://www.stata-press.com/data/r16/ships
. xtpoisson accident op_75_79 co_65_69 co_70_74 co_75_79, exp(service) irr
```

Fitting Poisson model:

```
Iteration 0: log likelihood = -147.37993
Iteration 1: log likelihood = -80.372714
Iteration 2: log likelihood = -80.116093
Iteration 3: log likelihood = -80.115916
Iteration 4: log likelihood = -80.115916
```

Fitting full model:

```
Iteration 0: log likelihood = -79.653186
Iteration 1: log likelihood = -76.990836 (not concave)
Iteration 2: log likelihood = -74.824942
Iteration 3: log likelihood = -74.811243
Iteration 4: log likelihood = -74.811217
Iteration 5: log likelihood = -74.811217
```

Random-effects Poisson regression	Number of obs	=	34
Group variable: ship	Number of groups	=	5
Random effects u_i ~ Gamma	Obs per group:		
	min =	6	
	avg =	6.8	
	max =	7	
Log likelihood = -74.811217	Wald chi2(4)	=	50.90
	Prob > chi2	=	0.0000

accident	IRR	Std. Err.	z	P> z	[95% Conf. Interval]
op_75_79	1.466305	.1734005	3.24	0.001	1.162957 1.848777
co_65_69	2.032543	.304083	4.74	0.000	1.515982 2.72512
co_70_74	2.356853	.3999259	5.05	0.000	1.690033 3.286774
co_75_79	1.641913	.3811398	2.14	0.033	1.04174 2.58786
_cons	.0013724	.0002992	-30.24	0.000	.0008952 .002104
ln(service)	1	(exposure)			
/lnalpha	-2.368406	.8474597		-4.029397	-.7074155
alpha	.0936298	.0793475		.0177851	.4929165

Note: Estimates are transformed only in the first equation.

Note: \_cons estimates baseline incidence rate (conditional on zero random effects).

LR test of alpha=0: chibar2(01) = 10.61 Prob >= chibar2 = 0.001

The output also includes a likelihood-ratio test of  $\alpha = 0$ , which compares the panel estimator with the pooled (Poisson) estimator.

We find that the incidence rate for accidents is significantly different for the periods of construction and operation of the ships and that the random-effects model is significantly different from the pooled model.

We may alternatively fit a fixed-effects specification instead of a random-effects specification:

```
. xtpoisson accident op_75_79 co_65_69 co_70_74 co_75_79, exp(service) irr fe
Iteration 0: log likelihood = -80.738973
Iteration 1: log likelihood = -54.857546
Iteration 2: log likelihood = -54.641897
Iteration 3: log likelihood = -54.641859
Iteration 4: log likelihood = -54.641859

Conditional fixed-effects Poisson regression      Number of obs      =      34
Group variable: ship                           Number of groups   =       5

Obs per group:
    min =          6
    avg =        6.8
    max =          7

Wald chi2(4) =      48.44
Prob > chi2 =     0.0000

Log likelihood = -54.641859
```

accident	IRR	Std. Err.	z	P> z	[95% Conf. Interval]
op_75_79	1.468831	.1737218	3.25	0.001	1.164926 1.852019
co_65_69	2.008002	.3004803	4.66	0.000	1.497577 2.692398
co_70_74	2.26693	.384865	4.82	0.000	1.625274 3.161912
co_75_79	1.573695	.3669393	1.94	0.052	.9964273 2.485397
ln(service)	1	(exposure)			

Both of these models fit the same thing but will differ in efficiency, depending on whether the assumptions of the random-effects model are true.

We could have assumed that the random effects followed a normal distribution,  $N(0, \sigma_\nu^2)$ , instead of a “log-gamma” distribution, and obtained

```
. xtpoisson accident op_75_79 co_65_69 co_70_74 co_75_79, exp(service) irr
> normal nolog

Random-effects Poisson regression      Number of obs      =      34
Group variable: ship                           Number of groups   =       5

Random effects u_i ~ Gaussian
Obs per group:
    min =          6
    avg =        6.8
    max =          7

Integration method: mvaghermite
Integration pts. =      12

Wald chi2(4) =      50.95
Prob > chi2 =     0.0000

Log likelihood = -74.780982
```

accident	IRR	Std. Err.	z	P> z	[95% Conf. Interval]
op_75_79	1.466677	.1734403	3.24	0.001	1.163259 1.849236
co_65_69	2.032604	.3040933	4.74	0.000	1.516025 2.725205
co_70_74	2.357045	.3998397	5.05	0.000	1.690338 3.286717
co_75_79	1.646935	.3820235	2.15	0.031	1.045278 2.594905
_cons	.0013075	.0002775	-31.28	0.000	.0008625 .001982
ln(service)	1	(exposure)			
/lnsig2u	-2.351868	.8586262			-4.034745 -.6689918
sigma_u	.3085306	.1324562			.1330045 .7156988

Note: Estimates are transformed only in the first equation.

Note: \_cons estimates baseline incidence rate (conditional on zero random effects).

LR test of sigma\_u=0: chibar2(01) = 10.67

Prob >= chibar2 = 0.001

The output includes the additional panel-level variance component. This is parameterized as the log of the variance  $\ln(\sigma_\nu^2)$  (labeled `lnsig2u` in the output). The standard deviation  $\sigma_\nu$  is also included in the output labeled `sigma_u`.

When `sigma_u` is zero, the panel-level variance component is unimportant and the panel estimator is no different from the pooled estimator. A likelihood-ratio test of this is included at the bottom of the output. This test formally compares the pooled estimator (`poisson`) with the panel estimator. Here  $\sigma_\nu$  is significantly greater than zero, so a panel estimator is indicated.  $\blacktriangleleft$

## ▷ Example 2

This time we fit a robust equal-correlation population-averaged model:

```
. xtpoisson accident op_75_79 co_65_69 co_70_74 co_75_79, exp(service) pa
> vce(robust) eform

Iteration 1: tolerance = .04083192
Iteration 2: tolerance = .00270188
Iteration 3: tolerance = .00030663
Iteration 4: tolerance = .00003466
Iteration 5: tolerance = 3.891e-06
Iteration 6: tolerance = 4.359e-07

GEE population-averaged model
Number of obs      =          34
Group variable:    ship
Number of groups   =           5
Link:              log
Obs per group:
Family:            Poisson
Correlation:       exchangeable
min =             6
avg =             6.8
max =             7
Wald chi2(4)      =     252.94
Scale parameter:   1
Prob > chi2       =     0.0000
(Std. Err. adjusted for clustering on ship)
```

accident	Robust					
	IRR	Std. Err.	z	P> z	[95% Conf. Interval]	
op_75_79	1.483299	.1197901	4.88	0.000	1.266153	1.737685
co_65_69	2.038477	.1809524	8.02	0.000	1.712955	2.425859
co_70_74	2.643467	.4093947	6.28	0.000	1.951407	3.580962
co_75_79	1.876656	.33075	3.57	0.000	1.328511	2.650966
_cons	.0010255	.0000721	-97.90	0.000	.0008935	.001177
ln(service)	1	(exposure)				

Note: \_cons estimates baseline incidence rate (conditional on zero random effects).

We may compare this with a pooled estimator with clustered robust-variance estimates:

```
. poisson accident op_75_79 co_65_69 co_70_74 co_75_79, exp(service)
> vce(cluster ship) irr
Iteration 0: log pseudolikelihood = -147.37993
Iteration 1: log pseudolikelihood = -80.372714
Iteration 2: log pseudolikelihood = -80.116093
Iteration 3: log pseudolikelihood = -80.115916
Iteration 4: log pseudolikelihood = -80.115916

Poisson regression
Number of obs      =      34
Wald chi2(3)       =      .
Prob > chi2        =      .
Log pseudolikelihood = -80.115916
Pseudo R2          =     0.3438
(Std. Err. adjusted for 5 clusters in ship)
```

accident	IRR	Robust Std. Err.	z	P> z	[95% Conf. Interval]
op_75_79	1.47324	.1287036	4.44	0.000	1.2414 1.748377
co_65_69	2.125914	.2850531	5.62	0.000	1.634603 2.764897
co_70_74	2.860138	.6213563	4.84	0.000	1.868384 4.378325
co_75_79	2.021926	.4265285	3.34	0.001	1.337221 3.057227
_cons	.0009609	.0000277	-240.66	0.000	.000908 .0010168
ln(service)	1	(exposure)			

Note: \_cons estimates baseline incidence rate.



## □ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the quadchk command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the intpoints() option and run quadchk again. Do not attempt to interpret the results of estimates when the coefficients reported by quadchk differ substantially. See [XT] quadchk for details and [XT] xtprobit for an example.

Because the xtpoisson, re normal likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.



## Stored results

**xtpoisson, re** stores the following in **e()**:

### Scalars

<b>e(N)</b>	number of observations
<b>e(N_g)</b>	number of groups
<b>e(k)</b>	number of parameters
<b>e(k_aux)</b>	number of auxiliary parameters
<b>e(k_eq)</b>	number of equations in <b>e(b)</b>
<b>e(k_eq_model)</b>	number of equations in overall model test
<b>e(k_dv)</b>	number of dependent variables
<b>e(df_m)</b>	model degrees of freedom
<b>e(l1)</b>	log likelihood
<b>e(l1_0)</b>	log likelihood, constant-only model
<b>e(l1_c)</b>	log likelihood, comparison model
<b>e(chi2)</b>	$\chi^2$
<b>e(chi2_c)</b>	$\chi^2$ for comparison test
<b>e(N_clust)</b>	number of clusters
<b>e(alpha)</b>	value of alpha
<b>e(g_min)</b>	smallest group size
<b>e(g_avg)</b>	average group size
<b>e(g_max)</b>	largest group size
<b>e(p)</b>	<i>p</i> -value for model test
<b>e(rank)</b>	rank of <b>e(V)</b>
<b>e(rank0)</b>	rank of <b>e(V)</b> for constant-only model
<b>e(ic)</b>	number of iterations
<b>e(rc)</b>	return code
<b>e(converged)</b>	1 if converged, 0 otherwise

### Macros

<b>e(cmd)</b>	<b>xtpoisson</b>
<b>e(cmdline)</b>	command as typed
<b>e(depvar)</b>	name of dependent variable
<b>e(ivars)</b>	variable denoting groups
<b>e(model)</b>	<b>re</b>
<b>e(wtype)</b>	weight type
<b>e(wexp)</b>	weight expression
<b>e(title)</b>	title in estimation output
<b>e(clustvar)</b>	name of cluster variable
<b>e(offset)</b>	linear offset variable
<b>e(chi2type)</b>	Wald or LR; type of model $\chi^2$ test
<b>e(chi2_ct)</b>	Wald or LR; type of model $\chi^2$ test corresponding to <b>e(chi2_c)</b>
<b>e(vce)</b>	<i>vcetype</i> specified in <b>vce()</b>
<b>e(vcetype)</b>	title used to label Std. Err.
<b>e(method)</b>	requested estimation method
<b>e(distrib)</b>	Gamma; the distribution of the random effect
<b>e(opt)</b>	type of optimization
<b>e(which)</b>	<b>max</b> or <b>min</b> ; whether optimizer is to perform maximization or minimization
<b>e(ml_method)</b>	type of <b>ml</b> method
<b>e(user)</b>	name of likelihood-evaluator program
<b>e(technique)</b>	maximization technique
<b>e(properties)</b>	<b>b V</b>
<b>e(predict)</b>	program used to implement <b>predict</b>
<b>e(asbalanced)</b>	factor variables <b>fvset</b> as <b>asbalanced</b>
<b>e(asobserved)</b>	factor variables <b>fvset</b> as <b>asobserved</b>

## Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(ilog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

## Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

`xtpoisson, re normal` stores the following in `e()`:

## Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(ll)</code>	log likelihood
<code>e(ll_0)</code>	log likelihood, constant-only model
<code>e(ll_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	$\chi^2$
<code>e(chi2_c)</code>	$\chi^2$ for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

## Macros

e(cmd)	xtpoisson
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(model)	re
e(wtype)	weight type
e(wexp)	weight expression
e(title)	title in estimation output
e(clustvar)	name of cluster variable
e(offset)	linear offset variable
e(chi2type)	Wald or LR; type of model $\chi^2$ test
e(chi2_ct)	Wald or LR; type of model $\chi^2$ test corresponding to e(chi2_c)
e(vce)	vctype specified in vce()
e(vcetype)	title used to label Std. Err.
e(intmethod)	integration method
e(distrib)	Gaussian; the distribution of the random effect
e(opt)	type of optimization
e(which)	max or min; whether optimizer is to perform maximization or minimization
e(ml_method)	type of ml method
e(user)	name of likelihood-evaluator program
e(technique)	maximization technique
e(properties)	b V
e(predict)	program used to implement predict
e(marginsdefault)	default predict() specification for margins
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

## Matrices

e(b)	coefficient vector
e(Cns)	constraints matrix
e(iolog)	iteration log
e(gradient)	gradient vector
e(V)	variance-covariance matrix of the estimators
e(V_modelbased)	model-based variance

## Functions

e(sample)	marks estimation sample
-----------	-------------------------

**xtpoisson, fe** stores the following in **e()**:

## Scalars

e(N)	number of observations
e(N_g)	number of groups
e(k)	number of parameters
e(k_eq)	number of equations in e(b)
e(k_eq_model)	number of equations in overall model test
e(k_dv)	number of dependent variables
e(df_m)	model degrees of freedom
e(ll)	log likelihood
e(ll_c)	log likelihood, comparison model
e(chi2)	$\chi^2$
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(p)	p-value for model test
e(rank)	rank of e(V)
e(ic)	number of iterations
e(rc)	return code
e(converged)	1 if converged, 0 otherwise

Macros	
e(cmd)	xtpoisson
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(model)	fe
e(wtype)	weight type
e(wexp)	weight expression
e(title)	title in estimation output
e(offset)	linear offset variable
e(chi2type)	Wald; type of model $\chi^2$ test
e(vce)	<i>vcetype</i> specified in vce()
e(vcetype)	title used to label Std. Err.
e(method)	requested estimation method
e(opt)	type of optimization
e(which)	max or min; whether optimizer is to perform maximization or minimization
e(ml_method)	type of ml method
e(user)	name of likelihood-evaluator program
e(technique)	maximization technique
e(properties)	b V
e(predict)	program used to implement predict
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved
Matrices	
e(b)	coefficient vector
e(Cns)	constraints matrix
e(ilog)	iteration log
e(gradient)	gradient vector
e(V)	variance-covariance matrix of the estimators
Functions	
e(sample)	marks estimation sample

xtpoisson, pa stores the following in e():

Scalars	
e(N)	number of observations
e(N_g)	number of groups
e(df_m)	model degrees of freedom
e(chi2)	$\chi^2$
e(p)	<i>p</i> -value for model test
e(df_pear)	degrees of freedom for Pearson $\chi^2$
e(chi2_dev)	$\chi^2$ test of deviance
e(chi2_dis)	$\chi^2$ test of deviance dispersion
e(deviance)	deviance
e(dispers)	deviance dispersion
e(phi)	scale parameter
e(g_min)	smallest group size
e(g_avg)	average group size
e(g_max)	largest group size
e(rank)	rank of e(V)
e(tol)	target tolerance
e(dif)	achieved tolerance
e(rc)	return code

Macros	
e(cmd)	xtgee
e(cmd2)	xtpoisson
e(cmdline)	command as typed
e(depvar)	name of dependent variable
e(ivar)	variable denoting groups
e(tvar)	variable denoting time within groups
e(model)	pa
e(family)	Poisson
e(link)	log: link function
e(corr)	correlation structure
e(scale)	x2, dev, phi, or #; scale parameter
e(wtype)	weight type
e(wexp)	weight expression
e(offset)	linear offset variable
e(chi2type)	Wald; type of model $\chi^2$ test
e(vce)	vcetype specified in vce()
e(vcetype)	covariance estimation method
e(nmp)	nmp, if specified
e(properties)	b V
e(predict)	program used to implement predict
e(marginsnotok)	predictions disallowed by margins
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved
Matrices	
e(b)	coefficient vector
e(R)	estimated working correlation matrix
e(V)	variance-covariance matrix of the estimators
e(V_modelbased)	model-based variance
Functions	
e(sample)	marks estimation sample

## Methods and formulas

`xtpoisson`, `fe` reports the population-averaged results obtained by using `xtgee`, `family(poisson)` `link(log)` to obtain estimates. See [XT] `xtgee` for details about the methods and formulas.

`xtpoisson`, `fe` with robust standard errors implements the formula presented in Wooldridge (1999). The formula is a cluster-robust estimate of the VCE in which the ID variable specifies the clusters.

Although Hausman, Hall, and Griliches (1984) wrote the seminal article on the random-effects and fixed-effects models, Cameron and Trivedi (2013) provide a good textbook treatment. Allison (2009, chap. 4) succinctly discusses these models and illustrates the differences between them using Stata.

For a random-effects specification, we know that

$$\Pr(y_{i1}, \dots, y_{in_i} | \alpha_i, \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) = \left( \prod_{t=1}^{n_i} \frac{\lambda_{it}^{y_{it}}}{y_{it}!} \right) \exp \left\{ -\exp(\alpha_i) \sum_{t=1}^{n_i} \lambda_{it} \right\} \exp \left( \alpha_i \sum_{t=1}^{n_i} y_{it} \right)$$

where  $\lambda_{it} = \exp(\mathbf{x}_{it}\beta)$ . We may rewrite the above as [defining  $\epsilon_i = \exp(\alpha_i)$ ]

$$\begin{aligned}\Pr(y_{i1}, \dots, y_{in_i} | \epsilon_i, \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) &= \left\{ \prod_{t=1}^{n_i} \frac{(\lambda_{it}\epsilon_i)^{y_{it}}}{y_{it}!} \right\} \exp\left(-\sum_{t=1}^{n_i} \lambda_{it}\epsilon_i\right) \\ &= \left( \prod_{t=1}^{n_i} \frac{\lambda_{it}^{y_{it}}}{y_{it}!} \right) \exp\left(-\epsilon_i \sum_{t=1}^{n_i} \lambda_{it}\right) \epsilon_i^{\sum_{t=1}^{n_i} y_{it}}\end{aligned}$$

We now assume that  $\epsilon_i$  follows a gamma distribution with mean one and variance  $1/\theta$  so that unconditional on  $\epsilon_i$

$$\begin{aligned}\Pr(y_{i1}, \dots, y_{in_i} | \mathbf{X}_i) &= \frac{\theta^\theta}{\Gamma(\theta)} \left( \prod_{t=1}^{n_i} \frac{\lambda_{it}^{y_{it}}}{y_{it}!} \right) \int_0^\infty \exp\left(-\epsilon_i \sum_{t=1}^{n_i} \lambda_{it}\right) \epsilon_i^{\sum_{t=1}^{n_i} y_{it}} \epsilon_i^{\theta-1} \exp(-\theta\epsilon_i) d\epsilon_i \\ &= \frac{\theta^\theta}{\Gamma(\theta)} \left( \prod_{t=1}^{n_i} \frac{\lambda_{it}^{y_{it}}}{y_{it}!} \right) \int_0^\infty \exp\left\{-\epsilon_i \left(\theta + \sum_{t=1}^{n_i} \lambda_{it}\right)\right\} \epsilon_i^{\theta+\sum_{t=1}^{n_i} y_{it}-1} d\epsilon_i \\ &= \left( \prod_{t=1}^{n_i} \frac{\lambda_{it}^{y_{it}}}{y_{it}!} \right) \frac{\Gamma\left(\theta + \sum_{t=1}^{n_i} y_{it}\right)}{\Gamma(\theta)} \left( \frac{\theta}{\theta + \sum_{t=1}^{n_i} \lambda_{it}} \right)^\theta \left( \frac{1}{\theta + \sum_{t=1}^{n_i} \lambda_{it}} \right)^{\sum_{t=1}^{n_i} y_{it}}\end{aligned}$$

for  $\mathbf{X}_i = (\mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i})$ .

The log likelihood (assuming gamma heterogeneity) is then derived using

$$u_i = \frac{\theta}{\theta + \sum_{t=1}^{n_i} \lambda_{it}} \quad \lambda_{it} = \exp(\mathbf{x}_{it}\beta)$$

$$\Pr(Y_{i1} = y_{i1}, \dots, Y_{in_i} = y_{in_i} | \mathbf{X}_i) = \frac{\prod_{t=1}^{n_i} \lambda_{it}^{y_{it}} \Gamma(\theta + \sum_{t=1}^{n_i} y_{it})}{\prod_{t=1}^{n_i} y_{it}! \Gamma(\theta) (\sum_{t=1}^{n_i} \lambda_{it})^{\sum_{t=1}^{n_i} y_{it}}} u_i^\theta (1 - u_i)^{\sum_{t=1}^{n_i} y_{it}}$$

such that the log likelihood may be written as

$$\begin{aligned}L &= \sum_{i=1}^n w_i \left\{ \log\Gamma\left(\theta + \sum_{t=1}^{n_i} y_{it}\right) - \sum_{t=1}^{n_i} \log\Gamma(1 + y_{it}) - \log\Gamma(\theta) + \theta \log u_i \right. \\ &\quad \left. + \log(1 - u_i) \sum_{t=1}^{n_i} y_{it} + \sum_{t=1}^{n_i} y_{it}(\mathbf{x}_{it}\beta) - \left( \sum_{t=1}^{n_i} y_{it} \right) \log\left(\sum_{t=1}^{n_i} \lambda_{it}\right) \right\}\end{aligned}$$

where  $w_i$  is the user-specified weight for panel  $i$ ; if no weights are specified,  $w_i = 1$ .

Alternatively, if we assume a normal distribution,  $N(0, \sigma_\nu^2)$ , for the random effects  $\nu_i$

$$\Pr(y_{i1}, \dots, y_{in_i} | \mathbf{X}_i) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i$$

where

$$F(y, z) = \exp \left\{ -\exp(z) + yz - \log(y!) \right\}.$$

The panel-level likelihood  $l_i$  is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with  $M$ -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp \{(a_m^*)^2\} f(a_m^*)$$

where the  $w_m^*$  denote the quadrature weights and the  $a_m^*$  denote the quadrature abscissas. The log likelihood,  $L$ , is the sum of the logs of the panel-level likelihoods  $l_i$ .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp \{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)$$

where  $\hat{\sigma}_i$  and  $\hat{\mu}_i$  are the adaptive parameters for panel  $i$ . Therefore, with the definition of  $g(y_{it}, x_{it}, \nu_i)$ , the total log likelihood is approximated by

$$\begin{aligned} L &\approx \sum_{i=1}^n w_i \log \left[ \sqrt{2}\hat{\sigma}_i \sum_{m=1}^M w_m^* \exp \{(a_m^*)^2\} \frac{\exp \{-(\sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i)^2/2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \right. \\ &\quad \left. \prod_{t=1}^{n_i} F(y_{it}, x_{it}\beta + \sqrt{2}\hat{\sigma}_i a_m^* + \hat{\mu}_i) \right] \end{aligned}$$

where  $w_i$  is the user-specified weight for panel  $i$ ; if no weights are specified,  $w_i = 1$ .

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for  $\hat{\mu}_i$  and  $\hat{\sigma}_i$  by following the method of Naylor and Smith (1982), further discussed in Skrondal and Rabe-Hesketh (2004). We start with  $\hat{\sigma}_{i,0} = 1$  and  $\hat{\mu}_{i,0} = 0$ , and the posterior means and variances are updated in the  $k$ th iteration. That is, at the  $k$ th iteration of the optimization for  $l_i$ , we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2\hat{\sigma}_{i,k-1}} a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2\hat{\sigma}_{i,k-1}} a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until  $\hat{\mu}_{i,k}$  and  $\hat{\sigma}_{i,k}$  have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of  $1e-6$ ; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature, the `int-method(ghermite)` option, where  $\rho = \sigma_\nu^2 / (\sigma_\nu^2 + 1)$ :

$$\begin{aligned} L &= \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ &\approx \sum_{i=1}^n w_i \log \left[ \frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left\{ y_{it}, \mathbf{x}_{it} \boldsymbol{\beta} + a_m^* \left( \frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right] \end{aligned}$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it} \boldsymbol{\beta} + \nu_i)$$

is well approximated by a polynomial. As panel size and  $\rho$  increase, the quadrature approximation can become less accurate. For large  $\rho$ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] `quadchk`) to verify the quadrature approximation used in this command, whichever approximation you choose.

For a fixed-effects specification, we know that

$$\begin{aligned}\Pr(Y_{it} = y_{it} | \mathbf{x}_{it}) &= \exp\{-\exp(\alpha_i + \mathbf{x}_{it}\beta)\} \exp(\alpha_i + \mathbf{x}_{it}\beta)^{y_{it}} / y_{it}! \\ &= \frac{1}{y_{it}!} \exp\{-\exp(\alpha_i) \exp(\mathbf{x}_{it}\beta) + \alpha_i y_{it}\} \exp(\mathbf{x}_{it}\beta)^{y_{it}} \\ &\equiv F_{it}\end{aligned}$$

Because we know that the observations are independent, we may write the joint probability for the observations within a panel as

$$\begin{aligned}\Pr(Y_{i1} = y_{i1}, \dots, Y_{in_i} = y_{in_i} | \mathbf{X}_i) &= \prod_{t=1}^{n_i} \frac{1}{y_{it}!} \exp\{-\exp(\alpha_i) \exp(\mathbf{x}_{it}\beta) + \alpha_i y_{it}\} \exp(\mathbf{x}_{it}\beta)^{y_{it}} \\ &= \left( \prod_{t=1}^{n_i} \frac{\exp(\mathbf{x}_{it}\beta)^{y_{it}}}{y_{it}!} \right) \exp\left\{ -\exp(\alpha_i) \sum_t \exp(\mathbf{x}_{it}\beta) + \alpha_i \sum_t y_{it} \right\}\end{aligned}$$

and we also know that the sum of  $n_i$  Poisson independent random variables, each with parameter  $\lambda_{it}$  for  $t = 1, \dots, n_i$ , is distributed as Poisson with parameter  $\sum_t \lambda_{it}$ . Thus

$$\begin{aligned}\Pr\left(\sum_t Y_{it} = \sum_t y_{it} | \mathbf{X}_i\right) &= \\ &\frac{1}{(\sum_t y_{it})!} \exp\left\{ -\exp(\alpha_i) \sum_t \exp(\mathbf{x}_{it}\beta) + \alpha_i \sum_t y_{it} \right\} \left\{ \sum_t \exp(\mathbf{x}_{it}\beta) \right\}^{\sum_t y_{it}}\end{aligned}$$

So, the conditional likelihood is conditioned on the sum of the outcomes in the set (panel). The appropriate function is given by

$$\begin{aligned}\Pr\left(Y_{i1} = y_{i1}, \dots, Y_{in_i} = y_{in_i} | \mathbf{X}_i, \sum_t Y_{it} = \sum_t y_{it}\right) &= \\ &\left[ \left( \prod_{t=1}^{n_i} \frac{\exp(\mathbf{x}_{it}\beta)^{y_{it}}}{y_{it}!} \right) \exp\left\{ -\exp(\alpha_i) \sum_t \exp(\mathbf{x}_{it}\beta) + \alpha_i \sum_t y_{it} \right\} \right] / \\ &\left[ \frac{1}{(\sum_t y_{it})!} \exp\left\{ -\exp(\alpha_i) \sum_t \exp(\mathbf{x}_{it}\beta) + \alpha_i \sum_t y_{it} \right\} \left\{ \sum_t \exp(\mathbf{x}_{it}\beta) \right\}^{\sum_t y_{it}} \right] \\ &= \left( \sum_t y_{it} \right)! \prod_{t=1}^{n_i} \frac{\exp(\mathbf{x}_{it}\beta)^{y_{it}}}{y_{it}! \{ \sum_k \exp(\mathbf{x}_{ik}\beta) \}^{y_{it}}}\end{aligned}$$

which is free of  $\alpha_i$ .

The conditional log likelihood is given by

$$\begin{aligned}
 L &= \log \prod_{i=1}^n \left[ \left( \sum_{t=1}^{n_i} y_{it} \right)! \prod_{t=1}^{n_i} \frac{\exp(\mathbf{x}_{it}\beta)^{y_{it}}}{y_{it}! \{ \sum_{\ell=1}^{n_i} \exp(\mathbf{x}_{i\ell}\beta) \}^{y_{it}}} \right]^{w_i} \\
 &= \log \prod_{i=1}^n \left\{ \frac{(\sum_{t=1}^{n_i} y_{it})!}{\prod_{t=1}^{n_i} y_{it}!} \prod_{t=1}^{n_i} p_{it}^{y_{it}} \right\}^{w_i} \\
 &= \sum_{i=1}^n w_i \left\{ \log \Gamma \left( \sum_{t=1}^{n_i} y_{it} + 1 \right) - \sum_{t=1}^{n_i} \log \Gamma(y_{it} + 1) + \sum_{t=1}^{n_i} y_{it} \log p_{it} \right\}
 \end{aligned}$$

where

$$p_{it} = e^{\mathbf{x}_{it}\beta} / \sum_{\ell} e^{\mathbf{x}_{i\ell}\beta}$$

## xtpoisson, re and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] **\_robust**, particularly *Introduction* and *Methods and formulas*. Wooldridge (2020) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2020), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in  $\epsilon_{it}$ .

The cluster–robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

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## Also see

- [XT] **xtpoisson postestimation** — Postestimation tools for xtpoisson
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtnbreg** — Fixed-effects, random-effects, & population-averaged negative binomial models
- [XT] **xtset** — Declare data to be panel data
- [ME] **mepoisson** — Multilevel mixed-effects Poisson regression
- [MI] **Estimation** — Estimation commands for use with mi estimate
- [R] **poisson** — Poisson regression
- [U] **20 Estimation and postestimation commands**

**xtpoisson postestimation** — Postestimation tools for xtpoisson

Postestimation commands  
Methods and formulas

[predict](#)  
[Also see](#)

[margins](#)

Remarks and examples

## Postestimation commands

The following postestimation commands are available after `xtpoisson`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
* <code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
† <code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
* <code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from <code>margins</code> (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

\* `estat ic` and `lrtest` are not appropriate after `xtpoisson, pa`.

† `forecast` is not appropriate with `mi` estimation results.

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions, standard errors, numbers of events, incidence rates, probabilities, and equation-level scores.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

*Random-effects (RE) model*

```
predict [type] newvar [if] [in] [, RE-statistic nooffset]
```

*Fixed-effects (FE) model*

```
predict [type] newvar [if] [in] [, FE-statistic nooffset]
```

*Population-averaged (PA) model*

```
predict [type] newvar [if] [in] [, PA-statistic nooffset]
```

---

<i>RE-statistic</i>	Description
Main	

<i>RE-statistic</i>	Description
Main	
<code>xb</code>	linear prediction; the default
<code>stdp</code>	standard error of the linear prediction
<code>n</code>	predicted number of events marginal with respect to the random effect; only allowed after <code>xtpoisson, re normal</code>
<code>nu0</code>	predicted number of events assuming the random effect is zero
<code>iru0</code>	predicted incidence rate assuming the random effect is zero
<code>pr0(n)</code>	probability $\Pr(y = n)$ assuming the random effect is zero
<code>pr0(a,b)</code>	probability $\Pr(a \leq y \leq b)$ assuming the random effect is zero

---

<i>FE-statistic</i>	Description
---------------------	-------------

Main	
<code>xb</code>	linear prediction; the default
<code>stdp</code>	standard error of the linear prediction
<code>nu0</code>	predicted number of events assuming the fixed effect is zero
<code>iru0</code>	predicted incidence rate assuming the fixed effect is zero

---

PA_statistic	Description
Main	
<code>mu</code>	predicted number of events; considers the <code>offset()</code> ; the default
<code>rate</code>	predicted number of events
<code>xb</code>	linear prediction
<code>pr(n)</code>	probability $\Pr(y = n)$
<code>pr(a,b)</code>	probability $\Pr(a \leq y \leq b)$
<code>stdp</code>	standard error of the linear prediction
<code>score</code>	first derivative of the log likelihood with respect to $\mathbf{x}_{it}\beta$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

## Options for predict

Main

`xb` calculates the linear prediction. This is the default for the random-effects and fixed-effects models.

`mu` and `rate` both calculate the predicted number of events. `mu` takes into account the `offset()`, and `rate` ignores those adjustments. `mu` and `rate` are equivalent if you did not specify `offset()`. `mu` is the default for the population-averaged model.

`stdp` calculates the standard error of the linear prediction.

`n` calculates the predicted number of events marginally with respect to the random effect, which means that the statistic is calculated by integrating the prediction function with respect to the random effect over its entire support. This option is only allowed after `xtpoisson, re normal`.

`nu0` calculates the predicted number of events, assuming a zero random or fixed effect.

`iru0` calculates the predicted incidence rate, assuming a zero random or fixed effect.

`pr0(n)` calculates the probability  $\Pr(y = n)$  assuming the random effect is zero, where  $n$  is a nonnegative integer that may be specified as a number or a variable (only allowed after `xtpoisson, re`).

`pr0(a,b)` calculates the probability  $\Pr(a \leq y \leq b)$  assuming the random effect is zero, where  $a$  and  $b$  are nonnegative integers that may be specified as numbers or variables (only allowed after `xtpoisson, re`);

$b$  missing ( $b \geq .$ ) means  $+\infty$ ;

`pr0(20,.)` calculates  $\Pr(y \geq 20)$ ;

`pr0(20,b)` calculates  $\Pr(y \geq 20)$  in observations for which  $b \geq .$  and calculates  $\Pr(20 \leq y \leq b)$  elsewhere.

`pr0(.,b)` produces a syntax error. A missing value in an observation of the variable  $a$  causes a missing value in that observation for `pr0(a,b)`.

`pr(n)` calculates the probability  $\Pr(y = n)$ , where  $n$  is a nonnegative integer that may be specified as a number or a variable (only allowed after `xtpoisson, pa`).

`pr(a,b)` calculates the probability  $\Pr(a \leq y \leq b)$  (only allowed after `xtpoisson, pa`). The syntax for this option is analogous to that used with `pr0(a,b)`.

`score` calculates the equation-level score,  $u_{it} = \partial \ln L(\mathbf{x}_{it}\beta) / \partial (\mathbf{x}_{it}\beta)$ .

`nooffset` is relevant only if you specified `offset(varname)` for `xtpoisson`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\beta$  rather than  $\mathbf{x}_{it}\beta + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions, numbers of events, incidence rates, and probabilities.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

`margins [marginlist] [, options]`

`margins [marginlist] , predict(statistic ...) [predict(statistic ...) ...] [options]`

#### Random-effects (RE) model

statistic	Description
<code>xb</code>	linear prediction; the default after <code>xtpoisson, re</code>
<code>n</code>	predicted number of events marginal with respect to the random effect; the default
<code>nu0</code>	predicted number of events assuming the random effect is zero
<code>iru0</code>	predicted incidence rate assuming the random effect is zero
<code>pr0(n)</code>	probability $\Pr(y = n)$ assuming the random effect is zero
<code>pr0(a,b)</code>	probability $\Pr(a \leq y \leq b)$ assuming the random effect is zero
<code>stdp</code>	not allowed with <code>margins</code>

#### Fixed-effects (FE) model

statistic	Description
<code>xb</code>	linear prediction; the default
<code>nu0</code>	predicted number of events assuming the fixed effect is zero
<code>iru0</code>	predicted incidence rate assuming the fixed effect is zero
<code>stdp</code>	not allowed with <code>margins</code>

#### Population-averaged (PA) model

statistic	Description
<code>mu</code>	predicted number of events; considers the <code>offset()</code> ; the default
<code>rate</code>	predicted number of events
<code>xb</code>	linear prediction
<code>pr(n)</code>	probability $\Pr(y = n)$
<code>pr(a,b)</code>	probability $\Pr(a \leq y \leq b)$
<code>stdp</code>	not allowed with <code>margins</code>
<code>score</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] `margins`.

## Remarks and examples

### Example 1: Predicted number of events and incidence rate with no random effect

In example 1 of [XT] `xtpoisson`, we fit a random-effects model of the number of accidents experienced by five different types of ships on the basis of when the ships were constructed and operated. Here we obtain the predicted number of accidents for each observation, assuming that the random effect for each panel is zero:

```
. use https://www.stata-press.com/data/r16/ships
. xtpoisson accident op_75_79 co_65_69 co_70_74 co_75_79, exposure(service) irr
  (output omitted)
. predict n_acc, nu0
(6 missing values generated)
. summarize n_acc
```

Variable	Obs	Mean	Std. Dev.	Min	Max
n_acc	34	13.52307	23.15885	.0617592	83.31905

From these results, you may be tempted to conclude that some types of ships are safe, with a predicted number of accidents close to zero, whereas others are dangerous, because 1 observation is predicted to have more than 83 accidents.

However, when we fit the model, we specified the `exposure(service)` option. The variable `service` records the total number of months of operation for each type of ship constructed in and operated during particular years. Because ships experienced different utilization rates and thus were exposed to different levels of accident risk, we included `service` as our exposure variable. When comparing different types of ships, we must therefore predict the number of accidents, assuming that all ships faced the same exposure to risk. To do that, we use the `iru0` option with `predict`:

```
. predict acc_rate, iru0
. summarize acc_rate
```

Variable	Obs	Mean	Std. Dev.	Min	Max
acc_rate	40	.002975	.0010497	.0013724	.0047429

These results show that if each ship were used for 1 month, the expected number of accidents is 0.002975. Depending on the type of ship and years of construction and operation, the *incidence rate* of accidents ranges from 0.00137 to 0.00474.



## Methods and formulas

The probabilities calculated using the `pr0(n)` option are the probability  $\Pr(y_{it} = n)$  for a RE model assuming the random effect is zero. Define  $\mu_{it} = \exp(\mathbf{x}_{it}\beta + \text{offset}_{it})$ . The probabilities in `pr0(n)` are calculated as the probability that  $y_{it} = n$ , where  $y_{it}$  has a Poisson distribution with mean  $\mu_{it}$ . Specifically,

$$\Pr(y_{it} = n) = (n!)^{-1} \exp(-\mu_{it})(\mu_{it})^n$$

Probabilities calculated using the `pr(n)` option after fitting a PA model are also calculated as described above.

## Also see

[**XT**] **xtpoisson** — Fixed-effects, random-effects, and population-averaged Poisson models

[**U**] **20 Estimation and postestimation commands**

**xtprobit** — Random-effects and population-averaged probit models

Description  
Options for RE model  
Methods and formulas

Quick start  
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## Description

**xtprobit** fits random-effects and population-averaged probit models for a binary dependent variable. The probability of a positive outcome is assumed to be determined by the standard normal cumulative distribution function.

## Quick start

Random-effects probit model of *y* as a function of *x1*, *x2*, and [indicators](#) for levels of categorical variable *a* using [xtset](#) data

```
xtprobit y x1 x2 i.a
```

Population-averaged model with robust standard errors

```
xtprobit y x1 x2 i.a, pa vce(robust)
```

As above, but specify an autoregressive correlation structure of order 1

```
xtprobit y x1 x2 i.a, pa vce(robust) corr(ar 1)
```

Random-effects model with cluster-robust standard errors for panels nested within *cvar*

```
xtprobit y x1 x2 i.a, vce(cluster cvar)
```

## Menu

Statistics > Longitudinal/panel data > Binary outcomes > Probit regression (RE, PA)

## Syntax

*Random-effects (RE) model*

```
xtprobit depvar [indepvars] [if] [in] [weight] [, re RE_options]
```

*Population-averaged (PA) model*

```
xtprobit depvar [indepvars] [if] [in] [weight], pa [PA_options]
```

<i>RE_options</i>	Description
Model	
<u>noconstant</u>	suppress constant term
<u>re</u>	use random-effects estimator; the default
<u>offset(varname)</u>	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints(constraints)</u>	apply specified linear constraints
<u>asis</u>	retain perfect predictor variables
SE/Robust	
<u>vce(vcetype)</u>	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level(#)</u>	set confidence level; default is <i>level(95)</i>
<u>lrmodel</u>	perform the likelihood-ratio model test instead of the default Wald test
<u>nocnsreport</u>	do not display constraints
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod(intmethod)</u>	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints(#)</u>	use # quadrature points; default is <i>intpoints(12)</i>
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

<i>PA_options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term
<u>pa</u>	use population-averaged estimator
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<u>asis</u>	retain perfect predictor variables
<b>Correlation</b>	
<u>corr</u> ( <i>correlation</i> )	within-panel correlation structure
<u>force</u>	estimate even if observations unequally spaced in time
<b>SE/Robust</b>	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be conventional, <u>robust</u> , <u>bootstrap</u> , or <u>jackknife</u>
<u>nmp</u>	use divisor $N - P$ instead of the default $N$
<u>scale</u> ( <i>parm</i> )	overrides the default scale parameter; <i>parm</i> may be x2, dev, phi, or #
<b>Reporting</b>	
<u>level</u> (#)	set confidence level; default is <b>level(95)</b>
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Optimization</b>	
<u>optimize_options</u>	control the optimization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>correlation</i>	Description
<u>exchangeable</u>	exchangeable
<u>independent</u>	independent
<u>unstructured</u>	unstructured
<u>fixed</u> <i>matname</i>	user-specified
<u>ar</u> #	autoregressive of order #
<u>stationary</u> #	stationary of order #
<u>nonstationary</u> #	nonstationary of order #

A panel variable must be specified. For `xtprobit`, `pa`, correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] `xtset`.

`indepvars` may contain factor variables; see [U] 11.4.3 Factor variables.

`depvar` and `indepvars` may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by`, `mi estimate`, and `statsby` are allowed; see [U] 11.1.10 Prefix commands. `fp` is allowed for the random-effects model.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] `mi estimate`.

`iweights`, `fweights`, and `pweights` are allowed for the population-averaged model, and `iweights` are allowed for the random-effects model; see [U] 11.1.6 weight. Weights must be constant within panel.

`collinear` and `coeflegend` do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options for RE model

### Model

`noconstant`; see [R] **Estimation options**.

`re` requests the random-effects estimator. `re` is the default if neither `re` nor `pa` is specified.

`offset(varname)`, `constraints(constraints)`; see [R] **Estimation options**.

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] **probit**.

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] **vce\_options**.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see **xtprobit, re and the robust VCE estimator** in *Methods and formulas*.

### Reporting

`level(#)`, `lrmodel`, `nocnsreport`; see [R] **Estimation options**.

`display_options`: `noci`, `novalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] **Estimation options**.

### Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] **Estimation options**.

### Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `nrtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] **Maximize**. These options are seldom used.

The following options are available with `xtprobit` but are not shown in the dialog box:  
`collinear`, `coeflegend`; see [R] **Estimation options**.

## Options for PA model

### Model

`noconstant`; see [R] **Estimation options**.

`pa` requests the population-averaged estimator.

`offset(varname)`; see [R] **Estimation options**.

`asis` forces retention of perfect predictor variables and their associated, perfectly predicted observations and may produce instabilities in maximization; see [R] **probit**.

**Correlation**

`corr(correlation)` specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

`force` specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify `force`, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

**SE/Robust**

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

`nmp`, `scale(x2 | dev | phi | #)`; see [XT] [vce\\_options](#).

**Reporting**

`level(#)`; see [R] [Estimation options](#).

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwwrap(#)`, `fwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

**Optimization**

`optimize_options` control the iterative optimization process. These options are seldom used.

`iterate(#)` specifies the maximum number of iterations. When the number of iterations equals `#`, the optimization stops and presents the current results, even if convergence has not been reached. The default is `iterate(100)`.

`tolerance(#)` specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to `#`, the optimization process is stopped. `tolerance(1e-6)` is the default.

`log` and `nolog` specify whether to display the iteration log. The iteration log is displayed by default unless you used `set iterlog off` to suppress it; see `set iterlog` in [R] [set iter](#).

`trace` specifies that the current estimates be printed at each iteration.

The following option is available with `xtprobit` but is not shown in the dialog box:

`coeflegend`; see [R] [Estimation options](#).

## Remarks and examples

**xtprobit** may be used to fit a population-averaged model or a random-effects probit model. There is no command for a conditional fixed-effects model, as there does not exist a sufficient statistic allowing the fixed effects to be conditioned out of the likelihood. Unconditional fixed-effects probit models may be fit with the **probit** command with indicator variables for the panels. However, unconditional fixed-effects estimates are biased. We do not discuss fixed-effects further in this entry.

By default, the population-averaged model is an equal-correlation model; that is, **xtprobit**, **pa** assumes **corr(exchangeable)**. Thus, **xtprobit** is a convenience command for obtaining the population-averaged model using **xtgee**; see [XT] **xtgee**. Typing

```
. xtprobit ..., pa ...
```

is equivalent to typing

```
. xtgee ..., ... family(binomial) link(probit) corr(exchangeable)
```

See also [XT] **xtgee** for information about **xtprobit**.

By default or when **re** is specified, **xtprobit** fits via maximum likelihood the random-effects model

$$\Pr(y_{it} \neq 0 | \mathbf{x}_{it}) = \Phi(\mathbf{x}_{it}\boldsymbol{\beta} + \nu_i)$$

for  $i = 1, \dots, n$  panels, where  $t = 1, \dots, n_i$ ,  $\nu_i$  are i.i.d.,  $N(0, \sigma_\nu^2)$ , and  $\Phi$  is the standard normal cumulative distribution function.

Underlying this model is the variance components model

$$y_{it} \neq 0 \iff \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} > 0$$

where  $\epsilon_{it}$  are i.i.d. Gaussian distributed with mean zero and variance  $\sigma_\epsilon^2 = 1$ , independently of  $\nu_i$ .

### ▷ Example 1: Random-effects model

We are studying unionization of women in the United States and are using the **union** dataset; see [XT] **xt**. We wish to fit a random-effects model of union membership:

```

. use https://www.stata-press.com/data/r16/union
(NLS Women 14-24 in 1968)
. xtprobit union age grade i.not_smsa south##c.year
Fitting comparison model:
Iteration 0: log likelihood = -13864.23
Iteration 1: log likelihood = -13545.541
Iteration 2: log likelihood = -13544.385
Iteration 3: log likelihood = -13544.385
Fitting full model:
rho = 0.0    log likelihood = -13544.385
rho = 0.1    log likelihood = -12237.655
rho = 0.2    log likelihood = -11590.282
rho = 0.3    log likelihood = -11211.185
rho = 0.4    log likelihood = -10981.319
rho = 0.5    log likelihood = -10852.793
rho = 0.6    log likelihood = -10808.759
rho = 0.7    log likelihood = -10865.57
Iteration 0: log likelihood = -10807.712
Iteration 1: log likelihood = -10599.332
Iteration 2: log likelihood = -10552.287
Iteration 3: log likelihood = -10552.225
Iteration 4: log likelihood = -10552.225
Random-effects probit regression
Number of obs      =      26,200
Group variable: idcode
Number of groups   =      4,434
Random effects u_i ~ Gaussian
Obs per group:
min =           1
avg =          5.9
max =         12
Integration method: mvaghermite
Integration pts. =        12
Wald chi2(6)      =     220.91
Prob > chi2       =     0.0000
Log likelihood = -10552.225

```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
1. not_smsa	.0082967	.0084599	0.98	0.327	-.0082843 .0248778
	.0482731	.0099469	4.85	0.000	.0287776 .0677686
	-.139657	.0460548	-3.03	0.002	-.2299227 -.0493913
	-.1584394	.358473	-4.42	0.000	-2.286989 -.8818002
	-.0039854	.0088399	-0.45	0.652	-.0213113 .0133406
south#c.year					
1	.0134017	.0044622	3.00	0.003	.0046559 .0221475
_cons	-1.668202	.4751819	-3.51	0.000	-2.599542 -.7368628
/lnsig2u	.6103616	.0458783			.5204418 .7002814
sigma_u	1.35687	.0311255			1.297217 1.419267
	.6480233	.0104643			.6272511 .6682502

LR test of rho=0: chibar2(01) = 5984.32

Prob >= chibar2 = 0.000

The output includes the additional panel-level variance component, which is parameterized as the log of the variance  $\ln(\sigma_\nu^2)$  (labeled `lnsig2u` in the output). The standard deviation  $\sigma_\nu$  is also included in the output (labeled `sigma_u`) together with  $\rho$  (labeled `rho`), where

$$\rho = \frac{\sigma_\nu^2}{\sigma_\nu^2 + 1}$$

which is the proportion of the total variance contributed by the panel-level variance component.

When rho is zero, the panel-level variance component is unimportant, and the panel estimator is not different from the pooled estimator. A likelihood-ratio test of this is included at the bottom of the output. This test formally compares the pooled estimator (probit) with the panel estimator.



## □ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the quadchk command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the intpoints() option and run quadchk again. Do not attempt to interpret the results of estimates when the coefficients reported by quadchk differ substantially.

	Quadrature check			
	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-10552.225	-10554.496 -2.2712569 .00021524	-10552.399 -.17396615 .00001649	Difference Relative difference
union: age	.00829671	.00828745 -9.265e-06 -.0011167	.00831488 .00001817 .00218987	Difference Relative difference
union: grade	.0482731	.04860277 .00032967 .00682917	.04826287 -.00001023 -.00021188	Difference Relative difference
union: 1.not_smsa	-.13965702	-.14057441 -.00091739 .00656891	-.13953521 .00012181 -.00087218	Difference Relative difference
union: 1.south	-1.5843944	-1.5909857 -.00659135 .00416017	-1.5843375 .00005689 -.00003591	Difference Relative difference
union: year	-.00398535	-.00397811 7.237e-06 -.00181578	-.00400181 -.00001646 .00412982	Difference Relative difference
union: 1.south#c.~r	.01340169	.01344457 .00004288 .00319946	.01340388 2.193e-06 .0001636	Difference Relative difference
union: _cons	-1.6682022	-1.6757524 -.00755024 .00452597	-1.6665327 .00166948 -.00100077	Difference Relative difference
/: lnsig2u	.61036163	.61780789 .00744626 .01219976	.60974814 -.00061349 -.00100513	Difference Relative difference

The results obtained for 12 quadrature points were closer to the results for 16 points than to the results for eight points. Although the relative and absolute differences are a bit larger than we would like, they are not large. We can increase the number of quadrature points with the `intpoints()` option; if we choose `intpoints(20)` and do another `quadchk` we will get acceptable results, with relative differences around 0.01%.

This is not the case if we use nonadaptive quadrature. Then the results we obtain are

```
. xtprobit union age grade i.not_smsa south##c.year, intmethod(ghermite)
Fitting comparison model:
Iteration 0: log likelihood = -13864.23
Iteration 1: log likelihood = -13545.541
Iteration 2: log likelihood = -13544.385
Iteration 3: log likelihood = -13544.385

Fitting full model:
rho = 0.0      log likelihood = -13544.385
rho = 0.1      log likelihood = -12237.655
rho = 0.2      log likelihood = -11590.282
rho = 0.3      log likelihood = -11211.185
rho = 0.4      log likelihood = -10981.319
rho = 0.5      log likelihood = -10852.793
rho = 0.6      log likelihood = -10808.759
rho = 0.7      log likelihood = -10865.57
Iteration 0: log likelihood = -10808.759
Iteration 1: log likelihood = -10594.349
Iteration 2: log likelihood = -10560.913
Iteration 3: log likelihood = -10560.876
Iteration 4: log likelihood = -10560.876

Random-effects probit regression                               Number of obs     =    26,200
Group variable: idcode                                     Number of groups  =     4,434
Random effects u_i ~ Gaussian                            Obs per group:
                                                               min =          1
                                                               avg =        5.9
                                                               max =       12

Integration method: ghermite                                Integration pts. =      12
                                                               Wald chi2(6) =   218.99
                                                               Prob > chi2 = 0.0000

Log likelihood = -10560.876


```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
age	.0093488	.0083385	1.12	0.262	-.0069945 .025692
grade	.0488014	.0101168	4.82	0.000	.0289728 .06863
1.not_smsa	-.1364862	.0462831	-2.95	0.003	-.2271995 -.045773
1.south	-1.592711	.3576715	-4.45	0.000	-2.293734 -.8916877
year	-.0053723	.0087219	-0.62	0.538	-.0224668 .0117223
south##c.year					
1	.0136764	.0044532	3.07	0.002	.0049482 .0224046
_cons	-1.575539	.4639881	-3.40	0.001	-2.484939 -.6661388
/lnsig2u	.5615976	.0432021			.476923 .6462722
sigma_u	1.324187	.0286038			1.269295 1.381453
rho	.6368221	.0099918			.617021 .6561699

LR test of rho=0: chibar2(01) = 5967.02

Prob >= chibar2 = 0.000

We now check the stability of the quadrature technique for this nonadaptive quadrature model. We expect it to be less stable.

Quadrature check				
	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-10560.876	-10574.239 -13.362535 .00126529	-10555.792 5.0839579 -.0004814	Difference Relative difference
union: age	.00934876	.01264615 .0032974 .35270966	.00731888 -.00202987 -.21712744	Difference Relative difference
union: grade	.04880139	.05710089 .00829951 .17006703	.04432417 -.00447722 -.09174372	Difference Relative difference
union: 1.not_smsa	-.13648624	-.13327724 .003209 -.0235115	-.14094541 -.00445917 .03267123	Difference Relative difference
union: 1.south	-1.592711	-1.5275627 .06514823 -.04090399	-1.6059143 -.01320331 .00828983	Difference Relative difference
union: year	-.00537226	-.00867673 -.00330447 .61509968	-.00307042 .00230184 -.4284678	Difference Relative difference
union: 1.south#c.r	.01367641	.01278071 -.0008957 -.06549266	.01369009 .00001368 .00100054	Difference Relative difference
union: _cons	-1.5755388	-1.4888646 .08667418 -.0550124	-1.6505526 -.0750138 .04761152	Difference Relative difference
/: lnsig2u	.56159763	.49290978 -.06868786 -.12230795	.58068904 .0190914 .03399481	Difference Relative difference

Once again, the results obtained for 12 quadrature points were closer to the results for 16 points than to the results for eight points. However, here the convergence point seems to be sensitive to the number of quadrature points, so we should not trust these results. We should increase the number of quadrature points with the `intpoints()` option and then use `quadchk` again. We should not use the results of a random-effects specification when there is evidence that the numeric technique for calculating the model is not stable (as shown by `quadchk`).

Generally, the relative differences in the coefficients should not change by more than 1% if the quadrature technique is stable. See [XT] `quadchk` for details. Increasing the number of quadrature points can often improve the stability, and for models with high `rho` we may need many. We can also switch between adaptive and nonadaptive quadrature. As a rule, adaptive quadrature, which is the default integration method, is much more flexible and robust.

Because the `xtprobit, re` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.



## ▷ Example 2: Equal-correlation model

As an alternative to the random-effects specification, we can fit an equal-correlation probit model:

```
. xtprobit union age grade i.not_smsa south##c.year, pa
Iteration 1: tolerance = .12544249
Iteration 2: tolerance = .0034686
Iteration 3: tolerance = .00017448
Iteration 4: tolerance = 8.382e-06
Iteration 5: tolerance = 3.997e-07

GEE population-averaged model
Group variable: idcode      Number of obs     =    26,200
Link:          probit       Number of groups  =      4,434
Family:        binomial    Obs per group:
Correlation:   exchangeable min =           1
                           avg =         5.9
                           max =        12
                           Wald chi2(6) =    242.57
Scale parameter: 1          Prob > chi2 = 0.0000
```

union	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
age	.0089699	.0053208	1.69	0.092	-.0014586 .0193985
grade	.0333174	.0062352	5.34	0.000	.0210966 .0455382
1.not_smsa	-.0715717	.027543	-2.60	0.009	-.1255551 -.0175884
1.south	-1.017368	.207931	-4.89	0.000	-1.424905 -.6098308
year	-.0062708	.0055314	-1.13	0.257	-.0171122 .0045706
south##c.year					
1	.0086294	.00258	3.34	0.001	.0035727 .013686
_cons	-.8670997	.294771	-2.94	0.003	-1.44484 -.2893592



## ▷ Example 3: Population-averaged model

In example 3 of [R] `probit`, we showed the above results and compared them with `probit, vce(cluster id)`. `xtprobit` with the `pa` option allows a `vce(robust)` option, so we can obtain the population-averaged probit estimator with the robust variance calculation by typing

```
. xtprobit union age grade i.not_smsa south##c.year, pa vce(robust) nolog
GEE population-averaged model
Group variable: idcode           Number of obs = 26,200
Link:          probit            Number of groups = 4,434
Family:        binomial          Obs per group:
Correlation:   exchangeable      min = 1
                           avg = 5.9
                           max = 12
                           Wald chi2(6) = 156.33
Scale parameter: 1             Prob > chi2 = 0.0000
                           (Std. Err. adjusted for clustering on idcode)
```

union	Semirobust					[95% Conf. Interval]
	Coef.	Std. Err.	z	P> z		
age	.0089699	.0051169	1.75	0.080	-.001059	.0189988
grade	.0333174	.0076425	4.36	0.000	.0183383	.0482965
1.not_smsa	-.0715717	.0348659	-2.05	0.040	-.1399076	-.0032359
1.south	-1.017368	.3026981	-3.36	0.001	-1.610645	-.4240906
year	-.0062708	.0055745	-1.12	0.261	-.0171965	.0046549
south##c.year						
1	.0086294	.0037866	2.28	0.023	.0012078	.0160509
_cons	-.8670997	.3243959	-2.67	0.008	-1.502904	-.2312955

These standard errors are similar to those shown for `probit`, `vce(cluster id)` in [R] [probit](#).



#### ▷ Example 4: Random-effects model with stable quadrature

In a [previous example](#), we showed how `quadchk` indicated that the quadrature technique was numerically unstable. Here we present an example in which the quadrature is stable.

In this example, we have (synthetic) data on whether workers complain to managers at fast-food restaurants. The covariates are `age` (in years of the worker), `grade` (years of schooling completed by the worker), `south` (equal to 1 if the restaurant is located in the South), `tenure` (the number of years spent on the job by the worker), `gender` (of the worker), `race` (of the worker), `income` (in thousands of dollars by the restaurant), `genderm` (gender of the manager), `burger` (equal to 1 if the restaurant specializes in hamburgers), and `chicken` (equal to 1 if the restaurant specializes in chicken). The model is given by

```
. use https://www.stata-press.com/data/r16/chicken
. xtprobit complain age grade south tenure gender race income genderm burger
> chicken, nolog
Random-effects probit regression
Number of obs      =      2,763
Group variable: restaurant
Number of groups   =       500
Random effects u_i ~ Gaussian
Obs per group:
    min =           3
    avg =         5.5
    max =          8
Integration method: mvaghermite
Integration pts.   =        12
Wald chi2(10)     =     126.59
Prob > chi2       =     0.0000
Log likelihood = -1318.2088
```

complain	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
age	-.0430409	.0130211	-3.31	0.001	-.0685617    -.01752
grade	.0330934	.0264572	1.25	0.211	-.0187618    .0849486
south	.1012	.0707196	1.43	0.152	-.037408    .2398079
tenure	-.0440079	.0987099	-0.45	0.656	-.2374758    .14946
gender	.3318499	.0601382	5.52	0.000	.2139812    .4497185
race	.3417901	.0382251	8.94	0.000	.2668703    .4167098
income	-.0022702	.0008885	-2.56	0.011	-.0040117    -.0005288
genderm	.0524577	.0706585	0.74	0.458	-.0860305    .1909459
burger	.0448931	.0956151	0.47	0.639	-.1425091    .2322953
chicken	.1904714	.0953067	2.00	0.046	.0036737    .3772691
_cons	-.2145311	.6240549	-0.34	0.731	-1.437656    1.008594
/lnsig2u	-1.704494	.2502057			-2.194888    -1.214099
sigma_u	.4264557	.0533508			.333723    .5449563
rho	.1538793	.0325769			.1002105    .2289765

LR test of rho=0: chibar2(01) = 29.91

Prob >= chibar2 = 0.000

Again we would like to check the stability of the quadrature technique of the model before interpreting the results. Given the estimate of  $\rho$  and the small size of the panels (between 3 and 8), we should find that the quadrature technique is numerically stable.

```
. quadchk, nooutput
```

```
Refitting model intpoints() = 8
Refitting model intpoints() = 16
```

Quadrature check

	Fitted quadrature 12 points	Comparison quadrature 8 points	Comparison quadrature 16 points	
Log likelihood	-1318.2088	-1318.2088	-1318.2088	Difference
		-2.002e-06	-1.194e-09	Relative difference
		1.519e-09	9.061e-13	
complain: age	-.04304086	-.04304086	-.04304086	Difference
		-3.896e-10	-2.625e-12	Relative difference
		9.051e-09	6.100e-11	
complain: grade	.0330934	.0330934	.0330934	Difference
		2.208e-11	1.867e-12	Relative difference
		6.673e-10	5.643e-11	
complain: south	.10119998	.10119999	.10119998	Difference
		2.369e-09	3.957e-11	Relative difference
		2.341e-08	3.910e-10	
complain: tenure	-.04400789	-.0440079	-.04400789	Difference
		-3.362e-09	-2.250e-11	Relative difference
		7.640e-08	5.114e-10	
complain: gender	.33184986	.33184986	.33184986	Difference
		3.190e-09	2.546e-11	Relative difference
		9.612e-09	7.673e-11	
complain: race	.34179006	.34179007	.34179006	Difference
		3.801e-09	2.990e-11	Relative difference
		1.112e-08	8.749e-11	
complain: income	-.00227021	-.00227021	-.00227021	Difference
		-4.468e-11	-9.252e-13	Relative difference
		1.968e-08	4.075e-10	
complain: genderm	.05245769	.05245769	.05245769	Difference
		1.963e-09	4.481e-11	Relative difference
		3.742e-08	8.542e-10	
complain: burger	.04489311	.04489311	.04489311	Difference
		4.173e-10	6.628e-12	Relative difference
		9.296e-09	1.476e-10	
complain: chicken	.19047138	.19047139	.19047138	Difference
		3.096e-09	4.916e-11	Relative difference
		1.625e-08	2.581e-10	
complain: _cons	-.21453112	-.21453111	-.21453112	Difference
		1.281e-08	2.682e-10	Relative difference
		-5.972e-08	-1.250e-09	
/:	-1.7044935	-1.7044934	-1.7044935	Difference
lnsig2u		1.255e-07	-4.135e-10	Relative difference
		-7.365e-08	2.426e-10	

The relative and absolute differences are all small between the default 12 quadrature points and the result with 16 points. We do not have any coefficients that have a large difference between the default 12 quadrature points and eight quadrature points.

We conclude that the quadrature technique is stable. Because the differences here are so small, we would plan on using and interpreting these results rather than trying to rerun with more quadrature points.



## Stored results

`xtprobit, re` stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_aux)</code>	number of auxiliary parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(l1_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	$\chi^2$
<code>e(chi2_c)</code>	$\chi^2$ for comparison test
<code>e(N_clust)</code>	number of clusters
<code>e(rho)</code>	$\rho$
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

### Macros

<code>e(cmd)</code>	<code>xtprobit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	
<code>e(wtype)</code>	<code>re</code>
<code>e(wexp)</code>	weight type
<code>e(title)</code>	weight expression
<code>e(clustvar)</code>	title in estimation output
<code>e(offset)</code>	name of cluster variable
<code>e(chi2type)</code>	linear offset variable
<code>e(chi2_ct)</code>	$\text{Wald}$ or $\text{LR}$ ; type of model $\chi^2$ test
<code>e(vce)</code>	$\text{Wald}$ or $\text{LR}$ ; type of model $\chi^2$ test corresponding to <code>e(chi2_c)</code>
<code>e(vcetype)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(intmethod)</code>	title used to label Std. Err.
<code>e(distrib)</code>	integration method
<code>e(opt)</code>	<code>Gaussian</code> ; the distribution of the random effect
<code>e(which)</code>	type of optimization
	<code>max</code> or <code>min</code> ; whether optimizer is to perform maximization or minimization

<code>e(ml_method)</code>	type of <code>ml</code> method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsdefault)</code>	default <code>predict()</code> specification for <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

## Matrices

<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(iolog)</code>	iteration log
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance

## Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

`xtprobit, pa` stores the following in `e()`:

## Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(chi2)</code>	$\chi^2$
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(df_pear)</code>	degrees of freedom for Pearson $\chi^2$
<code>e(chi2_dev)</code>	$\chi^2$ test of deviance
<code>e(chi2_dis)</code>	$\chi^2$ test of deviance dispersion
<code>e(deviance)</code>	deviance
<code>e(dispers)</code>	deviance dispersion
<code>e(phi)</code>	scale parameter
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(tol)</code>	target tolerance
<code>e(dif)</code>	achieved tolerance
<code>e(rc)</code>	return code

## Macros

<code>e(cmd)</code>	<code>xtgee</code>
<code>e(cmd2)</code>	<code>xtprobit</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(tvar)</code>	variable denoting time within groups
<code>e(model)</code>	<code>pa</code>
<code>e(family)</code>	<code>binomial</code>
<code>e(link)</code>	probit; link function
<code>e(corr)</code>	correlation structure
<code>e(scale)</code>	<code>x2, dev, phi, or #; scale parameter</code>
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	<code>Wald; type of model <math>\chi^2</math> test</code>
<code>e(vce)</code>	<code>vctype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(nmp)</code>	<code>nmp</code> , if specified
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>

<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>
Matrices	
<code>e(b)</code>	coefficient vector
<code>e(R)</code>	estimated working correlation matrix
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_modelbased)</code>	model-based variance
Functions	
<code>e(sample)</code>	marks estimation sample

## Methods and formulas

`xtprobit` reports the population-averaged results obtained by using `xtgee`, `family(binomial)` `link(probit)` to obtain estimates.

Assuming a normal distribution,  $N(0, \sigma_\nu^2)$ , for the random effects  $\nu_i$

$$\Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i$$

where

$$F(y, z) = \begin{cases} \Phi(z) & \text{if } y \neq 0 \\ 1 - \Phi(z) & \text{otherwise} \end{cases}$$

where  $\Phi$  is the cumulative normal distribution.

The panel-level likelihood  $l_i$  is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with  $M$ -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the  $w_m^*$  denote the quadrature weights and the  $a_m^*$  denote the quadrature abscissas. The log likelihood,  $L$ , is the sum of the logs of the panel-level likelihoods  $l_i$ .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel-level likelihood with

$$l_i \approx \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i)$$

where  $\hat{\sigma}_i$  and  $\hat{\mu}_i$  are the adaptive parameters for panel  $i$ . Therefore, with the definition of  $g(y_{it}, x_{it}, \nu_i)$ , the total log likelihood is approximated by

$$L \approx \sum_{i=1}^n w_i \log \left[ \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i)^2/2\sigma_\nu^2\}}{\sqrt{2\pi}\sigma_\nu} \right. \\ \left. \prod_{t=1}^{n_i} F(y_{it}, x_{it}\beta + \sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i) \right]$$

where  $w_i$  is the user-specified weight for panel  $i$ ; if no weights are specified,  $w_i = 1$ .

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for  $\hat{\mu}_i$  and  $\hat{\sigma}_i$  by following the method of [Naylor and Smith \(1982\)](#), further discussed in [Skrondal and Rabe-Hesketh \(2004\)](#). We start with  $\hat{\sigma}_{i,0} = 1$  and  $\hat{\mu}_{i,0} = 0$ , and the posterior means and variances are updated in the  $k$ th iteration. That is, at the  $k$ th iteration of the optimization for  $l_i$ , we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until  $\hat{\mu}_{i,k}$  and  $\hat{\sigma}_{i,k}$  have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of  $1e-6$ ; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature, the `int-method(ghermite)` option, where  $\rho = \sigma_\nu^2 / (\sigma_\nu^2 + 1)$ :

$$L = \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ \approx \sum_{i=1}^n w_i \log \left[ \frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left\{ y_{it}, \mathbf{x}_{it}\beta + a_m^* \left( \frac{2\rho}{1-\rho} \right)^{1/2} \right\} \right]$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. The number of periods (panel size) can affect whether

$$\prod_{t=1}^{n_i} F(y_{it}, \mathbf{x}_{it}\beta + \nu_i)$$

is well approximated by a polynomial. As panel size and  $\rho$  increase, the quadrature approximation can become less accurate. For large  $\rho$ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] `quadchk`) to verify the quadrature approximation used in this command, whichever approximation you choose.

## xtprobit, re and the robust VCE estimator

Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] `_robust`, particularly *Introduction* and *Methods and formulas*. Wooldridge (2020) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2020), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in  $\epsilon_{it}$ .

The cluster–robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

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## Also see

- [XT] **xtprobit postestimation** — Postestimation tools for xtprobit
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtcloglog** — Random-effects and population-averaged cloglog models
- [XT] **xteprobit** — Extended random-effects probit regression
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtlogit** — Fixed-effects, random-effects, and population-averaged logit models
- [XT] **xtset** — Declare data to be panel data
- [ME] **meprobit** — Multilevel mixed-effects probit regression
- [MI] **Estimation** — Estimation commands for use with mi estimate
- [R] **probit** — Probit regression
- [U] **20 Estimation and postestimation commands**

**xtprobit postestimation** — Postestimation tools for xtprobit

Postestimation commands predict margins Remarks and examples  
Also see

## Postestimation commands

The following postestimation commands are available after `xtprobit`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
* <code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
† <code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
* <code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from <code>margins</code> (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

\* `estat ic` and `lrtest` are not appropriate after `xtprobit`, pa.

† `forecast` is not appropriate with `mi` estimation results.

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions, probabilities, standard errors, and equation-level scores.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

*Random-effects model*

```
predict [type] newvar [if] [in] [, RE_statistic nooffset]
```

*Population-averaged model*

```
predict [type] newvar [if] [in] [, PA_statistic nooffset]
```

<i>RE_statistic</i>	Description
<b>Main</b>	
<b>xb</b>	linear prediction; the default
<b>pr</b>	marginal probability of a positive outcome
<b>pu0</b>	probability of a positive outcome
<b>stdp</b>	standard error of the linear prediction

<i>PA_statistic</i>	Description
<b>Main</b>	
<b>mu</b>	probability of <i>depvar</i> ; considers the <code>offset()</code> ; the default
<b>rate</b>	probability of <i>depvar</i>
<b>xb</b>	linear prediction
<b>stdp</b>	standard error of the linear prediction
<b>score</b>	first derivative of the log likelihood with respect to $\mathbf{x}_{it}\beta$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

## Options for predict

### Main

**xb** calculates the linear prediction. This is the default for the random-effects model.

**pr** calculates the probability of a positive outcome that is marginal with respect to the random effect, which means that the probability is calculated by integrating the prediction function with respect to the random effect over its entire support.

**pu0** calculates the probability of a positive outcome, assuming that the random effect for that observation's panel is zero ( $\nu_i = 0$ ). This probability may not be similar to the proportion of observed outcomes in the group.

**mu** and **rate** both calculate the predicted probability of *depvar*. **mu** takes into account the `offset()`, and **rate** ignores those adjustments. **mu** and **rate** are equivalent if you did not specify `offset()`. **mu** is the default for the population-averaged model.

**stdp** calculates the standard error of the linear prediction.

**score** calculates the equation-level score,  $u_{it} = \partial \ln L(\mathbf{x}_{it}\beta) / \partial (\mathbf{x}_{it}\beta)$ .

**nooffset** is relevant only if you specified `offset(varname)` for `xtprobit`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\beta$  rather than  $\mathbf{x}_{it}\beta + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions and probabilities.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist] , predict(statistic ...) [predict(statistic ...) ...] [options]
```

Random-effects model

<i>statistic</i>	Description
------------------	-------------

<code>pr</code>	marginal probability of a positive outcome; the default
<code>pu0</code>	probability of a positive outcome
<code>xb</code>	linear prediction
<code>stdp</code>	not allowed with <code>margins</code>

Population-averaged model

<i>statistic</i>	Description
------------------	-------------

<code>mu</code>	probability of <i>depvar</i> ; considers the <code>offset()</code> ; the default
<code>rate</code>	probability of <i>depvar</i>
<code>xb</code>	linear prediction
<code>stdp</code>	not allowed with <code>margins</code>
<code>score</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] **margins**.

## Remarks and examples

### ▷ Example 1: Calculating average marginal effects

In example 2 of [XT] **xtprobit**, we fit a population-averaged model of union status on the woman's age and level of schooling, whether she lived in an urban area, whether she lived in the south, and the year observed. Here we compute the average marginal effects from that fitted model on the probability of being in a union.

```
. use https://www.stata-press.com/data/r16/union
(NLS Women 14-24 in 1968)
. xtprobit union age grade i.not_smsa south##c.year, pa
  (output omitted)
. margins, dydx(*)

Average marginal effects                               Number of obs      =     26,200
Model VCE    : Conventional
Expression   : Pr(union != 0), predict()
dy/dx w.r.t. : age grade 1.not_smsa 1.south year
```

	Delta-method					
	dy/dx	Std. Err.	z	P> z	[95% Conf. Interval]	
age	.0025337	.0015035	1.69	0.092	-.0004132	.0054805
grade	.0094109	.0017566	5.36	0.000	.005968	.0128537
1.not_smsa	-.0199744	.0075879	-2.63	0.008	-.0348464	-.0051023
1.south	-.0910805	.0073315	-12.42	0.000	-.10545	-.076711
year	-.000938	.0015413	-0.61	0.543	-.0039589	.0020828

Note: dy/dx for factor levels is the discrete change from the base level.

On average, not living in a metropolitan area (`not_smsa = 1`) lowers the probability of being in a union by about two percentage points.



## Also see

[XT] **xtprobit** — Random-effects and population-averaged probit models

[U] **20 Estimation and postestimation commands**

**xtrc** — Random-coefficients model[Description](#)  
[Options](#)  
[References](#)[Quick start](#)  
[Remarks and examples](#)  
[Also see](#)[Menu](#)  
[Stored results](#)[Syntax](#)  
[Methods and formulas](#)

## Description

**xtrc** fits the [Swamy \(1970\)](#) random-coefficients linear regression model, which does not impose the assumption of constant parameters across panels. Average coefficient estimates are reported by default, but panel-specific coefficients may be requested.

## Quick start

Random-coefficients regression of *y* on *x1* and *x2* using [\*xtset\*](#) data

```
xtrc y x1 x2
```

As above, but report panel-specific best linear predictors

```
xtrc y x1 x2, betas
```

Multiple-imputation estimates of random-coefficients regression using [\*mi xtset\*](#) data

```
mi estimate: xtrc y x
```

## Menu

Statistics > Longitudinal/panel data > Random-coefficients regression by GLS

## Syntax

`xtrc depvar indepvars [if] [in] [, options]`

<i>options</i>	Description
<hr/>	
Main	
<u>noconstant</u>	suppress constant term
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<hr/>	
SE	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be <u>conventional</u> , <u>bootstrap</u> , or <u>jackknife</u>
<hr/>	
Reporting	
<u>level</u> (#)	set confidence level; default is <code>level(95)</code>
<u>betas</u>	display group-specific best linear predictors
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<u>coeflegend</u>	display legend instead of statistics
<hr/>	

A panel variable must be specified; use `xtset`; see [XT] `xtset`.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

`by`, `mi estimate`, and `statsby` are allowed; see [U] 11.1.10 Prefix commands.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] `mi estimate`.

`coeflegend` does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

Main

`noconstant`, `offset`(*varname*); see [R] Estimation options

SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (conventional) and that use bootstrap or jackknife methods (bootstrap, jackknife); see [XT] `vce_options`.

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Reporting

`level`(#); see [R] Estimation options.

`betas` requests that the group-specific best linear predictors also be displayed.

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] Estimation options.

The following option is available with **xtrc** but is not shown in the dialog box:  
`coeflegend`; see [R] **Estimation options**.

## Remarks and examples

In random-coefficients models, we wish to treat the parameter vector as a realization (in each panel) of a stochastic process. **xtrc** fits the [Swamy \(1970\)](#) random-coefficients model, which is suitable for linear regression of panel data. See [Greene \(2012, chap. 11\)](#) and [Poi \(2003\)](#) for more information about this and other panel-data models.

### ▷ Example 1

[Greene \(2012, 1112\)](#) reprints data from a classic study of investment demand by [Grunfeld and Griliches \(1960\)](#). In [XT] **xtgls**, we use this dataset to illustrate many of the possible models that may be fit with the **xtgls** command. Although the models included in the **xtgls** command offer considerable flexibility, they all assume that there is no parameter variation across firms (the cross-sectional units).

To take a first look at the assumption of parameter constancy, we should **reshape** our data so that we may fit a simultaneous-equation model with **sureg**; see [R] **sureg**. Because there are only five panels here, this is not too difficult.

```
. use https://www.stata-press.com/data/r16/invest2
. reshape wide invest market stock, i(time) j(company)
(note: j = 1 2 3 4 5)
Data          long    ->   wide
Number of obs.      100    ->     20
Number of variables           5    ->     16
j variable (5 values)       company    ->  (dropped)
xij variables:
                  invest    ->  invest1 invest2 ... invest5
                  market    ->  market1 market2 ... market5
                  stock    ->  stock1 stock2 ... stock5
```

---

```
. sureg (invest1 market1 stock1) (invest2 market2 stock2)
> (invest3 market3 stock3) (invest4 market4 stock4) (invest5 market5 stock5)
```

Seemingly unrelated regression

Equation	Obs	Parms	RMSE	"R-sq"	chi2	P
invest1	20	2	84.94729	0.9207	261.32	0.0000
invest2	20	2	12.36322	0.9119	207.21	0.0000
invest3	20	2	26.46612	0.6876	46.88	0.0000
invest4	20	2	9.742303	0.7264	59.15	0.0000
invest5	20	2	95.85484	0.4220	14.97	0.0006

	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
invest1					
market1	.120493	.0216291	5.57	0.000	.0781007 .1628853
stock1	.3827462	.032768	11.68	0.000	.318522 .4469703
_cons	-162.3641	89.45922	-1.81	0.070	-337.7009 12.97279
invest2					
market2	.0695456	.0168975	4.12	0.000	.0364271 .1026641
stock2	.3085445	.0258635	11.93	0.000	.2578529 .3592362
_cons	.5043112	11.51283	0.04	0.965	-22.06042 23.06904
invest3					
market3	.0372914	.0122631	3.04	0.002	.0132561 .0613268
stock3	.130783	.0220497	5.93	0.000	.0875663 .1739997
_cons	-22.43892	25.51859	-0.88	0.379	-72.45443 27.57659
invest4					
market4	.0570091	.0113623	5.02	0.000	.0347395 .0792788
stock4	.0415065	.0412016	1.01	0.314	-.0392472 .1222602
_cons	1.088878	6.258805	0.17	0.862	-11.17815 13.35591
invest5					
market5	.1014782	.0547837	1.85	0.064	-.0058958 .2088523
stock5	.3999914	.1277946	3.13	0.002	.1495186 .6504642
_cons	85.42324	111.8774	0.76	0.445	-133.8525 304.6989

Here we instead fit a random-coefficients model:

. use https://www.stata-press.com/data/r16/invest2	Number of obs = 100
. xtrc invest market stock	Number of groups = 5
Random-coefficients regression	Obs per group:
Group variable: company	min = 20
	avg = 20.0
	max = 20
	Wald chi2(2) = 17.55
	Prob > chi2 = 0.0002

invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
market	.0807646	.0250829	3.22	0.001	.0316031 .1299261
stock	.2839885	.0677899	4.19	0.000	.1511229 .4168542
_cons	-23.58361	34.55547	-0.68	0.495	-91.31108 44.14386

Test of parameter constancy: chi2(12) = 603.99 Prob > chi2 = 0.0000

Just as the results of our simultaneous-equation model do not support the assumption of parameter constancy, the test included with the random-coefficients model also indicates that the assumption is not valid for these data. With large panel datasets, we would not want to take the time to look at a simultaneous-equations model (aside from the fact that our doing so was subjective). 

## Stored results

**xtrc** stores the following in **e()**:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(chi2)</code>	$\chi^2$
<code>e(chi2_c)</code>	$\chi^2$ for comparison test
<code>e(df_chi2c)</code>	degrees of freedom for comparison $\chi^2$ test
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>

### Macros

<code>e(cmd)</code>	<b>xtrc</b>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(tvars)</code>	variable denoting time within groups
<code>e(title)</code>	title in estimation output
<code>e(offset)</code>	linear offset variable
<code>e(chi2type)</code>	Wald; type of model $\chi^2$ test
<code>e(vce)</code>	<code>vcetype</code> specified in <code>vce()</code>
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement predict
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

### Matrices

<code>e(b)</code>	coefficient vector
<code>e(Sigma)</code>	$\widehat{\Sigma}$ matrix
<code>e(beta_ps)</code>	matrix of best linear predictors
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(V_ps)</code>	matrix of variances for the best linear predictors; row $i$ contains vec of variance matrix for group $i$ predictor

### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

## Methods and formulas

In a random-coefficients model, the parameter heterogeneity is treated as stochastic variation. Assume that we write

$$\mathbf{y}_i = \mathbf{X}_i \boldsymbol{\beta}_i + \boldsymbol{\epsilon}_i$$

where  $i = 1, \dots, m$ , and  $\boldsymbol{\beta}_i$  is the coefficient vector ( $k \times 1$ ) for the  $i$ th cross-sectional unit, such that

$$\boldsymbol{\beta}_i = \boldsymbol{\beta} + \boldsymbol{\nu}_i \quad E(\boldsymbol{\nu}_i) = \mathbf{0} \quad E(\boldsymbol{\nu}_i \boldsymbol{\nu}_i') = \boldsymbol{\Sigma}$$

Our goal is to find  $\widehat{\boldsymbol{\beta}}$  and  $\widehat{\boldsymbol{\Sigma}}$ .

The derivation of the estimator assumes that the cross-sectional specific coefficient vector  $\beta_i$  is the outcome of a random process with mean vector  $\beta$  and covariance matrix  $\Sigma$ ,

$$\mathbf{y}_i = \mathbf{X}_i\beta_i + \epsilon_i = \mathbf{X}_i(\beta + \nu_i) + \epsilon_i = \mathbf{X}_i\beta + (\mathbf{X}_i\nu_i + \epsilon_i) = \mathbf{X}_i\beta + \omega_i$$

where  $E(\omega_i) = \mathbf{0}$  and

$$E(\omega_i\omega'_i) = E\left\{(\mathbf{X}_i\nu_i + \epsilon_i)(\mathbf{X}_i\nu_i + \epsilon_i)'\right\} = E(\epsilon_i\epsilon'_i) + \mathbf{X}_iE(\nu_i\nu'_i)\mathbf{X}'_i = \sigma_i^2\mathbf{I} + \mathbf{X}_i\Sigma\mathbf{X}'_i = \Pi_i$$

Stacking the  $m$  equations, we have

$$\mathbf{y} = \mathbf{X}\beta + \omega$$

where  $\Pi \equiv E(\omega\omega')$  is a block diagonal matrix with  $\Pi_i$ ,  $i = 1\dots m$ , along the main diagonal and zeros elsewhere. The GLS estimator of  $\hat{\beta}$  is then

$$\hat{\beta} = \left( \sum_i \mathbf{X}'_i \Pi_i^{-1} \mathbf{X}_i \right)^{-1} \sum_i \mathbf{X}'_i \Pi_i^{-1} \mathbf{y}_i = \sum_{i=1}^m \mathbf{W}_i \mathbf{b}_i$$

where

$$\mathbf{W}_i = \left\{ \sum_{i=1}^m (\Sigma + \mathbf{V}_i)^{-1} \right\}^{-1} (\Sigma + \mathbf{V}_i)^{-1}$$

$\mathbf{b}_i = (\mathbf{X}'_i \mathbf{X}_i)^{-1} \mathbf{X}'_i \mathbf{y}_i$  and  $\mathbf{V}_i = \sigma_i^2 (\mathbf{X}'_i \mathbf{X}_i)^{-1}$ , showing that the resulting GLS estimator is a matrix-weighted average of the panel-specific OLS estimators. The variance of  $\hat{\beta}$  is

$$\text{Var}(\hat{\beta}) = \sum_{i=1}^m (\Sigma + \mathbf{V}_i)^{-1}$$

To calculate the above estimator  $\hat{\beta}$  for the unknown  $\Sigma$  and  $\mathbf{V}_i$  parameters, we use the two-step approach suggested by Swamy (1970):

$\mathbf{b}_i$  = OLS panel-specific estimator

$$\hat{\sigma}_i^2 = \frac{\hat{\epsilon}'_i \hat{\epsilon}_i}{n_i - k}$$

$$\hat{\mathbf{V}}_i = \hat{\sigma}_i^2 (\mathbf{X}'_i \mathbf{X}_i)^{-1}$$

$$\bar{\mathbf{b}} = \frac{1}{m} \sum_{i=1}^m \mathbf{b}_i$$

$$\hat{\Sigma} = \frac{1}{m-1} \left( \sum_{i=1}^m \mathbf{b}_i \mathbf{b}'_i - m \bar{\mathbf{b}} \bar{\mathbf{b}}' \right) - \frac{1}{m} \sum_{i=1}^m \hat{\mathbf{V}}_i$$

The two-step procedure begins with the usual OLS estimates of  $\beta_i$ . With those estimates, we may proceed by obtaining estimates of  $\hat{\mathbf{V}}_i$  and  $\hat{\Sigma}$  (and thus  $\hat{\mathbf{W}}_i$ ) and then obtain an estimate of  $\beta$ .

Swamy (1970) further points out that the matrix  $\widehat{\Sigma}$  may not be positive definite and that because the second term is of order  $1/(mT)$ , it is negligible in large samples. A simple and asymptotically expedient solution is simply to drop this second term and instead use

$$\widehat{\Sigma} = \frac{1}{m-1} \left( \sum_{i=1}^m \mathbf{b}_i \mathbf{b}_i' - m \bar{\mathbf{b}} \bar{\mathbf{b}}' \right)$$

As discussed by Judge et al. (1985, 541), the feasible best linear predictor of  $\beta_i$  is given by

$$\begin{aligned}\widehat{\beta}_i &= \widehat{\beta} + \widehat{\Sigma} \mathbf{X}'_i \left( \mathbf{X}_i \widehat{\Sigma} \mathbf{X}'_i + \widehat{\sigma}_i^2 \mathbf{I} \right)^{-1} \left( \mathbf{y}_i - \mathbf{X}_i \widehat{\beta} \right) \\ &= \left( \widehat{\Sigma}^{-1} + \widehat{\mathbf{V}}_i^{-1} \right)^{-1} \left( \widehat{\Sigma}^{-1} \widehat{\beta} + \widehat{\mathbf{V}}_i^{-1} \mathbf{b}_i \right)\end{aligned}$$

The conventional variance of  $\widehat{\beta}_i$  is given by

$$\text{Var}(\widehat{\beta}_i) = \text{Var}(\widehat{\beta}) + (\mathbf{I} - \mathbf{A}_i) \left\{ \widehat{\mathbf{V}}_i - \text{Var}(\widehat{\beta}) \right\} (\mathbf{I} - \mathbf{A}_i)'$$

where

$$\mathbf{A}_i = \left( \widehat{\Sigma}^{-1} + \widehat{\mathbf{V}}_i^{-1} \right)^{-1} \widehat{\Sigma}^{-1}$$

To test the model, we may look at the difference between the OLS estimate of  $\beta$ , ignoring the panel structure of the data and the matrix-weighted average of the panel-specific OLS estimators. The test statistic suggested by Swamy (1970) is given by

$$\chi^2_{k(m-1)} = \sum_{i=1}^m (\mathbf{b}_i - \bar{\beta}^*)' \widehat{\mathbf{V}}_i^{-1} (\mathbf{b}_i - \bar{\beta}^*) \quad \text{where} \quad \bar{\beta}^* = \left( \sum_{i=1}^m \widehat{\mathbf{V}}_i^{-1} \right)^{-1} \sum_{i=1}^m \widehat{\mathbf{V}}_i^{-1} \mathbf{b}_i$$

Johnston and DiNardo (1997) have shown that the test is algebraically equivalent to testing

$$H_0 : \beta_1 = \beta_2 = \cdots = \beta_m$$

in the generalized (groupwise heteroskedastic) **xtgls** model, where  $\mathbf{V}$  is block diagonal with  $i$ th diagonal element  $\Pi_i$ .

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## Also see

- [XT] **xtrc postestimation** — Postestimation tools for xtrc
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtset** — Declare data to be panel data
- [ME] **mixed** — Multilevel mixed-effects linear regression
- [MI] **Estimation** — Estimation commands for use with mi estimate
- [U] **20 Estimation and postestimation commands**

**xtrc postestimation** — Postestimation tools for xtrc

[Postestimation commands](#)    [predict](#)    [margins](#)    [Also see](#)

## Postestimation commands

The following postestimation commands are available after `xtrc`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>*forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combination of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from <code>margins</code> (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

\* `forecast` is not appropriate with `mi` estimation results.

# **predict**

## Description for predict

`predict` creates a new variable containing predictions such as linear predictions and standard errors.

## Menu for predict

Statistics > Postestimation

## Syntax for predict

```
predict [type] newvar [if] [in] [, statistic nooffset]
```

<i>statistic</i>	Description
<hr/>	
Main	
<code>xb</code>	linear prediction; the default
<code>stdp</code>	standard error of the linear prediction
<code>group(group)</code>	linear prediction based on group <i>group</i>

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

## Options for predict

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Main

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`xb`, the default, calculates the linear prediction using the mean parameter vector.

`stdp` calculates the standard error of the linear prediction.

`group(group)` calculates the linear prediction using the best linear predictors for group *group*.

`nooffset` is relevant only if you specified `offset(varname)` for `xtrc`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\mathbf{b}$  rather than  $\mathbf{x}_{it}\mathbf{b} + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]  
margins [marginlist] , predict(statistic ...) [options]
```

<i>statistic</i>	Description
<code>xb</code>	linear prediction; the default
<code>stdp</code>	not allowed with <code>margins</code>
<code>group</code> ( <i>group</i> )	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

### Also see

[\[XT\] xtrc](#) — Random-coefficients model

[\[U\] 20 Estimation and postestimation commands](#)

**xtreg** — Fixed-, between-, and random-effects and population-averaged linear models

Description	Quick start	Menu
Syntax	Options for RE model	Options for BE model
Options for FE model	Options for MLE model	Options for PA model
Remarks and examples	Stored results	Methods and formulas
Acknowledgments	References	Also see

## Description

**xtreg** fits regression models to panel data. In particular, **xtreg** with the **be** option fits random-effects models by using the between regression estimator; with the **fe** option, it fits fixed-effects models (by using the within regression estimator); and with the **re** option, it fits random-effects models by using the GLS estimator (producing a matrix-weighted average of the between and within results). See [XT] **xtdata** for a faster way to fit fixed- and random-effects models.

## Quick start

Random-effects linear regression by GLS of **y** on **x1** and **xt2** using **xtset** data

```
xtreg y x1 x2
```

As above, but estimate by maximum likelihood

```
xtreg y x1 x2, mle
```

Fixed-effects model with cluster-robust standard errors for panels nested within **cvar**

```
xtreg y x1 x2, fe vce(cluster cvar)
```

Population-averaged model with an exchangeable within-panel correlation structure

```
xtreg y x1 x2, pa
```

As above, but specify an autoregressive correlation structure of order 1

```
xtreg y x1 x2, pa corr(ar 1)
```

Between-effects model

```
xtreg y x1 x2, be
```

## Menu

Statistics > Longitudinal/panel data > Linear models > Linear regression (FE, RE, PA, BE)

## Syntax

*GLS random-effects (RE) model*

***xtreg depvar [indepvars] [if] [in] [, re RE\_options]***

*Between-effects (BE) model*

***xtreg depvar [indepvars] [if] [in], be BE\_options***

*Fixed-effects (FE) model*

***xtreg depvar [indepvars] [if] [in] [weight], fe FE\_options***

*ML random-effects (MLE) model*

***xtreg depvar [indepvars] [if] [in] [weight], mle MLE\_options***

*Population-averaged (PA) model*

***xtreg depvar [indepvars] [if] [in] [weight], pa PA\_options***

<i>RE_options</i>	Description
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### Model

<b>re</b>	use random-effects estimator; the default
<b>sa</b>	use Swamy–Arora estimator of the variance components

### SE/Robust

<b>vce(vcetype)</b>	<i>vcetype</i> may be conventional, <b>robust</b> , <b>cluster</b> <i>clustvar</i> , <b>bootstrap</b> , or <b>jackknife</b>
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### Reporting

<b>level(#)</b>	set confidence level; default is <b>level(95)</b>
<b>theta</b>	report $\theta$
<b>display_options</b>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>coeflegend</b>	display legend instead of statistics

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<i>BE_options</i>	Description
Model	
<code>be</code>	use between-effects estimator
<code>wls</code>	use weighted least squares
SE	
<code>vce(vcetype)</code>	<i>vcetype</i> may be <code>conventional</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>display_options</code>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<code>coeflegend</code>	display legend instead of statistics
<i>FE_options</i>	Description
Model	
<code>fe</code>	use fixed-effects estimator
SE/Robust	
<code>vce(vcetype)</code>	<i>vcetype</i> may be <code>conventional</code> , <code>robust</code> , <code>cluster clustvar</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>display_options</code>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<code>coeflegend</code>	display legend instead of statistics
<i>MLE_options</i>	Description
Model	
<code>noconstant</code>	suppress constant term
<code>mle</code>	use ML random-effects estimator
SE/Robust	
<code>vce(vcetype)</code>	<i>vcetype</i> may be <code>oim</code> , <code>robust</code> , <code>cluster clustvar</code> , <code>bootstrap</code> , or <code>jackknife</code>
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>display_options</code>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Maximization	
<code>maximize_options</code>	control the maximization process; seldom used
<code>coeflegend</code>	display legend instead of statistics

<i>PA_options</i>	Description
<b>Model</b>	
<u>noconstant</u>	suppress constant term
<u>pa</u>	use population-averaged estimator
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<b>Correlation</b>	
<u>corr</u> ( <i>correlation</i> )	within-panel correlation structure
<u>force</u>	estimate even if observations unequally spaced in time
<b>SE/Robust</b>	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be conventional, robust, bootstrap, or jackknife
<u>nmp</u>	use divisor $N - P$ instead of the default $N$
<u>rgf</u>	multiply the robust variance estimate by $(N - 1)/(N - P)$
<u>scale</u> ( <i>parm</i> )	overrides the default scale parameter; <i>parm</i> may be x2, dev, phi, or #
<b>Reporting</b>	
<u>level</u> (#)	set confidence level; default is <code>level(95)</code>
<i>display_options</i>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Optimization</b>	
<u>optimize_options</u>	control the optimization process; seldom used
<u>coeflegend</u>	display legend instead of statistics

<i>correlation</i>	Description
<u>exchangeable</u>	exchangeable
<u>independent</u>	independent
<u>unstructured</u>	unstructured
<u>fixed</u> <i>matname</i>	user-specified
<u>ar</u> #	autoregressive of order #
<u>stationary</u> #	stationary of order #
<u>nonstationary</u> #	nonstationary of order #

A panel variable must be specified. For `xtreg`, `pa`, correlation structures other than `exchangeable` and `independent` require that a time variable also be specified. Use `xtset`; see [XT] `xtset`.

`indepvars` may contain factor variables; see [U] 11.4.3 Factor variables.

`depvar` and `indepvars` may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by`, `mi estimate`, and `statsby` are allowed; see [U] 11.1.10 Prefix commands. `fp` is allowed for the between-effects, fixed-effects, and maximum-likelihood random-effects models.

`vce(bootstrap)` and `vce(jackknife)` are not allowed with the `mi estimate` prefix; see [MI] `mi estimate`.

`aweights`, `fweights`, and `pweights` are allowed for the fixed-effects model. `iweights`, `fweights`, and `pweights` are allowed for the population-averaged model. `iweights` are allowed for the maximum-likelihood random-effects (MLE) model. See [U] 11.1.6 weight. Weights must be constant within panel.

`coeflegend` does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options for RE model

### Model

`re`, the default, requests the GLS random-effects estimator.

`sa` specifies that the small-sample Swamy–Arora estimator individual-level variance component be used instead of the default consistent estimator. See [xtreg, re](#) in *Methods and formulas* for details.

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [\[XT\] vce\\_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtreg, re](#) in *Methods and formulas*.

### Reporting

`level(#)`; see [\[R\] Estimation options](#).

`theta` specifies that the output include the estimated value of  $\theta$  used in combining the between and fixed estimators. For balanced data, this is a constant, and for unbalanced data, a summary of the values is presented in the header of the output.

`display_options`: `noci`, `novalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [\[R\] Estimation options](#).

The following option is available with `xtreg` but is not shown in the dialog box:

`coeflegend`; see [\[R\] Estimation options](#).

## Options for BE model

### Model

`be` requests the between regression estimator.

`wls` specifies that, for unbalanced data, weighted least squares be used rather than the default OLS.

Both methods produce consistent estimates. The true variance of the between-effects residual is  $\sigma_\nu^2 + T_i \sigma_\epsilon^2$  (see [xtreg, be](#) in *Methods and formulas* below). WLS produces a “stabilized” variance of  $\sigma_\nu^2/T_i + \sigma_\epsilon^2$ , which is also not constant. Thus the choice between OLS and WLS amounts to which is more stable.

Comment: `xtreg, be` is rarely used anyway, but between estimates are an ingredient in the random-effects estimate. Our implementation of `xtreg, re` uses the OLS estimates for this ingredient, based on our judgment that  $\sigma_\nu^2$  is large relative to  $\sigma_\epsilon^2$  in most models. Formally, only a consistent estimate of the between estimates is required.

## SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

## Reporting

`level(#)`; see [R] [Estimation options](#).

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

The following option is available with `xtreg` but is not shown in the dialog box:

`coflegend`; see [R] [Estimation options](#).

## Options for FE model

## Model

`fe` requests the fixed-effects (within) regression estimator.

## SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`conventional`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

`vce(conventional)`, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see [xtreg](#), `fe` in *Methods and formulas*.

## Reporting

`level(#)`; see [R] [Estimation options](#).

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

The following option is available with `xtreg` but is not shown in the dialog box:

`coflegend`; see [R] [Estimation options](#).

## Options for MLE model

### Model

`noconstant`; see [R] [Estimation options](#).

`mle` requests the maximum-likelihood random-effects estimator.

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] [vce\\_options](#).

### Reporting

`level(#)`; see [R] [Estimation options](#).

`display_options`: `noci`, `notvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] [Estimation options](#).

### Maximization

`maximize_options`: `iterate(#)`, `[no]log`, `trace`, `tolerance(#)`, `ltolerance(#)`, and `from(init_specs)`; see [R] [Maximize](#). These options are seldom used.

The following option is available with `xtreg` but is not shown in the dialog box:

`coeflegend`; see [R] [Estimation options](#).

## Options for PA model

### Model

`noconstant`; see [R] [Estimation options](#).

`pa` requests the population-averaged estimator. For linear regression, this is the same as a random-effects estimator (both interpretations hold).

`xtreg, pa` is equivalent to `xtgee`, `family(gaussian)` `link(id)` `corr(exchangeable)`, which are the defaults for the `xtgee` command. `xtreg, pa` allows all the relevant `xtgee` options such as `vce(robust)`. Whether you use `xtreg, pa` or `xtgee` makes no difference. See [XT] [xtgee](#).

`offset(varname)`; see [R] [Estimation options](#).

### Correlation

`corr(correlation)` specifies the within-panel correlation structure; the default corresponds to the equal-correlation model, `corr(exchangeable)`.

When you specify a correlation structure that requires a lag, you indicate the lag after the structure's name with or without a blank; for example, `corr(ar 1)` or `corr(ar1)`.

If you specify the fixed correlation structure, you specify the name of the matrix containing the assumed correlations following the word `fixed`, for example, `corr(fixed myr)`.

**force** specifies that estimation be forced even though the time variable is not equally spaced.

This is relevant only for correlation structures that require knowledge of the time variable. These correlation structures require that observations be equally spaced so that calculations based on lags correspond to a constant time change. If you specify a time variable indicating that observations are not equally spaced, the (time dependent) model will not be fit. If you also specify **force**, the model will be fit, and it will be assumed that the lags based on the data ordered by the time variable are appropriate.

#### SE/Robust

**vce(vcetype)** specifies the type of standard error reported, which includes types that are derived from asymptotic theory (**conventional**), that are robust to some kinds of misspecification (**robust**), and that use bootstrap or jackknife methods (**bootstrap**, **jackknife**); see [XT] **vce\_options**.

**vce(conventional)**, the default, uses the conventionally derived variance estimator for generalized least-squares regression.

**nmp**; see [XT] **vce\_options**.

**rgf** specifies that the robust variance estimate is multiplied by  $(N - 1)/(N - P)$ , where  $N$  is the total number of observations and  $P$  is the number of coefficients estimated. This option can be used with **family(gaussian)** only when **vce(robust)** is either specified or implied by the use of **pweights**. Using this option implies that the robust variance estimate is not invariant to the scale of any weights used.

**scale(x2 | dev | phi | #)**; see [XT] **vce\_options**.

#### Reporting

**level(#)**; see [R] **Estimation options**.

**display\_options**: **noci**, **nopvalues**, **noomitted**, **vsquish**, **noemptycells**, **baselevels**, **allbaselevels**, **nofvlabel**, **fvwrap(#)**, **fvwrapon(style)**, **cformat(%fmt)**, **pformat(%fmt)**, **sformat(%fmt)**, and **nolstretch**; see [R] **Estimation options**.

#### Optimization

**optimize\_options** control the iterative optimization process. These options are seldom used.

**iterate(#)** specifies the maximum number of iterations. When the number of iterations equals **#**, the optimization stops and presents the current results, even if convergence has not been reached. The default is **iterate(100)**.

**tolerance(#)** specifies the tolerance for the coefficient vector. When the relative change in the coefficient vector from one iteration to the next is less than or equal to **#**, the optimization process is stopped. **tolerance(1e-6)** is the default.

**log** and **nolog** specify whether to display the iteration log. The iteration log is displayed by default unless you used **set iterlog off** to suppress it; see **set iterlog** in [R] **set iter**.

**trace** specifies that the current estimates be printed at each iteration.

The following option is available with **xtreg** but is not shown in the dialog box:

**coeflegend**; see [R] **Estimation options**.

## Remarks and examples

If you have not read [XT] **xt**, please do so.

See [Baltagi \(2013\)](#), chap. 2) and [Wooldridge \(2020\)](#), chap. 14) for good overviews of fixed-effects and random-effects models. [Allison \(2009\)](#) provides perspective on the use of fixed- versus random-effects estimators and provides many examples using Stata.

Consider fitting models of the form

$$y_{it} = \alpha + \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it} \quad (1)$$

In this model,  $\nu_i + \epsilon_{it}$  is the error term that we have little interest in; we want estimates of  $\beta$ .  $\nu_i$  is the unit-specific error term; it differs between units, but for any particular unit, its value is constant. In the pulmonary data of [XT] **xt**, a person who exercises less would presumably have a lower forced expiratory volume (FEV) year after year and so would have a negative  $\nu_i$ .

$\epsilon_{it}$  is the “usual” error term with the usual properties (mean 0, uncorrelated with itself, uncorrelated with  $\mathbf{x}$ , uncorrelated with  $\nu$ , and homoskedastic), although in a more thorough development, we could decompose  $\epsilon_{it} = v_t + \omega_{it}$ , assume that  $\omega_{it}$  is a conventional error term, and better describe  $v_t$ .

Before making the assumptions necessary for estimation, let’s perform some useful algebra on (1). Whatever the properties of  $\nu_i$  and  $\epsilon_{it}$ , if (1) is true, it must also be true that

$$\bar{y}_i = \alpha + \bar{\mathbf{x}}_i\beta + \nu_i + \bar{\epsilon}_i \quad (2)$$

where  $\bar{y}_i = \sum_t y_{it}/T_i$ ,  $\bar{\mathbf{x}}_i = \sum_t \mathbf{x}_{it}/T_i$ , and  $\bar{\epsilon}_i = \sum_t \epsilon_{it}/T_i$ . Subtracting (2) from (1), it must be equally true that

$$(y_{it} - \bar{y}_i) = (\mathbf{x}_{it} - \bar{\mathbf{x}}_i)\beta + (\epsilon_{it} - \bar{\epsilon}_i) \quad (3)$$

These three equations provide the basis for estimating  $\beta$ . In particular, **xtreg, fe** provides what is known as the fixed-effects estimator—also known as the within estimator—and amounts to using OLS to perform the estimation of (3). **xtreg, be** provides what is known as the between estimator and amounts to using OLS to perform the estimation of (2). **xtreg, re** provides the random-effects estimator and is a (matrix) weighted average of the estimates produced by the between and within estimators. In particular, the random-effects estimator turns out to be equivalent to estimation of

$$(y_{it} - \theta\bar{y}_i) = (1 - \theta)\alpha + (\mathbf{x}_{it} - \theta\bar{\mathbf{x}}_i)\beta + \{(1 - \theta)\nu_i + (\epsilon_{it} - \theta\bar{\epsilon}_i)\} \quad (4)$$

where  $\theta$  is a function of  $\sigma_\nu^2$  and  $\sigma_\epsilon^2$ . If  $\sigma_\nu^2 = 0$ , meaning that  $\nu_i$  is always 0,  $\theta = 0$  and (1) can be estimated by OLS directly. Alternatively, if  $\sigma_\epsilon^2 = 0$ , meaning that  $\epsilon_{it}$  is 0,  $\theta = 1$  and the within estimator returns all the information available (which will, in fact, be a regression with an  $R^2$  of 1).

For more reasonable cases, few assumptions are required to justify the fixed-effects estimator of (3). The estimates are, however, conditional on the sample in that the  $\nu_i$  are not assumed to have a distribution but are instead treated as fixed and estimable. This statistical fine point can lead to difficulty when making out-of-sample predictions, but that aside, the fixed-effects estimator has much to recommend it.

More is required to justify the between estimator of (2), but the conditioning on the sample is not assumed because  $\nu_i + \bar{\epsilon}_i$  is treated as an error term. Newly required is that we assume that  $\nu_i$  and  $\bar{\mathbf{x}}_i$  are uncorrelated. This follows from the assumptions of the OLS estimator but is also transparent: were  $\nu_i$  and  $\bar{\mathbf{x}}_i$  correlated, the estimator could not determine how much of the change in  $\bar{y}_i$ , associated with an increase in  $\bar{\mathbf{x}}_i$ , to assign to  $\beta$  versus how much to attribute to the unknown correlation. (This, of course, suggests the use of an instrumental-variable estimator,  $\bar{z}_i$ , which is correlated with  $\bar{\mathbf{x}}_i$  but uncorrelated with  $\nu_i$ , though that approach is not implemented here.)

The random-effects estimator of (4) requires the same no-correlation assumption. In comparison with the between estimator, the random-effects estimator produces more efficient results, albeit ones with unknown small-sample properties. The between estimator is less efficient because it discards the over-time information in the data in favor of simple means; the random-effects estimator uses both the within and the between information.

All of this would seem to leave the between estimator of (2) with no role (except for a minor, technical part it plays in helping to estimate  $\sigma_\nu^2$  and  $\sigma_\epsilon^2$ , which are used in the calculation of  $\theta$ , on which the random-effects estimates depend). Let's, however, consider a variation on (1):

$$y_{it} = \alpha + \bar{\mathbf{x}}_i \boldsymbol{\beta}_1 + (\mathbf{x}_{it} - \bar{\mathbf{x}}_i) \boldsymbol{\beta}_2 + \nu_i + \epsilon_{it} \quad (1')$$

In this model, we postulate that changes in the average value of  $\mathbf{x}$  for an individual have a different effect from temporary departures from the average. In an economic situation,  $y$  might be purchases of some item and  $\mathbf{x}$  income; a change in average income should have more effect than a transitory change. In a clinical situation,  $y$  might be a physical response and  $\mathbf{x}$  the level of a chemical in the brain; the model allows a different response to permanent rather than transitory changes.

The variations of (2) and (3) corresponding to (1') are

$$\bar{y}_i = \alpha + \bar{\mathbf{x}}_i \boldsymbol{\beta}_1 + \nu_i + \bar{\epsilon}_i \quad (2')$$

$$(y_{it} - \bar{y}_i) = (\mathbf{x}_{it} - \bar{\mathbf{x}}_i) \boldsymbol{\beta}_2 + (\epsilon_{it} - \bar{\epsilon}_i) \quad (3')$$

That is, the between estimator estimates  $\boldsymbol{\beta}_1$  and the within  $\boldsymbol{\beta}_2$ , and neither estimates the other. Thus even when estimating equations like (1), it is worth comparing the within and between estimators. Differences in results can suggest models like (1'), or at the least some other specification error.

Finally, it is worth understanding the role of the between and within estimators with regressors that are constant over time or constant over units. Consider the model

$$y_{it} = \alpha + \mathbf{x}_{it} \boldsymbol{\beta}_1 + \mathbf{s}_i \boldsymbol{\beta}_2 + \mathbf{z}_t \boldsymbol{\beta}_3 + \nu_i + \epsilon_{it} \quad (1'')$$

This model is the same as (1), except that we explicitly identify the variables that vary over both time and  $i$  ( $\mathbf{x}_{it}$ , such as output or FEV); variables that are constant over time ( $\mathbf{s}_i$ , such as race or sex); and variables that vary solely over time ( $\mathbf{z}_t$ , such as the consumer price index or age in a cohort study). The corresponding between and within equations are

$$\bar{y}_i = \alpha + \bar{\mathbf{x}}_i \boldsymbol{\beta}_1 + \mathbf{s}_i \boldsymbol{\beta}_2 + \bar{\mathbf{z}} \boldsymbol{\beta}_3 + \nu_i + \bar{\epsilon}_i \quad (2'')$$

$$(y_{it} - \bar{y}_i) = (\mathbf{x}_{it} - \bar{\mathbf{x}}_i) \boldsymbol{\beta}_1 + (\mathbf{z}_t - \bar{\mathbf{z}}) \boldsymbol{\beta}_3 + (\epsilon_{it} - \bar{\epsilon}_i) \quad (3'')$$

In the between estimator of (2''), no estimate of  $\boldsymbol{\beta}_3$  is possible because  $\bar{\mathbf{z}}$  is a constant across the  $i$  observations; the regression-estimated intercept will be an estimate of  $\alpha + \bar{\mathbf{z}} \boldsymbol{\beta}_3$ . On the other hand, it can provide estimates of  $\boldsymbol{\beta}_1$  and  $\boldsymbol{\beta}_2$ . It can estimate effects of factors that are constant over time, such as race and sex, but to do so it must assume that  $\nu_i$  is uncorrelated with those factors.

The within estimator of (3''), like the between estimator, provides an estimate of  $\beta_1$  but provides no estimate of  $\beta_2$  for time-invariant factors. Instead, it provides an estimate of  $\beta_3$ , the effects of the time-varying factors. The within estimator can also provide estimates  $u_i$  for  $\nu_i$ . More correctly, the estimator  $u_i$  is an estimator of  $\nu_i + s_i\beta_2$ . Thus  $u_i$  is an estimator of  $\nu_i$  only if there are no time-invariant variables in the model. If there are time-invariant variables,  $u_i$  is an estimate of  $\nu_i$  plus the effects of the time-invariant variables.

Remarks are presented under the following headings:

*Assessing goodness of fit  
xtreg and associated commands*

## Assessing goodness of fit

$R^2$  is a popular measure of goodness of fit in ordinary regression. In our case, given  $\hat{\alpha}$  and  $\hat{\beta}$  estimates of  $\alpha$  and  $\beta$ , we can assess the goodness of fit with respect to (1), (2), or (3). The prediction equations are, respectively,

$$\hat{y}_{it} = \hat{\alpha} + \mathbf{x}_{it}\hat{\beta} \quad (1''')$$

$$\bar{\hat{y}}_i = \hat{\alpha} + \bar{\mathbf{x}}_i\hat{\beta} \quad (2''')$$

$$\tilde{\hat{y}}_{it} = (\hat{y}_{it} - \bar{\hat{y}}_i) = (\mathbf{x}_{it} - \bar{\mathbf{x}}_i)\hat{\beta} \quad (3''')$$

xtreg reports “ $R$ -squares” corresponding to these three equations.  $R$ -squares is in quotes because the  $R$ -squares reported do not have all the properties of the OLS  $R^2$ .

The ordinary properties of  $R^2$  include being equal to the squared correlation between  $\hat{y}$  and  $y$  and being equal to the fraction of the variation in  $y$  explained by  $\hat{y}$ —formally defined as  $\text{Var}(\hat{y})/\text{Var}(y)$ . The identity of the definitions is from a special property of the OLS estimates; in general, given a prediction  $\hat{y}$  for  $y$ , the squared correlation is not equal to the ratio of the variances, and the ratio of the variances is not required to be less than 1.

xtreg reports  $R^2$  values calculated as correlations squared, calling them  $R^2$  overall, corresponding to (1''');  $R^2$  between, corresponding to (2'''); and  $R^2$  within, corresponding to (3'''). In fact, you can think of each of these three numbers as having all the properties of ordinary  $R^2$ 's, if you bear in mind that the prediction being judged is not  $\hat{y}_{it}$ ,  $\bar{\hat{y}}_i$ , and  $\tilde{\hat{y}}_{it}$ , but  $\gamma_1\hat{y}_{it}$  from the regression  $y_{it} = \gamma_1\hat{y}_{it}$ ;  $\gamma_2\bar{\hat{y}}_i$  from the regression  $\bar{y}_i = \gamma_2\bar{\hat{y}}_i$ ; and  $\gamma_3\tilde{\hat{y}}_{it}$  from  $\tilde{y}_{it} = \gamma_3\tilde{\hat{y}}_{it}$ .

In particular, xtreg, be obtains its estimates by performing OLS on (2), and therefore its reported  $R^2$  between is an ordinary  $R^2$ . The other two reported  $R^2$ 's are merely correlations squared, or, if you prefer,  $R^2$ 's from the second-round regressions  $y_{it} = \gamma_{11}\hat{y}_{it}$  and  $\tilde{y}_{it} = \gamma_{13}\tilde{\hat{y}}_{it}$ .

xtreg, fe obtains its estimates by performing OLS on (3), so its reported  $R^2$  within is an ordinary  $R^2$ . As with be, the other  $R^2$ 's are correlations squared, or, if you prefer,  $R^2$ 's from the second-round regressions  $\bar{y}_i = \gamma_{22}\bar{\hat{y}}_i$  and, as with be,  $\tilde{y}_{it} = \gamma_{23}\tilde{\hat{y}}_{it}$ .

xtreg, re obtains its estimates by performing OLS on (4); none of the  $R^2$ 's corresponding to (1'''), (2'''), or (3''') correspond directly to this estimator (the “relevant”  $R^2$  is the one corresponding to (4)). All three reported  $R^2$ 's are correlations squared, or, if you prefer, from second-round regressions.

## xtreg and associated commands

### ▷ Example 1: Between-effects model

Using `nlswork.dta` described in [XT] **xt**, we will model `ln_wage` in terms of completed years of schooling (`grade`), current age and age squared, current years worked (`experience`) and experience squared, current years of tenure on the current job and tenure squared, whether black (`race = 2`), whether residing in an area not designated a standard metropolitan statistical area (`SMSA`), and whether residing in the South.

```
. use https://www.stata-press.com/data/r16/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
```

To obtain the between-effects estimates, we use `xtreg, be`. `nlswork.dta` has previously been `xtset idcode year` because that is what is true of the data, but for running `xtreg`, it would have been sufficient to have `xtset idcode` by itself.

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure
> c.tenure#c.tenure 2.race not_smsa south, be

Between regression (regression on group means)  Number of obs      =    28,091
Group variable: idcode                         Number of groups   =     4,697
R-sq:                                           Obs per group:
within  = 0.1591                               min =           1
between = 0.4900                             avg =          6.0
overall = 0.3695                            max =          15
                                                F(10,4686)       =    450.23
sd(u_i + avg(e_i.))= .3036114               Prob > F        =    0.0000
```

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
grade	.0607602	.0020006	30.37	0.000	.0568382 .0646822
age	.0323158	.0087251	3.70	0.000	.0152105 .0494211
c.age#c.age	-.0005997	.0001429	-4.20	0.000	-.0008799 -.0003194
ttl_exp	.0138853	.0056749	2.45	0.014	.0027598 .0250108
c.ttl_exp#c.ttl_exp	.0007342	.0003267	2.25	0.025	.0000936 .0013747
tenure	.0698419	.0060729	11.50	0.000	.0579361 .0817476
c.tenure#c.tenure	-.0028756	.0004098	-7.02	0.000	-.0036789 -.0020722
race					
black	-.0564167	.0105131	-5.37	0.000	-.0770272 -.0358061
not_smsa	-.1860406	.0112495	-16.54	0.000	-.2080949 -.1639862
south	-.0993378	.010136	-9.80	0.000	-.1192091 -.0794665
_cons	.3339113	.1210434	2.76	0.006	.0966093 .5712133

The between-effects regression is estimated on person-averages, so the “n = 4697” result is relevant. `xtreg, be` reports the “number of observations” and group-size information: `describe` in [XT] **xt** showed that we have 28,534 “observations”—person-years, really—of data. If we take the subsample that has no missing values in `ln_wage`, `grade`, ..., `south` leaves us with 28,091 observations on person-years, reflecting 4,697 persons, each observed for an average of 6.0 years.

For goodness of fit, the  $R^2$  between is directly relevant; our  $R^2$  is 0.4900. If, however, we use these estimates to predict the within model, we have an  $R^2$  of 0.1591. If we use these estimates to fit the overall data, our  $R^2$  is 0.3695.

The  $F$  statistic tests that the coefficients on the regressors `grade`, `age`, ..., `south` are all jointly zero. Our model is significant.

The root mean squared error of the fitted regression, which is an estimate of the standard deviation of  $\nu_i + \bar{\epsilon}_i$ , is 0.3036.

For our coefficients, each year of schooling increases hourly wages by 6.1%; age increases wages up to age 26.9 and thereafter decreases them (because the quadratic  $ax^2 + bx + c$  turns over at  $x = -b/2a$ , which for our `age` and `c.age#c.age` coefficients is  $0.0323158/(2 \times 0.0005997) \approx 26.9$ ); total experience increases wages at an increasing rate (which is surprising and bothersome); tenure on the current job increases wages up to a tenure of 12.1 years and thereafter decreases them; wages of blacks are, these things held constant, (approximately) 5.6% below that of nonblacks (approximately because `2.race` is an indicator variable); residing in a non-SMSA (rural area) reduces wages by 18.6%; and residing in the South reduces wages by 9.9%. □

## ► Example 2: Fixed-effects model

To fit the same model with the fixed-effects estimator, we specify the `fe` option.

ln_wage	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
grade	0	(omitted)			
age	.0359987	.0033864	10.63	0.000	.0293611 .0426362
c.age#c.age	-.000723	.0000533	-13.58	0.000	-.0008274 -.0006186
ttl_exp	.0334668	.0029653	11.29	0.000	.0276545 .039279
c.ttl_exp# c.ttl_exp	.0002163	.0001277	1.69	0.090	-.0000341 .0004666
tenure	.0357539	.0018487	19.34	0.000	.0321303 .0393775
c.tenure# c.tenure	-.0019701	.000125	-15.76	0.000	-.0022151 -.0017251
race	0	(omitted)			
black					
not_smsa	-.0890108	.0095316	-9.34	0.000	-.1076933 -.0703282
south	-.0606309	.0109319	-5.55	0.000	-.0820582 -.0392036
_cons	1.03732	.0485546	21.36	0.000	.9421496 1.13249
sigma_u	.35562203				
sigma_e	.29068923				
rho	.59946283	(fraction of variance due to u_i)			

F test that all u\_i=0: F(4696, 23386) = 6.65 Prob > F = 0.0000

The observation summary at the top is the same as for the between-effects model, although this time it is the “Number of obs” that is relevant.

Our three  $R^2$ 's are not too different from those reported previously; the  $R^2$  within is slightly higher (0.1727 versus 0.1591), and the  $R^2$  between is a little lower (0.3505 versus 0.4900), as expected, because the between estimator maximizes  $R^2$  between and the within estimator  $R^2$  within. In terms of overall fit, these estimates are somewhat worse (0.2625 versus 0.3695).

If the unobserved time-invariant component  $\nu$  is not correlated with the regressors, estimates from the fixed-effects model are consistent but inefficient relative to estimates from the random-effects model. In this case, the interpretation of `sigma_u` in the coefficient table is the same for the fixed-effects and random-effects models. However, `sigma_u` is a nuisance parameter when  $\nu$  is correlated with the covariates.

Here both `grade` and `2.race` were omitted from the model because they do not vary over time. Because `grade` and `2.race` are time invariant, our estimate  $u_i$  is an estimate of  $\nu_i$  plus the effects of `grade` and `2.race`, so our estimate of the standard deviation is based on the variation in  $\nu_i$ , `grade`, and `2.race`. On the other hand, had `2.race` and `grade` been omitted merely because they were collinear with the other regressors in our model,  $u_i$  would be an estimate of  $\nu_i$ , and 0.355622 would be an estimate of  $\sigma_\nu$ . (`xtsum` and `xttab` allow you to determine whether a variable is time invariant; see [XT] `xtsum` and [XT] `xttab`.)

Regardless of the status of  $u_i$ , our estimate of the standard deviation of  $\epsilon_{it}$  is valid (and, in fact, is the estimate that would be used by the random-effects estimator to produce its results).

Our estimate of the correlation of  $u_i$  with  $\mathbf{x}_{it}$  suffers from the problem of what  $u_i$  measures. We find correlation but cannot say whether this is correlation of  $\nu_i$  with  $\mathbf{x}_{it}$  or merely correlation of `grade` and `2.race` with  $\mathbf{x}_{it}$ . In any case, the fixed-effects estimator is robust to such a correlation, and the other estimates it produces are unbiased.

So, although this estimator produces no estimates of the effects of `grade` and `2.race`, it does predict that age has a positive effect on wages up to age 24.9 years (compared with 26.9 years estimated by the between estimator); that total experience still increases wages at an increasing rate (which is still bothersome); that tenure increases wages up to 9.1 years (compared with 12.1); that living in a non-SMSA reduces wages by 8.9% (compared with a more drastic 18.6%); and that living in the South reduces wages by 6.1% (as compared with 9.9%).



► Example 3: Fixed-effects models with robust standard errors

If we suspect that there is heteroskedasticity or within-panel serial correlation in the idiosyncratic error term  $\epsilon_{it}$ , we could specify the `vce(robust)` option:

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure
> c.tenure#c.tenure 2.race not_smsa south, fe vce(robust)
note: grade omitted because of collinearity
note: 2.race omitted because of collinearity

Fixed-effects (within) regression                               Number of obs     =      28,091
Group variable: idcode                                     Number of groups  =      4,697
R-sq:                                         Obs per group:
    within = 0.1727                                         min =          1
    between = 0.3505                                        avg =         6.0
    overall = 0.2625                                       max =        15
                                                F(8,4696)      =     273.86
corr(u_i, Xb)  = 0.1936                                         Prob > F       =     0.0000
                                                               (Std. Err. adjusted for 4,697 clusters in idcode)
```

ln_wage	Coef.	Robust Std. Err.	t	P> t	[95% Conf. Interval]
grade	0	(omitted)			
age	.0359987	.0052407	6.87	0.000	.0257243 .046273
c.age#c.age	-.000723	.0000845	-8.56	0.000	-.0008887 -.0005573
ttl_exp	.0334668	.004069	8.22	0.000	.0254896 .0414439
c.ttl_exp#c.ttl_exp	.0002163	.0001763	1.23	0.220	-.0001294 .0005619
tenure	.0357539	.0024683	14.49	0.000	.0309148 .040593
c.tenure#c.tenure	-.0019701	.0001696	-11.62	0.000	-.0023026 -.0016376
race	0	(omitted)			
black					
not_smsa	-.0890108	.0137629	-6.47	0.000	-.1159926 -.062029
south	-.0606309	.0163366	-3.71	0.000	-.0926583 -.0286035
_cons	1.03732	.0739644	14.02	0.000	.8923149 1.182325
sigma_u	.35562203				
sigma_e	.29068923				
rho	.59946283	(fraction of variance due to u_i)			

Although the estimated coefficients are the same with and without the `vce(robust)` option, the robust estimator produced larger standard errors and a  $p$ -value for `c.ttl_exp#c.ttl_exp` above the conventional 10%. The  $F$  test of  $\nu_i = 0$  is suppressed because it is too difficult to compute the robust form of the statistic when there are more than a few panels.



## □ Technical note

The robust standard errors reported above are identical to those obtained by clustering on the panel variable `idcode`. Clustering on the panel variable produces an estimator of the VCE that is robust to cross-sectional heteroskedasticity and within-panel (serial) correlation that is asymptotically equivalent to that proposed by Arellano (1987). Although the example above applies the fixed-effects estimator, the robust and cluster-robust VCE estimators are also available for the random-effects estimator. Wooldridge (2020) and Arellano (2003) discuss these robust and cluster-robust VCE estimators for the fixed-effects and random-effects estimators. More details are available in [Methods and formulas](#).



## ▷ Example 4: Random-effects model

Refitting our log-wage model with the random-effects estimator, we obtain

<pre>. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure &gt; c.tenure#c.tenure 2.race not_smsa south, re theta</pre>						
Random-effects GLS regression	Number of obs = 28,091					
Group variable: idcode	Number of groups = 4,697					
R-sq:	Obs per group:					
within = 0.1715	min = 1					
between = 0.4784	avg = 6.0					
overall = 0.3708	max = 15					
corr(u_i, X) = 0 (assumed)	Wald chi2(10) = 9244.74					
	Prob > chi2 = 0.0000					
theta						
min	5%					
0.2520	0.2520					
median	95%					
0.5499	0.7016					
	max					
	0.7206					
<hr/>						
ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]	
grade	.0646499	.0017812	36.30	0.000	.0611589	.0681409
age	.0368059	.0031195	11.80	0.000	.0306918	.0429201
c.age#c.age	-.0007133	.00005	-14.27	0.000	-.0008113	-.0006153
ttl_exp	.0290208	.002422	11.98	0.000	.0242739	.0337678
c.ttl_exp#c.ttl_exp	.0003049	.0001162	2.62	0.009	.000077	.0005327
tenure	.0392519	.0017554	22.36	0.000	.0358113	.0426925
c.tenure#c.tenure	-.0020035	.0001193	-16.80	0.000	-.0022373	-.0017697
race						
black	-.053053	.0099926	-5.31	0.000	-.0726381	-.0334679
not_smsa	-.1308252	.0071751	-18.23	0.000	-.1448881	-.1167622
south	-.0868922	.0073032	-11.90	0.000	-.1012062	-.0725781
_cons	.2387207	.049469	4.83	0.000	.1417633	.3356781
sigma_u	.25790526					
sigma_e	.29068923					
rho	.44045273	(fraction of variance due to u_i)				

According to the  $R^2$ 's, this estimator performs worse within than the within fixed-effects estimator and worse between than the between estimator, as it must, and slightly better overall.

We estimate that  $\sigma_\nu$  is 0.2579 and  $\sigma_\epsilon$  is 0.2907 and, by assertion, assume that the correlation of  $\nu$  and  $x$  is zero.

All that is known about the random-effects estimator is its asymptotic properties, so rather than reporting an  $F$  statistic for overall significance, **xtreg**, **re** reports a  $\chi^2$ . Taken jointly, our coefficients are significant.

**xtreg**, **re** also reports a summary of the distribution of  $\theta_i$ , an ingredient in the estimation of (4).  $\theta$  is not a constant here because we observe women for unequal periods.

We estimate that schooling has a rate of return of 6.5% (compared with 6.1% between and no estimate within); that the increase of wages with age turns around at 25.8 years (compared with 26.9 between and 24.9 within); that total experience yet again increases wages increasingly; that the effect of job tenure turns around at 9.8 years (compared with 12.1 between and 9.1 within); that being black reduces wages by 5.3% (compared with 5.6% between and no estimate within); that living in a non-SMSA reduces wages 13.1% (compared with 18.6% between and 8.9% within); and that living in the South reduces wages 8.7% (compared with 9.9% between and 6.1% within).

□

## ► Example 5: Random-effects model fit using ML

We could also have fit this random-effects model with the maximum likelihood estimator:

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure
> c.tenure#c.tenure 2.race not_smsa south, mle
```

Fitting constant-only model:

```
Iteration 0: log likelihood = -12663.954
Iteration 1: log likelihood = -12649.756
Iteration 2: log likelihood = -12649.614
Iteration 3: log likelihood = -12649.614
```

Fitting full model:

```
Iteration 0: log likelihood = -8922.145
Iteration 1: log likelihood = -8853.6409
Iteration 2: log likelihood = -8853.4255
Iteration 3: log likelihood = -8853.4254
```

Random-effects ML regression	Number of obs	=	28,091
Group variable: idcode	Number of groups	=	4,697
Random effects u_i ~ Gaussian	Obs per group:		
	min =	1	
	avg =	6.0	
	max =	15	
Log likelihood = -8853.4254	LR chi2(10)	=	7592.38
	Prob > chi2	=	0.0000

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
grade	.0646093	.0017372	37.19	0.000	.0612044 .0680142
age	.0368531	.0031226	11.80	0.000	.030733 .0429732
c.age#c.age	-.0007132	.0000501	-14.24	0.000	-.0008113 -.000615
ttl_exp	.0288196	.0024143	11.94	0.000	.0240877 .0335515
c.ttl_exp#c.ttl_exp	.000309	.0001163	2.66	0.008	.0000811 .0005369
tenure	.0394371	.0017604	22.40	0.000	.0359868 .0428875
c.tenure#c.tenure	-.0020052	.0001195	-16.77	0.000	-.0022395 -.0017709
race					
black	-.0533394	.0097338	-5.48	0.000	-.0724172 -.0342615
not_smsa	-.1323433	.0071322	-18.56	0.000	-.1463221 -.1183644
south	-.0875599	.0072143	-12.14	0.000	-.1016998 -.0734201
_cons	.2390837	.0491902	4.86	0.000	.1426727 .3354947
/sigma_u	.2485556	.0035017		.2417863	.2555144
/sigma_e	.2918458	.001352		.289208	.2945076
rho	.4204033	.0074828		.4057959	.4351212

LR test of sigma\_u=0: chibar2(01) = 7339.84

Prob >= chibar2 = 0.000

The estimates are nearly the same as those produced by **xtreg**, **re**—the GLS estimator. For instance, **xtreg**, **re** estimated the coefficient on **grade** to be 0.0646499, **xtreg**, **mle** estimated 0.0646093, and the ratio is  $0.0646499/0.0646093 = 1.001$  to three decimal places. Similarly, the standard errors are nearly equal:  $0.0017811/0.0017372 = 1.025$ . Below we compare all 11 coefficients:

Estimator	Coefficient ratio			SE ratio		
	mean	min.	max.	mean	min.	max.
<b>xtreg, mle</b> (ML)	1.	1.	1.	1.	1.	1.
<b>xtreg, re</b> (GLS)	.997	.987	1.007	1.006	.997	1.027



## ▷ Example 6: Population-averaged model

We could also have fit this model with the population-averaged estimator:

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure
> c.tenure#c.tenure 2.race not_smsa south, pa

Iteration 1: tolerance = .0310561
Iteration 2: tolerance = .00074898
Iteration 3: tolerance = .0000147
Iteration 4: tolerance = 2.880e-07

GEE population-averaged model
Group variable: idcode          Number of obs      =    28,091
Link:           identity        Number of groups   =      4,697
Family:          Gaussian        Obs per group:
Correlation:    exchangeable   min =            1
                           avg =          6.0
                           max =         15
                                         Wald chi2(10) =    9598.89
Scale parameter: .1436709     Prob > chi2     =    0.0000
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
grade	.0645427	.0016829	38.35	0.000	.0612442 .0678412
age	.036932	.0031509	11.72	0.000	.0307564 .0431076
c.age#c.age	-.0007129	.0000506	-14.10	0.000	-.0008121 -.0006138
ttl_exp	.0284878	.0024169	11.79	0.000	.0237508 .0332248
c.ttl_exp#c.ttl_exp	.0003158	.0001172	2.69	0.007	.000086 .0005456
tenure	.0397468	.0017779	22.36	0.000	.0362621 .0432315
c.tenure#c.tenure	-.002008	.0001209	-16.61	0.000	-.0022449 -.0017711
race					
black	-.0538314	.0094086	-5.72	0.000	-.072272 -.0353909
not_smsa	-.1347788	.0070543	-19.11	0.000	-.1486049 -.1209526
south	-.0885969	.0071132	-12.46	0.000	-.1025386 -.0746552
_cons	.2396286	.0491465	4.88	0.000	.1433034 .3359539

These results differ from those produced by `xtreg, re` and `xtreg, mle`. Coefficients are larger and standard errors smaller. `xtreg, pa` is simply another way to run the `xtgee` command. That is, we would have obtained the same output had we typed

```
. xtgee ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race not_smsa south
(output omitted because it is the same as above)
```

See [XT] `xtgee`. In the language of `xtgee`, the random-effects model corresponds to an exchangeable correlation structure and identity link, and `xtgee` also allows other correlation structures. Let's stay with the random-effects model, however. `xtgee` will also produce robust estimates of variance, and we refit this model that way by typing

```
. xtgee ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race not_smsa south, vce(robust)
(output omitted, coefficients the same, standard errors different)
```

In the [previous example](#), we presented a table comparing `xtreg, re` with `xtreg, mle`. Below we add the results from the estimates shown and the ones we did with `xtgee, vce(robust)`:

Estimator		Coefficient ratio			SE ratio		
		mean	min.	max.	mean	min.	max.
<code>xtreg, mle</code>	(ML)	1.	1.	1.	1.	1.	1.
<code>xtreg, re</code>	(GLS)	.997	.987	1.007	1.006	.997	1.027
<code>xtreg, pa</code>	(PA)	1.060	.847	1.317	.853	.626	.986
<code>xtgee, vce(robust)</code>	(PA)	1.060	.847	1.317	1.306	.957	1.545

So, which are right? This is a real dataset, and we do not know. However, in [example 2](#) in [XT] `xtreg postestimation`, we will present evidence that the assumptions underlying the `xtreg, re` and `xtreg, mle` results are not met. □

## Stored results

*xtreg, re* stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(Tcon)</code>	1 if $T$ is constant
<code>e(sigma)</code>	ancillary parameter ( <code>gamma</code> , <code>lnormal</code> )
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of $\epsilon_{it}$
<code>e(r2_w)</code>	$R$ -squared for within model
<code>e(r2_o)</code>	$R$ -squared for overall model
<code>e(r2_b)</code>	$R$ -squared for between model
<code>e(N_clust)</code>	number of clusters
<code>e(chi2)</code>	$\chi^2$
<code>e(p)</code>	$p$ -value for model test
<code>e(rho)</code>	$\rho$
<code>e(thta_min)</code>	minimum $\theta$
<code>e(thta_5)</code>	$\theta$ , 5th percentile
<code>e(thta_50)</code>	$\theta$ , 50th percentile
<code>e(thta_95)</code>	$\theta$ , 95th percentile
<code>e(thta_max)</code>	maximum $\theta$
<code>e(rmse)</code>	root mean squared error of GLS regression
<code>e(Tbar)</code>	harmonic mean of group sizes
<code>e(rank)</code>	rank of <code>e(V)</code>

### Macros

<code>e(cmd)</code>	<code>xtreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depyar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(model)</code>	<code>re</code>
<code>e(clustvar)</code>	name of cluster variable
<code>e(chi2type)</code>	Wald; type of model $\chi^2$ test
<code>e(vce)</code>	<code>vctype</code> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(sa)</code>	<code>sa</code> , if specified
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

### Matrices

<code>e(b)</code>	coefficient vector
<code>e(bf)</code>	coefficient vector for fixed-effects model
<code>e(theta)</code>	$\theta$
<code>e(V)</code>	variance–covariance matrix of the estimators
<code>e(VCEf)</code>	VCE for fixed-effects model

### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

`xtreg, be` stores the following in `e()`:

#### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(mss)</code>	model sum of squares
<code>e(df_m)</code>	model degrees of freedom
<code>e(rss)</code>	residual sum of squares
<code>e(df_r)</code>	residual degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(Tcon)</code>	1 if $T$ is constant
<code>e(r2)</code>	$R$ -squared
<code>e(r2_a)</code>	adjusted $R$ -squared
<code>e(r2_w)</code>	$R$ -squared for within model
<code>e(r2_o)</code>	$R$ -squared for overall model
<code>e(r2_b)</code>	$R$ -squared for between model
<code>e(F)</code>	$F$ statistic
<code>e(p)</code>	$p$ -value for model test
<code>e(rmse)</code>	root mean squared error
<code>e(Tbar)</code>	harmonic mean of group sizes
<code>e(rank)</code>	rank of <code>e(V)</code>

#### Macros

<code>e(cmd)</code>	<code>xtreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	<code>be</code>
<code>e(typ)</code>	WLS, if <code>wls</code> specified
<code>e(title)</code>	title in estimation output
<code>e(vce)</code>	<code>vctype</code> specified in <code>vce()</code>
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

#### Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

#### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

**xtreg, fe** stores the following in **e()**:

#### Scalars

<b>e(N)</b>	number of observations
<b>e(N_g)</b>	number of groups
<b>e(mss)</b>	model sum of squares
<b>e(df_m)</b>	model degrees of freedom
<b>e(rss)</b>	residual sum of squares
<b>e(df_r)</b>	residual degrees of freedom
<b>e(tss)</b>	total sum of squares
<b>e(g_min)</b>	smallest group size
<b>e(g_avg)</b>	average group size
<b>e(g_max)</b>	largest group size
<b>e(Tcon)</b>	1 if $T$ is constant
<b>e(sigma)</b>	ancillary parameter ( <i>gamma</i> , <i>lnormal</i> )
<b>e(corr)</b>	$\text{corr}(u_i, X_b)$
<b>e(sigma_u)</b>	panel-level standard deviation
<b>e(sigma_e)</b>	standard deviation of $\epsilon_{it}$
<b>e(r2)</b>	$R$ -squared
<b>e(r2_a)</b>	adjusted $R$ -squared
<b>e(r2_w)</b>	$R$ -squared for within model
<b>e(r2_o)</b>	$R$ -squared for overall model
<b>e(r2_b)</b>	$R$ -squared for between model
<b>e(l1)</b>	log likelihood
<b>e(l1_0)</b>	log likelihood, constant-only model
<b>e(N_clust)</b>	number of clusters
<b>e(rho)</b>	$\rho$
<b>e(F)</b>	$F$ statistic
<b>e(F_f)</b>	$F$ statistic for test of $u_i=0$
<b>e(p)</b>	$p$ -value for model test
<b>e(p_f)</b>	$p$ -value for test of $u_i=0$
<b>e(df_a)</b>	degrees of freedom for absorbed effect
<b>e(df_b)</b>	numerator degrees of freedom for $F$ statistic
<b>e(rmse)</b>	root mean squared error
<b>e(Tbar)</b>	harmonic mean of group sizes
<b>e(rank)</b>	rank of <b>e(V)</b>

#### Macros

<b>e(cmd)</b>	<b>xtreg</b>
<b>e(cmdline)</b>	command as typed
<b>e(depvar)</b>	name of dependent variable
<b>e(ivars)</b>	variable denoting groups
<b>e(model)</b>	<b>fe</b>
<b>e(wtype)</b>	weight type
<b>e(wexp)</b>	weight expression
<b>e(clustvar)</b>	name of cluster variable
<b>e(vce)</b>	<i>vctype</i> specified in <b>vce()</b>
<b>e(vcetype)</b>	title used to label Std. Err.
<b>e(properties)</b>	b V
<b>e(predict)</b>	program used to implement <b>predict</b>
<b>e(marginsnotok)</b>	predictions disallowed by <b>margins</b>
<b>e(asbalanced)</b>	factor variables <b>fvset</b> as <b>asbalanced</b>
<b>e(asobserved)</b>	factor variables <b>fvset</b> as <b>asobserved</b>

#### Matrices

<b>e(b)</b>	coefficient vector
<b>e(V)</b>	variance–covariance matrix of the estimators
<b>e(V_modelbased)</b>	model-based variance

#### Functions

<b>e(sample)</b>	marks estimation sample
------------------	-------------------------

`xtreg, mle` stores the following in `e()`:

#### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of $\epsilon_{it}$
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(l1_c)</code>	log likelihood, comparison model
<code>e(N_clust)</code>	number of clusters
<code>e(chi2)</code>	$\chi^2$
<code>e(chi2_c)</code>	$\chi^2$ for comparison test
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(rho)</code>	$\rho$
<code>e(rank)</code>	rank of <code>e(V)</code>

#### Macros

<code>e(cmd)</code>	<code>xtreg</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(model)</code>	<code>ml</code>
<code>e(wtype)</code>	weight type
<code>e(wexp)</code>	weight expression
<code>e(title)</code>	title in estimation output
<code>e(clustvar)</code>	name of cluster variable
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(chi2type)</code>	Wald or LR; type of model $\chi^2$ test
<code>e(chi2_ct)</code>	Wald or LR; type of model $\chi^2$ test corresponding to <code>e(chi2_c)</code>
<code>e(distrib)</code>	Gaussian; the distribution of the RE
<code>e(properties)</code>	b V
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

#### Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	variance–covariance matrix of the estimators

#### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

**xtreg**, **pa** stores the following in **e()**:

#### Scalars

<b>e(N)</b>	number of observations
<b>e(N_g)</b>	number of groups
<b>e(df_m)</b>	model degrees of freedom
<b>e(chi2)</b>	$\chi^2$
<b>e(p)</b>	p-value for model test
<b>e(df_pear)</b>	degrees of freedom for Pearson $\chi^2$
<b>e(chi2_dev)</b>	$\chi^2$ test of deviance
<b>e(chi2_dis)</b>	$\chi^2$ test of deviance dispersion
<b>e(deviance)</b>	deviance
<b>e(dispers)</b>	deviance dispersion
<b>e(phi)</b>	scale parameter
<b>e(g_min)</b>	smallest group size
<b>e(g_avg)</b>	average group size
<b>e(g_max)</b>	largest group size
<b>e(rank)</b>	rank of <b>e(V)</b>
<b>e(tol)</b>	target tolerance
<b>e(dif)</b>	achieved tolerance
<b>e(rc)</b>	return code

#### Macros

<b>e(cmd)</b>	<b>xtgee</b>
<b>e(cmd2)</b>	<b>xtreg</b>
<b>e(cmdline)</b>	command as typed
<b>e(depvar)</b>	name of dependent variable
<b>e(ivar)</b>	variable denoting groups
<b>e(tvar)</b>	variable denoting time within groups
<b>e(model)</b>	<b>pa</b>
<b>e(family)</b>	Gaussian
<b>e(link)</b>	identity; link function
<b>e(corr)</b>	correlation structure
<b>e(scale)</b>	x2, dev, phi, or #, scale parameter
<b>e(wtype)</b>	weight type
<b>e(wexp)</b>	weight expression
<b>e(offset)</b>	linear offset variable
<b>e(chi2type)</b>	Wald; type of model $\chi^2$ test
<b>e(vce)</b>	<b>vcetype</b> specified in <b>vce()</b>
<b>e(vcetype)</b>	title used to label Std. Err.
<b>e(rgf)</b>	<b>rgf</b> , if <b>rgf</b> specified
<b>e(nmp)</b>	<b>nmp</b> , if specified
<b>e(properties)</b>	b V
<b>e(predict)</b>	program used to implement <b>predict</b>
<b>e(marginsnotok)</b>	predictions disallowed by <b>margins</b>
<b>e(asbalanced)</b>	factor variables <b>fvset</b> as <b>asbalanced</b>
<b>e(asobserved)</b>	factor variables <b>fvset</b> as <b>asobserved</b>

#### Matrices

<b>e(b)</b>	coefficient vector
<b>e(R)</b>	estimated working correlation matrix
<b>e(V)</b>	variance–covariance matrix of the estimators
<b>e(V_modelbased)</b>	model-based variance

#### Functions

<b>e(sample)</b>	marks estimation sample
------------------	-------------------------

## Methods and formulas

The model to be fit is

$$y_{it} = \alpha + \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it}$$

for  $i = 1, \dots, n$  and, for each  $i$ ,  $t = 1, \dots, T$ , of which  $T_i$  periods are actually observed.

Methods and formulas are presented under the following headings:

`xtreg, fe`  
`xtreg, be`  
`xtreg, re`  
`xtreg, mle`  
`xtreg, pa`

## xtreg, fe

`xtreg, fe` produces estimates by running OLS on

$$(y_{it} - \bar{y}_i + \bar{\bar{y}}) = \alpha + (\mathbf{x}_{it} - \bar{\mathbf{x}}_i + \bar{\bar{\mathbf{x}}})\beta + (\epsilon_{it} - \bar{\epsilon}_i + \bar{\nu}) + \bar{\bar{\epsilon}}$$

where  $\bar{y}_i = \sum_{t=1}^{T_i} y_{it}/T_i$ , and similarly,  $\bar{\bar{y}} = \sum_i \sum_t y_{it}/(nT_i)$ . The conventional covariance matrix of the estimators is adjusted for the extra  $n - 1$  estimated means, so results are the same as using OLS on (1) to estimate  $\nu_i$  directly. Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] `_robust`, particularly *Introduction* and *Methods and formulas*. Wooldridge (2020) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2020), Stock and Watson (2008), and Arellano (2003), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where `panelvar` is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in  $\epsilon_{it}$ .

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation induced by the within transform.

From the estimates  $\hat{\alpha}$  and  $\hat{\beta}$ , estimates  $u_i$  of  $\nu_i$  are obtained as  $u_i = \bar{y}_i - \hat{\alpha} - \bar{\mathbf{x}}_i \hat{\beta}$ . Reported from the calculated  $u_i$  are its standard deviation and its correlation with  $\bar{\mathbf{x}}_i \hat{\beta}$ . Reported as the standard deviation of  $e_{it}$  is the regression's estimated root mean squared error,  $s$ , which is adjusted (as previously stated) for the  $n - 1$  estimated means.

Reported as  $R^2$  within is the  $R^2$  from the mean-deviated regression.

Reported as  $R^2$  between is  $\text{corr}(\bar{\mathbf{x}}_i \hat{\beta}, \bar{y}_i)^2$ .

Reported as  $R^2$  overall is  $\text{corr}(\mathbf{x}_{it} \hat{\beta}, y_{it})^2$ .

## xtreg, be

`xtreg, be` fits the following model:

$$\bar{y}_i = \alpha + \bar{\mathbf{x}}_i \beta + \nu_i + \bar{\epsilon}_i$$

Estimation is via OLS unless  $T_i$  is not constant and the `wls` option is specified. Otherwise, the estimation is performed via WLS. The estimates and conventional VCE are obtained from `regress` for both cases, but for WLS, [`aweight=T_i`] is specified.

Reported as  $R^2$  between is the  $R^2$  from the fitted regression.

Reported as  $R^2$  within is  $\text{corr}\{(\mathbf{x}_{it} - \bar{\mathbf{x}}_i) \hat{\beta}, y_{it} - \bar{y}_i\}^2$ .

Reported as  $R^2$  overall is  $\text{corr}(\mathbf{x}_{it} \hat{\beta}, y_{it})^2$ .

**xtreg, re**

The key to the random-effects estimator is the GLS transform. Given estimates of the idiosyncratic component,  $\hat{\sigma}_e^2$ , and the individual component,  $\hat{\sigma}_u^2$ , the GLS transform of a variable  $z$  for the random-effects model is

$$z_{it}^* = z_{it} - \hat{\theta}_i \bar{z}_i$$

where  $\bar{z}_i = 1/T_i \sum_{t=1}^{T_i} z_{it}$  and

$$\hat{\theta}_i = 1 - \sqrt{\frac{\hat{\sigma}_e^2}{T_i \hat{\sigma}_u^2 + \hat{\sigma}_e^2}}$$

Given an estimate of  $\hat{\theta}_i$ , one transforms the dependent and independent variables, and then the coefficient estimates and the conventional variance–covariance matrix come from an OLS regression of  $y_{it}^*$  on  $\mathbf{x}_{it}^*$  and the transformed constant  $1 - \hat{\theta}_i$ . Specifying `vce(robust)` or `vce(cluster clustvar)` causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] [robust](#); in particular, see [Introduction](#) and [Methods and formulas](#). [Wooldridge \(2020\)](#) and [Arellano \(2003\)](#) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by [Wooldridge \(2020\)](#), [Stock and Watson \(2008\)](#), and [Arellano \(2003\)](#), specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`, where `panelvar` is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in  $\epsilon_{it}$ .

The cluster–robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

Stata has two implementations of the Swamy–Arora method for estimating the variance components. They produce the same results in balanced panels and share the same estimator of  $\sigma_e^2$ . However, the two methods differ in their estimator of  $\sigma_u^2$  in unbalanced panels. We call the first  $\hat{\sigma}_{u\bar{T}}^2$  and the second  $\hat{\sigma}_{uSA}^2$ . Both estimators are consistent; however,  $\hat{\sigma}_{uSA}^2$  has a more elaborate adjustment for small samples than  $\hat{\sigma}_{u\bar{T}}^2$ . (See [Baltagi \[2013\]](#), [Baltagi and Chang \[1994\]](#), and [Swamy and Arora \[1972\]](#) for derivations of these methods.)

Both methods use the same function of within residuals to estimate the idiosyncratic error component  $\sigma_e$ . Specifically,

$$\hat{\sigma}_e^2 = \frac{\sum_{i=1}^n \sum_{t=1}^{T_i} e_{it}^2}{N - n - K + 1}$$

where

$$e_{it} = (y_{it} - \bar{y}_i + \bar{\bar{y}}) - \hat{\alpha}_w - (\mathbf{x}_{it} - \bar{\mathbf{x}}_i + \bar{\bar{\mathbf{x}}}) \hat{\beta}_w$$

and  $\hat{\alpha}_w$  and  $\hat{\beta}_w$  are the within estimates of the coefficients and  $N = \sum_{i=1}^n T_i$ . After passing the within residuals through the within transform, only the idiosyncratic errors are left.

The default method for estimating  $\sigma_u^2$  is

$$\widehat{\sigma}_{u\bar{T}}^2 = \max \left\{ 0, \frac{\text{SSR}_b}{n - K} - \frac{\widehat{\sigma}_e^2}{\bar{T}} \right\}$$

where

$$\text{SSR}_b = \sum_{i=1}^n \left( \bar{y}_i - \widehat{\alpha}_b - \bar{x}_i \widehat{\beta}_b \right)^2$$

$\widehat{\alpha}_b$  and  $\widehat{\beta}_b$  are coefficient estimates from the between regression and  $\bar{T}$  is the harmonic mean of  $T_i$ :

$$\bar{T} = \frac{n}{\sum_{i=1}^n \frac{1}{T_i}}$$

This estimator is consistent for  $\sigma_u^2$  and is computationally less expensive than the second method. The sum of squared residuals from the between model estimate a function of both the idiosyncratic component and the individual component. Using our estimator of  $\sigma_e^2$ , we can remove the idiosyncratic component, leaving only the desired individual component.

The second method is the Swamy–Arora method for unbalanced panels derived by [Baltagi and Chang \(1994\)](#), which has a more precise small-sample adjustment. Using this method,

$$\widehat{\sigma}_{\text{USA}}^2 = \max \left\{ 0, \frac{\text{SSR}_b^* - (n - K)\widehat{\sigma}_e^2}{N - c_{\text{tr}}} \right\}$$

where

$$\text{SSR}_b^* = \sum_{i=1}^n T_i \left( \bar{y}_i - \widehat{\alpha}_b - \bar{x}_i \widehat{\beta}_b \right)^2$$

$$c_{\text{tr}} = \text{trace} \left\{ (\mathbf{X}' \mathbf{P} \mathbf{X})^{-1} \mathbf{X}' \mathbf{Z} \mathbf{Z}' \mathbf{X} \right\}$$

$$\mathbf{P} = \text{diag} \left\{ \left( \frac{1}{T_i} \right) \boldsymbol{\iota}_{T_i} \boldsymbol{\iota}_{T_i}' \right\}$$

$$\mathbf{Z} = \text{diag} [\boldsymbol{\iota}_{T_i}]$$

$\mathbf{X}$  is the  $N \times K$  matrix of covariates, including the constant, and  $\boldsymbol{\iota}_{T_i}$  is a  $T_i \times 1$  vector of ones.

The estimated coefficients  $(\widehat{\alpha}, \widehat{\beta})$  and their estimated covariance matrix  $\widehat{\mathbf{V}}$  are reported together with the previously calculated quantities  $\widehat{\sigma}_e$  and  $\widehat{\sigma}_u$ . The standard deviation of  $\nu_i + e_{it}$  is calculated as  $\sqrt{\widehat{\sigma}_e^2 + \widehat{\sigma}_u^2}$ .

Reported as  $R^2$  between is  $\text{corr}(\bar{x}_i \widehat{\beta}, \bar{y}_i)^2$ .

Reported as  $R^2$  within is  $\text{corr}\{(\mathbf{x}_{it} - \bar{\mathbf{x}}_i)\widehat{\beta}, y_{it} - \bar{y}_i\}^2$ .

Reported as  $R^2$  overall is  $\text{corr}(\mathbf{x}_{it} \widehat{\beta}, y_{it})^2$ .

**xtreg, mle**

The log likelihood for the  $i$ th unit is

$$l_i = -\frac{1}{2} \left( \frac{1}{\sigma_e^2} \left[ \sum_{t=1}^{T_i} (y_{it} - \mathbf{x}_{it}\beta)^2 - \frac{\sigma_u^2}{T_i \sigma_u^2 + \sigma_e^2} \left\{ \sum_{t=1}^{T_i} (y_{it} - \mathbf{x}_{it}\beta) \right\}^2 \right] \right. \\ \left. + \ln \left( T_i \frac{\sigma_u^2}{\sigma_e^2} + 1 \right) + T_i \ln(2\pi\sigma_e^2) \right)$$

The **mle** and **re** options yield essentially the same results, except when total  $N = \sum_i T_i$  is small (200 or less) and the data are unbalanced.

Similarly to **xtreg, fe** and **xtreg, re**, specifying **vce(robust)** or **vce(cluster clustvar)** causes the Huber/White/sandwich VCE estimator to be calculated for the estimated parameters in this regression.

Specifying **vce(robust)** is equivalent to specifying **vce(cluster panelvar)**, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in it.

The cluster-robust VCE estimator requires that there are many clusters and the disturbances are uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

**xtreg, pa**

See [XT] **xtgee** for details on the methods and formulas used to calculate the population-averaged model using a generalized estimating equations approach.

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## Also see

- [XT] **xtreg postestimation** — Postestimation tools for xtreg
- [XT] **xteregress** — Extended random-effects linear regression
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtgls** — Fit panel-data models by using GLS
- [XT] **xheckman** — Random-effects regression with sample selection
- [XT] **xtivreg** — Instrumental variables and two-stage least squares for panel-data models
- [XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance
- [XT] **xtset** — Declare data to be panel data
- [ME] **mixed** — Multilevel mixed-effects linear regression
- [MI] **Estimation** — Estimation commands for use with mi estimate
- [R] **areg** — Linear regression with a large dummy-variable set
- [R] **regress** — Linear regression
- [SP] **spxtregress** — Spatial autoregressive models for panel data
- [TS] **forecast** — Econometric model forecasting
- [TS] **prais** — Prais–Winsten and Cochrane–Orcutt regression
- [U] **20 Estimation and postestimation commands**

**xtreg postestimation** — Postestimation tools for xtreg

[Postestimation commands](#)  
[Remarks and examples](#)

[predict](#)  
[Methods and formulas](#)

[margins](#)  
[References](#)

[xttest0](#)  
[Also see](#)

## Postestimation commands

The following postestimation commands are of special interest after **xtreg**:

Command	Description
<a href="#">xttest0</a>	Breusch and Pagan LM test for random effects

The following standard postestimation commands are also available:

Command	Description
<a href="#">contrast</a>	contrasts and ANOVA-style joint tests of estimates
* <a href="#">estat ic</a>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<a href="#">estat summarize</a>	summary statistics for the estimation sample
<a href="#">estat vce</a>	variance–covariance matrix of the estimators (VCE)
<a href="#">estimates</a>	cataloging estimation results
† <a href="#">forecast</a>	dynamic forecasts and simulations
<a href="#">hausman</a>	Hausman's specification test
<a href="#">lincom</a>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
* <a href="#">lrtest</a>	likelihood-ratio test
<a href="#">margins</a>	marginal means, predictive margins, marginal effects, and average marginal effects
<a href="#">marginsplot</a>	graph the results from margins (profile plots, interaction plots, etc.)
<a href="#">nlcom</a>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<a href="#">predict</a>	predictions, residuals, influence statistics, and other diagnostic measures
<a href="#">predictnl</a>	point estimates, standard errors, testing, and inference for generalized predictions
<a href="#">pwcompare</a>	pairwise comparisons of estimates
<a href="#">test</a>	Wald tests of simple and composite linear hypotheses
<a href="#">testnl</a>	Wald tests of nonlinear hypotheses

\* [estat ic](#) and [lrtest](#) are not appropriate after **xtreg** with the **pa** or **re** option.

† [forecast](#) is not appropriate with **mi** estimation results.

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as fitted values, standard errors, predicted values, linear predictions, and equation-level scores.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

For all but the population-averaged model

```
predict [type] newvar [if] [in] [, statistic nooffset]
```

Population-averaged model

```
predict [type] newvar [if] [in] [, PA_statistic nooffset]
```

statistic	Description
-----------	-------------

---

#### Main

<code>xb</code>	$\alpha + \mathbf{x}_{it}\beta$ , fitted values; the default
<code>stdp</code>	standard error of the fitted values
<code>ue</code>	$u_i + e_{it}$ , the combined residual
<code>* xbu</code>	$\alpha + \mathbf{x}_{it}\beta + u_i$ , prediction including effect
<code>* u</code>	$u_i$ , the fixed- or random-error component
<code>* e</code>	$e_{it}$ , the overall error component

Unstarred statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample. Starred statistics are calculated only for the estimation sample, even when `if e(sample)` is not specified.

<code>PA_statistic</code>	Description
---------------------------	-------------

---

#### Main

<code>mu</code>	predicted value of <code>depvar</code> ; considers the <code>offset()</code>
<code>rate</code>	predicted value of <code>depvar</code>
<code>xb</code>	linear prediction
<code>stdp</code>	standard error of the linear prediction
<code>score</code>	first derivative of the log likelihood with respect to $\mathbf{x}_{it}\beta$

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

## Options for predict

### Main

**xb** calculates the linear prediction, that is,  $\alpha + \mathbf{x}_{it}\beta$ . This is the default for all except the population-averaged model.

**stdp** calculates the standard error of the linear prediction. For the fixed-effects model, this excludes the variance due to uncertainty about the estimate of  $u_i$ .

**mu** and **rate** both calculate the predicted value of *depvar*. **mu** takes into account the `offset()`, and **rate** ignores those adjustments. **mu** and **rate** are equivalent if you did not specify `offset()`. **mu** is the default for the population-averaged model.

**ue** calculates the prediction of  $u_i + e_{it}$ .

**xbu** calculates the prediction of  $\alpha + \mathbf{x}_{it}\beta + u_i$ , the prediction including the fixed or random component.

**u** calculates the prediction of  $u_i$ , the estimated fixed or random effect.

**e** calculates the prediction of  $e_{it}$ .

**score** calculates the equation-level score,  $u_{it} = \partial \ln L(\mathbf{x}_{it}\beta) / \partial (\mathbf{x}_{it}\beta)$ .

**nooffset** is relevant only if you specified `offset(varname)` for `xtreg`, `pa`. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\beta$  rather than  $\mathbf{x}_{it}\beta + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for fitted values, probabilities, and linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

`margins [marginlist] [, options]`  
`margins [marginlist] , predict(statistic ...) [predict(statistic ...) ...] [options]`

For all but the population-averaged model

statistic	Description
<code>xb</code>	$\alpha + \mathbf{x}_{it}\beta$ , fitted values; the default
<code>stdp</code>	not allowed with <code>margins</code>
<code>ue</code>	not allowed with <code>margins</code>
<code>xbu</code>	not allowed with <code>margins</code>
<code>u</code>	not allowed with <code>margins</code>
<code>e</code>	not allowed with <code>margins</code>

Population-averaged model

statistic	Description
<code>mu</code>	probability of <code>depvar</code> ; considers the <code>offset()</code>
<code>rate</code>	probability of <code>depvar</code>
<code>xb</code>	linear prediction
<code>stdp</code>	not allowed with <code>margins</code>
<code>score</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

## xttest0

### Description for xttest0

xttest0, for use after `xtreg, re`, presents the Breusch and Pagan (1980) Lagrange multiplier test for random effects, a test that  $\text{Var}(\nu_i) = 0$ .

### Menu for xttest0

Statistics > Longitudinal/panel data > Linear models > Lagrange multiplier test for random effects

### Syntax for xttest0

```
xttest0
```

## Remarks and examples

### ▷ Example 1

Continuing with our `xtreg, re` estimation example (example 4) in `xtreg`, we can see that `xttest0` will report a test of  $\nu_i = 0$ . In case we have any doubts, we could type

```
. use https://www.stata-press.com/data/r16/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race not_smsa south, re theta
  (output omitted)
. xttest0
Breusch and Pagan Lagrangian multiplier test for random effects
      ln_wage[idcode,t] = Xb + u[idcode] + e[idcode,t]
Estimated results:
      Var          sd = sqrt(Var)
      ln_wage     .2283326    .4778416
      e           .0845002    .2906892
      u           .0665151    .2579053
Test:  Var(u) = 0
      chibar2(01) = 14779.98
      Prob > chibar2 =   0.0000
```



### ▷ Example 2

More importantly, after `xtreg, re` estimation, `hausman` will perform the Hausman specification test. If our model is correctly specified, and if  $\nu_i$  is uncorrelated with  $\mathbf{x}_{it}$ , the (subset of) coefficients that are estimated by the fixed-effects estimator and the same coefficients that are estimated here should not statistically differ:

```
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race not_smsa south, re
  (output omitted)
```

```
. estimates store random_effects
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race not_smsa south, fe
  (output omitted)
. hausman . random_effects
```

	Coefficients		(b-B)	sqrt(diag(V_b-V_B))
	(b)	(B) random_eff~s	Difference	S.E.
age	.0359987	.0368059	-.0008073	.0013177
c.age#c.age	-.000723	-.0007133	-9.68e-06	.0000184
ttl_exp	.0334668	.0290208	.0044459	.001711
c.ttl_exp#				
c.ttl_exp	.0002163	.0003049	-.0000886	.000053
tenure	.0357539	.0392519	-.003498	.0005797
c.tenure#				
c.tenure	-.0019701	-.0020035	.0000334	.0000373
not_smsa	-.0890108	-.1308252	.0418144	.0062745
south	-.0606309	-.0868922	.0262613	.0081345

b = consistent under Ho and Ha; obtained from xtreg

B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic

$$\begin{aligned} \text{chi2}(8) &= (\mathbf{b}-\mathbf{B})'[(V_{\mathbf{b}}-V_{\mathbf{B}})^{-1}](\mathbf{b}-\mathbf{B}) \\ &= 149.43 \\ \text{Prob}>\text{chi2} &= 0.0000 \end{aligned}$$

We can reject the hypothesis that the coefficients are the same. Before turning to what this means, note that `hausman` listed the coefficients estimated by the two models. It did not, however, list `grade` and `2.race`. `hausman` did not make a mistake; in the Hausman test, we compare only the coefficients estimated by both techniques.

What does this mean? We have an unpleasant choice: we can admit that our model is misspecified—that we have not parameterized it correctly—or we can hold that our specification is correct, in which case the observed differences must be due to the zero correlation of  $\nu_i$  and the  $\mathbf{x}_{it}$  assumption.



## □ Technical note

We can also mechanically explore the underpinnings of the test's dissatisfaction. In the comparison table from `hausman`, it is the coefficients on `not_smsa` and `south` that exhibit the largest differences. In [equation \(1'\)](#) of [\[XT\] xtreg](#), we showed how to decompose a model into within and between effects. Let's do that with these two variables, assuming that changes in the average have one effect, whereas transitional changes have another:

. egen avgnsmsa = mean(not_smsa), by(id)						
. generate devnsma = not_smsa -avgnsmsa						
(8 missing values generated)						
. egen avgsouth = mean(south), by(id)						
. generate devsouth = south - avgsouth						
(8 missing values generated)						
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp tenure c.tenure#						
> c.tenure 2.race avgnsmsa devnsma avgsouth devsou						
Random-effects GLS regression					Number of obs	= 28,091
Group variable: idcode					Number of groups	= 4,697
R-sq:					Obs per group:	
within = 0.1723					min =	1
between = 0.4809					avg =	6.0
overall = 0.3737					max =	15
					Wald chi2(12)	= 9319.56
corr(u_i, X) = 0 (assumed)					Prob > chi2	= 0.0000
ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf.	Interval
grade	.0631716	.0017903	35.29	0.000	.0596627	.0666805
age	.0375196	.0031186	12.03	0.000	.0314072	.043632
c.age#c.age	-.0007248	.00005	-14.50	0.000	-.0008228	-.0006269
ttl_exp	.0286543	.0024207	11.84	0.000	.0239098	.0333989
c.ttl_exp#c.ttl_exp	.0003222	.0001162	2.77	0.006	.0000945	.0005499
tenure	.0394423	.001754	22.49	0.000	.0360044	.0428801
c.tenure#c.tenure	-.0020081	.0001192	-16.85	0.000	-.0022417	-.0017746
race						
black	-.0545936	.0102101	-5.35	0.000	-.074605	-.0345821
avgnsmsa	-.1833237	.0109339	-16.77	0.000	-.2047537	-.1618937
devnsma	-.0887596	.0095071	-9.34	0.000	-.1073931	-.070126
avgsouth	-.1011235	.0098789	-10.24	0.000	-.1204858	-.0817611
devsouth	-.0598538	.0109054	-5.49	0.000	-.081228	-.0384797
_cons	.2682987	.0495778	5.41	0.000	.171128	.3654694
sigma_u	.2579182					
sigma_e	.29068923					
rho	.44047745				(fraction of variance due to u_i)	

We will leave the reinterpretation of this model to you, except that if we were really going to sell this model, we would have to explain why the between and within effects are different. Focusing on residence in a non-SMSA, we might tell a story about rural people being paid less and continuing to get paid less when they move to the SMSA. Given our panel data, we could create variables to measure this (an indicator for moved from non-SMSA to SMSA) and to measure the effects. In our assessment of this model, we should think about women in the cities moving to the country and their relative productivity in a bucolic setting.

In any case, the Hausman test now is

```
. estimates store new_random_effects
. xtreg ln_w grade age c.age#c.age ttl_exp c.ttl_exp#c.ttl_exp
> tenure c.tenure#c.tenure 2.race avgnsm devnsma avgssou devssou, fe
(output omitted)
. hausman . new_random_effects
```

	<b>Coefficients</b>		(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
	(b)	(B) new_random~s		
age	.0359987	.0375196	-.0015209	.0013198
c.age#c.age	-.000723	-.0007248	1.84e-06	.0000184
ttl_exp	.0334668	.0286543	.0048124	.0017127
c.ttl_exp#				
c.ttl_exp	.0002163	.0003222	-.0001059	.0000531
tenure	.0357539	.0394423	-.0036884	.0005839
c.tenure#				
c.tenure	-.0019701	-.0020081	.000038	.0000377
devnsma	-.0890108	-.0887596	-.0002512	.000683
devssou	-.0606309	-.0598538	-.0007771	.0007618

b = consistent under Ho and Ha; obtained from xtreg

B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic

$$\begin{aligned} \text{chi2}(8) &= (\mathbf{b}-\mathbf{B})'[(V_b-V_B)^{-1}](\mathbf{b}-\mathbf{B}) \\ &= 92.52 \\ \text{Prob}>\text{chi2} &= 0.0000 \end{aligned}$$

We have mechanically succeeded in greatly reducing the  $\chi^2$ , but not by enough. The major differences now are in the age, experience, and tenure effects. We already knew this problem existed because of the ever-increasing effect of experience. More careful parameterization work rather than simply including squares needs to be done.

□

## Methods and formulas

xttest0 reports the Lagrange multiplier test for random effects developed by Breusch and Pagan (1980) and as modified by Baltagi and Li (1990). The model

$$y_{it} = \alpha + \mathbf{x}_{it}\beta + \nu_i$$

is fit via OLS, and then the quantity

$$\lambda_{LM} = \frac{(n\bar{T})^2}{2} \left( \frac{A_1^2}{(\sum_i T_i^2) - n\bar{T}} \right)$$

is calculated, where

$$A_1 = 1 - \frac{\sum_{i=1}^n (\sum_{t=1}^{T_i} v_{it})^2}{\sum_i \sum_t v_{it}^2}$$

The Baltagi and Li modification allows for unbalanced data and reduces to the standard formula

$$\lambda_{LM} = \begin{cases} \frac{nT}{2(T-1)} \left\{ \frac{\sum_i (\sum_t v_{it})^2}{\sum_i \sum_t v_{it}^2} - 1 \right\}^2, & \hat{\sigma}_u^2 \geq 0 \\ 0 & , \quad \hat{\sigma}_u^2 < 0 \end{cases}$$

when  $T_i = T$  (balanced data). Under the null hypothesis,  $\lambda_{LM}$  is distributed as a 50:50 mixture of a point mass at zero and  $\chi^2(1)$ .

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## Also see

- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models  
 [U] **20 Estimation and postestimation commands**

**xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance

Description

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## Description

**xtregar** fits cross-sectional time-series regression models when the disturbance term is first-order autoregressive. **xtregar** offers a within estimator for fixed-effects models and a GLS estimator for random-effects models. **xtregar** can accommodate unbalanced panels whose observations are unequally spaced over time.

## Quick start

Random-effects model of *y* on *x1* with an AR(1) disturbance using *xtset* data

```
xtregar y x1
```

Add *x2* and *x3* as covariates and perform Baltagi–Wu LBI test

```
xtregar y x1 x2 x3, lbi
```

Fixed-effects model using the within estimator and observations where *tvar* is greater than 2,000

```
xtregar y x1 x2 x3 if tvar > 2000, fe
```

## Menu

Statistics > Longitudinal/panel data > Linear models > Linear regression with AR(1) disturbance (FE, RE)

## Syntax

*GLS random-effects (RE) model*

```
xtregar depvar [indepvars] [if] [in] [, re options]
```

*Fixed-effects (FE) model*

```
xtregar depvar [indepvars] [if] [in] [weight], fe [options]
```

<i>options</i>	Description
<hr/>	
Model	
<code>re</code>	use random-effects estimator; the default
<code>fe</code>	use fixed-effects estimator
<code>rhototype(rhomethod)</code>	specify method to compute autocorrelation; seldom used
<code>rhof(#)</code>	use # for $\rho$ and do not estimate $\rho$
<code>twostep</code>	perform two-step estimate of correlation
<hr/>	
Reporting	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>lbi</code>	perform Baltagi–Wu LBI test
<code>display_options</code>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<code>coeflegend</code>	display legend instead of statistics

---

A panel variable and a time variable must be specified; use `xtset`; see [XT] `xtset`.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

*depvar* and *indepvars* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by` and `statsby` are allowed; see [U] 11.1.10 Prefix commands.

`fweights` and `aweights` are allowed for the fixed-effects model with `rhototype(regress)` or `rhototype(freg)`, or with a fixed rho; see [U] 11.1.6 weight. Weights must be constant within panel.

`coeflegend` does not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

`re` requests the GLS estimator of the random-effects model, which is the default.

`fe` requests the within estimator of the fixed-effects model.

`rhototype(rhomethod)` allows the user to specify any of the following estimators of  $\rho$ :

<code>dw</code>	$\rho_{dw} = 1 - d/2$ , where $d$ is the Durbin–Watson $d$ statistic
<code>regress</code>	$\rho_{reg} = \beta$ from the residual regression $\epsilon_t = \beta\epsilon_{t-1}$
<code>freg</code>	$\rho_{freg} = \beta$ from the residual regression $\epsilon_t = \beta\epsilon_{t+1}$
<code>tscorr</code>	$\rho_{tscorr} = \epsilon'\epsilon_{t-1}/\epsilon'\epsilon$ , where $\epsilon$ is the vector of residuals and $\epsilon_{t-1}$ is the vector of lagged residuals
<code>theil</code>	$\rho_{theil} = \rho_{tscorr}(N - k)/N$
<code>nagar</code>	$\rho_{nagar} = (\rho_{dw}N^2 + k^2)/(N^2 - k^2)$
<code>onestep</code>	$\rho_{onestep} = (n/m_c)(\epsilon'\epsilon_{t-1}/\epsilon'\epsilon)$ , where $\epsilon$ is the vector of residuals, $n$ is the number of observations, and $m_c$ is the number of consecutive pairs of residuals

`dw` is the default method. Except for `onestep`, the details of these methods are given in [TS] **prais**. `prais` handles unequally spaced data. `onestep` is the one-step method proposed by Baltagi and Wu (1999). More details on this method are available below in *Methods and formulas*.

`rhof(#)` specifies that the given number be used for  $\rho$  and that  $\rho$  not be estimated.

`twostep` requests that a two-step implementation of the *rhomethod* estimator of  $\rho$  be used. Unless a fixed value of  $\rho$  is specified (with the `rhof()` option),  $\rho$  is estimated by running `prais` on the de-meaned data. When `twostep` is specified, `prais` will stop on the first iteration after the equation is transformed by  $\rho$ —the two-step efficient estimator. Although it is customary to iterate these estimators to convergence, they are efficient at each step. When `twostep` is not specified, the FGLS process iterates to convergence as described in the *Methods and formulas* of [TS] **prais**.

#### Reporting

`level(#); see [R] Estimation options.`

`lbi` requests that the Baltagi–Wu (1999) locally best invariant (LBI) test statistic that  $\rho = 0$  and a modified version of the Bhargava, Franzini, and Narendranathan (1982) Durbin–Watson statistic be calculated and reported. The default is not to report them. *p*-values are not reported for either statistic. Although Bhargava, Franzini, and Narendranathan (1982) published critical values for their statistic, no tables are currently available for the Baltagi–Wu LBI. Baltagi and Wu (1999) derive a normalized version of their statistic, but this statistic cannot be computed for datasets of moderate size. You can also specify these options upon replay.

`display_options:` `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] **Estimation options**.

The following option is available with `xtregar` but is not shown in the dialog box:

`coeflegend; see [R] Estimation options.`

## Remarks and examples

Remarks are presented under the following headings:

- Introduction*
- The fixed-effects model*
- The random-effects model*

## Introduction

If you have not read [XT] **xt**, please do so.

**xtregar** fits cross-sectional time-series regression models when the disturbance term is first-order autoregressive. The models of interest are described by

$$y_{it} = \alpha + \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it} \quad i = 1, \dots, N; \quad t = 1, \dots, T_i \quad (1)$$

where

$$\epsilon_{it} = \rho\epsilon_{i,t-1} + \eta_{it} \quad (2)$$

and where  $|\rho| < 1$  and  $\eta_{it}$  is independent and identically distributed (i.i.d.) with mean 0 and variance  $\sigma_\eta^2$ .

In the fixed-effects model, the  $\nu_i$  are assumed to be correlated with the covariates  $\mathbf{x}_{it}$ , whereas in the random-effects model they are assumed to follow an i.i.d. process with mean 0 and variance  $\sigma_\nu^2$  and to be uncorrelated with the  $\mathbf{x}_{it}$ .

Similar to other linear panel-data models, any  $\mathbf{x}_{it}$  that do not vary over  $t$  are collinear with the  $\nu_i$  and will be dropped from the fixed-effects model. In contrast, the random-effects model can accommodate covariates that are constant over time.

**xtregar** offers a within estimator for the fixed-effect model and the Baltagi–Wu (1999) GLS estimator of the random-effects model. Both of these estimators offer several estimators of  $\rho$ .

The Baltagi–Wu (1999) GLS estimator extends the balanced panel estimator in Baltagi and Li (1991) to a case of exogenously unbalanced panels with unequally spaced observations. Specifically, the dataset contains observations on individual  $i$  at times  $t_{ij}$  for  $j = 1, \dots, n_i$ . The difference  $t_{ij} - t_{i,j-1}$  plays an integral role in the estimation techniques used by **xtregar**.

For this reason, you must specify the `delta()` option when you `xtset panelvar timevar` if, for example, you have quarterly data with a monthly `timevar` recorded every three months instead of a quarterly `timevar`; see [XT] **xtset**.

## The fixed-effects model

Let's examine the fixed-effect model first. The basic approach is common to all fixed-effects models. The  $\nu_i$  are treated as nuisance parameters. We use a transformation of the model that removes the nuisance parameters and leaves behind the parameters of interest in an estimable form. Subtracting the group means from (1) removes the  $\nu_i$  from the model

$$y_{it_{ij}} - \bar{y}_i = (\bar{\mathbf{x}}_{it_{ij}} - \bar{\mathbf{x}}_i) \beta + \epsilon_{it_{ij}} - \bar{\epsilon}_i \quad (3)$$

where

$$\bar{y}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} y_{it_{ij}} \quad \bar{\mathbf{x}}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \mathbf{x}_{it_{ij}} \quad \bar{\epsilon}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} \epsilon_{it_{ij}}$$

After the transformation, (3) is a linear AR(1) model, potentially with unequally spaced observations. (3) can be used to estimate  $\rho$ . Given an estimate of  $\rho$ , we must do a Cochrane–Orcutt transformation on each panel and then remove the within-panel means and add back the overall mean for each variable. OLS on the transformed data will produce the within estimates of  $\alpha$  and  $\beta$ .

## ► Example 1: Fixed-effects model

Let's use the Grunfeld investment dataset to illustrate how `xtregar` can be used to fit the fixed-effects model. This dataset contains information on 10 firms' investment, market value, and the value of their capital stocks. The data were collected annually between 1935 and 1954. The following output shows that we have `xtset` our data and gives the results of running a fixed-effects model with investment as a function of market value and the capital stock.

```

. use https://www.stata-press.com/data/r16/grunfeld
. xtset
    panel variable: company (strongly balanced)
    time variable: year, 1935 to 1954
        delta: 1 year
. xtregar invest mvalue kstock, fe
FE (within) regression with AR(1) disturbances  Number of obs      =    190
Group variable: company                         Number of groups   =      10
R-sq:                                           Obs per group:
                                                min =          19
                                                between =     19.0
                                                overall =    19
                                                max =          19
corr(u_i, Xb) = -0.0454                      F(2, 178)       =    129.49
                                                Prob > F      =    0.0000



| invest  | Coef.     | Std. Err.                             | t      | P> t  | [95% Conf. Interval] |
|---------|-----------|---------------------------------------|--------|-------|----------------------|
| mvalue  | .0949999  | .0091377                              | 10.40  | 0.000 | .0769677 .113032     |
| kstock  | .350161   | .0293747                              | 11.92  | 0.000 | .2921935 .4081286    |
| _cons   | -63.22022 | 5.648271                              | -11.19 | 0.000 | -74.36641 -52.07402  |
| rho_ar  | .67210608 |                                       |        |       |                      |
| sigma_u | 91.507609 |                                       |        |       |                      |
| sigma_e | 40.992469 |                                       |        |       |                      |
| rho_fov | .8328647  | (fraction of variance because of u_i) |        |       |                      |


```

Because there are 10 groups, the panel-by-panel Cochrane–Orcutt method decreases the number of available observations from 200 to 190. The above example used the default dw estimator of  $\rho$ . Using the tscorr estimator of  $\rho$  yields

```
. xtregar invest mvalue kstock, fe rhotype(tscorr)
FE (within) regression with AR(1) disturbances  Number of obs      =      190
Group variable: company                         Number of groups     =       10
R-sq:                                              Obs per group:
         within  = 0.6583                           min    =        19
         between = 0.8024                          avg    =     19.0
         overall = 0.7933                          max    =        19
                                                F(2,178)          =     171.47
corr(u_i, Xb)  = -0.0709                      Prob > F        = 0.0000
```

	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
mvalue	.0978364	.0096786	10.11	0.000	.0787369 .1169359
kstock	.346097	.0242248	14.29	0.000	.2982922 .3939018
_cons	-61.84403	6.621354	-9.34	0.000	-74.91049 -48.77758
rho_ar	.54131231				
sigma_u	90.893572				
sigma_e	41.592151				
rho_fov	.82686297		(fraction of variance because of u_i)		

F test that all  $u_i=0$ : F(9,178) = 19.73

Prob > F = 0.0000



## □ Technical note

The `tscorr` estimator of  $\rho$  is bounded in  $[-1, 1]$ . The other estimators of  $\rho$  are not. In samples with short panels, the estimates of  $\rho$  produced by the other estimators of  $\rho$  may be outside  $[-1, 1]$ . If this happens, use the `tscorr` estimator. However, simulations have shown that the `tscorr` estimator is biased toward zero. `dw` is the default because it performs well in Monte Carlo simulations. In the example above, the estimate of  $\rho$  produced by `tscorr` is much smaller than the one produced by `dw`.



## ▷ Example 2: Using `xtset`

`xtregar` will complain if you try to run `xtregar` on a dataset that has not been `xtset`:

```
. xtset, clear
. xtregar invest mvalue kstock, fe
must specify panelvar and timevar; use xtset
r(459);
```

You must `xtset` your data to ensure that `xtregar` understands the nature of your time variable. Suppose that our observations were taken quarterly instead of annually. We will get the same results with the quarterly variable `t2` that we did with the annual variable `year`.

```
. generate t = year - 1934  
. generate t2 = tq(1934q4) + t  
. format t2 %tq  
. list year t2 in 1/5
```

year	t2
1935	1935q1
1936	1935q2
1937	1935q3
1938	1935q4
1939	1936q1

```

. xtset company t2
    panel variable: company (strongly balanced)
    time variable: t2, 1935q1 to 1939q4
        delta: 1 quarter
. xtregar invest mvalue kstock, fe

FE (within) regression with AR(1) disturbances Number of obs      =      190
Group variable: company                         Number of groups   =       10
R-sq:                                         Obs per group:
    within  = 0.5927                           min =          19
    between = 0.7989                          avg =        19.0
    overall = 0.7904                         max =          19
                                         F(2,178)      =     129.49
corr(u_i, Xb)  = -0.0454                      Prob > F      =     0.0000

```

invest	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]
mvalue	.0949999	.0091377	10.40	0.000	.0769677 .113032
kstock	.350161	.0293747	11.92	0.000	.2921935 .4081286
_cons	-63.22022	5.648271	-11.19	0.000	-74.36641 -52.07402
rho_ar	.67210608				
sigma_u	91.507609				
sigma_e	40.992469				
rho_fov	.8328647 (fraction of variance because of u_i)				

F test that all u\_i=0: F(9,178) = 11.53 Prob > F = 0.0000

◀

In all the examples thus far, we have assumed that  $\epsilon_{it}$  is first-order autoregressive. Testing the hypothesis of  $\rho = 0$  in a first-order autoregressive process produces test statistics with extremely complicated distributions. Bhargava, Franzini, and Narendranathan (1982) extended the Durbin–Watson statistic to the case of balanced, equally spaced panel datasets. Baltagi and Wu (1999) modify their statistic to account for unbalanced panels with unequally spaced data. In the same article, Baltagi and Wu (1999) derive the locally best invariant test statistic of  $\rho = 0$ . Both these test statistics have extremely complicated distributions, although Bhargava, Franzini, and Narendranathan (1982) did publish some critical values in their article. Specifying the `lbi` option to `xtregar` causes Stata to calculate and report the modified Bhargava et al. Durbin–Watson and the Baltagi–Wu LBI.

## ► Example 3: Testing for autocorrelation

In this example, we calculate the modified Bhargava et al. Durbin–Watson statistic and the Baltagi–Wu LBI. We exclude periods 9 and 10 from the sample, thereby reproducing the results of Baltagi

and Wu (1999, 822). *p*-values are not reported for either statistic. Although Bhargava, Franzini, and Narendranathan (1982) published critical values for their statistic, no tables are currently available for the Baltagi–Wu (LBI). Baltagi and Wu (1999) did derive a normalized version of their statistic, but this statistic cannot be computed for datasets of moderate size.

<pre>. xtregar invest mvalue kstock if year !=1934 &amp; year !=1944, fe lbi</pre>										
FE (within) regression with AR(1) disturbances	Number of obs = 180									
Group variable: company	Number of groups = 10									
R-sq:	Obs per group:									
within = 0.5954	min = 18									
between = 0.7952	avg = 18.0									
overall = 0.7889	max = 18									
	F(2,168) = 123.63									
corr(u_i, Xb) = -0.0516	Prob > F = 0.0000									
<hr/>										
invest	Coef.	Std. Err.	t	P> t	[95% Conf. Interval]					
mvalue	.0941122	.0090926	10.35	0.000	.0761617 .1120627					
kstock	.3535872	.0303562	11.65	0.000	.2936584 .4135161					
_cons	-64.82534	5.946885	-10.90	0.000	-76.56559 -53.08509					
<hr/>										
rho_ar	.6697198									
sigma_u	93.320452									
sigma_e	41.580712									
rho_fov	.83435413 (fraction of variance because of u_i)									
<hr/>										
F test that all u_i=0: F(9,168) = 11.55										
modified Bhargava et al. Durbin-Watson = .71380994										
Baltagi-Wu LBI = 1.0134522										

□

## The random-effects model

In the random-effects model, the  $\nu_i$  are assumed to be realizations of an i.i.d. process with mean 0 and variance  $\sigma_\nu^2$ . Furthermore, the  $\nu_i$  are assumed to be independent of both the  $\epsilon_{it}$  and the covariates  $\mathbf{x}_{it}$ . The latter of these assumptions can be strong, but inference is not conditional on the particular realizations of the  $\nu_i$  in the sample. See Mundlak (1978) for a discussion of this point.

### ▷ Example 4: Random-effects model

By specifying the `re` option, we obtain the Baltagi–Wu GLS estimator of the random-effects model. This estimator can accommodate unbalanced panels and unequally spaced data. We run this model on the Grunfeld dataset:

```
. xtregar invest mvalue kstock if year !=1934 & year !=1944, re lbi
RE GLS regression with AR(1) disturbances      Number of obs = 190
Group variable: company                         Number of groups = 10
R-sq:                                         Obs per group:
    within = 0.7707                               min = 19
    between = 0.8039                             avg = 19.0
    overall = 0.7958                            max = 19
                                                Wald chi2(3) = 351.37
corr(u_i, Xb) = 0 (assumed)                    Prob > chi2 = 0.0000
```

	invest	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
mvalue	.0947714	.0083691	11.32	0.000	.0783683	.1111746
kstock	.3223932	.0263226	12.25	0.000	.2708019	.3739845
_cons	-45.21427	27.12492	-1.67	0.096	-98.37814	7.949603
rho_ar	.6697198	(estimated autocorrelation coefficient)				
sigma_u	74.662876					
sigma_e	42.253042					
rho_fov	.75742494	(fraction of variance due to u_i)				
theta	.66973313					

modified Bhargava et al. Durbin-Watson = .71380994  
Baltagi-Wu LBI = 1.0134522

The modified Bhargava et al. Durbin-Watson and the Baltagi-Wu LBI are the same as those reported for the fixed-effects model because the formulas for these statistics do not depend on fitting the fixed-effects model or the random-effects model.



## Stored results

`xtregar, re` stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(df_m)</code>	model degrees of freedom
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(d1)</code>	Bhargava et al. Durbin–Watson
<code>e(LBI)</code>	Baltagi–Wu LBI statistic
<code>e(N_LBI)</code>	number of obs used in <code>e(LBI)</code>
<code>e(Tcon)</code>	1 if $T$ is constant
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of $\eta_{it}$
<code>e(r2_w)</code>	$R^2$ for within model
<code>e(r2_o)</code>	$R^2$ for overall model
<code>e(r2_b)</code>	$R^2$ for between model
<code>e(chi2)</code>	$\chi^2$
<code>e(rho_ar)</code>	autocorrelation coefficient
<code>e(rho_fov)</code>	$u_i$ fraction of variance
<code>e(thta_min)</code>	minimum $\theta$
<code>e(thta_5)</code>	$\theta$ , 5th percentile
<code>e(thta_50)</code>	$\theta$ , 50th percentile
<code>e(thta_95)</code>	$\theta$ , 95th percentile
<code>e(thta_max)</code>	maximum $\theta$
<code>e(Tbar)</code>	harmonic mean of group sizes
<code>e(rank)</code>	rank of <code>e(V)</code>

### Macros

<code>e(cmd)</code>	<code>xtregar</code>
<code>e(cmdline)</code>	command as typed
<code>e(depvar)</code>	name of dependent variable
<code>e(ivars)</code>	variable denoting groups
<code>e(tvars)</code>	variable denoting time within groups
<code>e(model)</code>	<code>re</code>
<code>e(rhotype)</code>	method of estimating $\rho_{ar}$
<code>e(dw)</code>	<code>lbi</code> , if <code>lbi</code> specified
<code>e(chi2type)</code>	<code>Wald</code> ; type of model $\chi^2$ test
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>

### Matrices

<code>e(b)</code>	coefficient vector
<code>e(V)</code>	VCE for random-effects model

### Functions

<code>e(sample)</code>	marks estimation sample
------------------------	-------------------------

**xtregar, fe** stores the following in **e()**:

#### Scalars

<b>e(N)</b>	number of observations
<b>e(N_g)</b>	number of groups
<b>e(df_m)</b>	model degrees of freedom
<b>e(mss)</b>	model sum of squares
<b>e(rss)</b>	residual sum of squares
<b>e(g_min)</b>	smallest group size
<b>e(g_avg)</b>	average group size
<b>e(g_max)</b>	largest group size
<b>e(d1)</b>	Bhargava et al. Durbin-Watson
<b>e(LBI)</b>	Baltagi-Wu LBI statistic
<b>e(N_LBI)</b>	number of obs used in <b>e(LBI)</b>
<b>e(Tcon)</b>	1 if $T$ is constant
<b>e(corr)</b>	$\text{corr}(u_i, \mathbf{X}\mathbf{b})$
<b>e(sigma_u)</b>	panel-level standard deviation
<b>e(sigma_e)</b>	standard deviation of $\epsilon_{it}$
<b>e(r2_a)</b>	adjusted $R$ -squared
<b>e(r2_w)</b>	$R$ -squared for within model
<b>e(r2_o)</b>	$R$ -squared for overall model
<b>e(r2_b)</b>	$R$ -squared for between model
<b>e(l1)</b>	log likelihood
<b>e(l1_0)</b>	log likelihood, constant-only model
<b>e(rho_ar)</b>	autocorrelation coefficient
<b>e(rho_fov)</b>	$u_i$ fraction of variance
<b>e(F)</b>	$F$ statistic
<b>e(F_f)</b>	$F$ for $u_i=0$
<b>e(df_r)</b>	residual degrees of freedom
<b>e(df_a)</b>	degrees of freedom for absorbed effect
<b>e(df_b)</b>	numerator degrees of freedom for $F$ statistic
<b>e(rmse)</b>	root mean squared error
<b>e(Tbar)</b>	harmonic mean of group sizes
<b>e(rank)</b>	rank of <b>e(V)</b>

#### Macros

<b>e(cmd)</b>	<b>xtregar</b>
<b>e(cmdline)</b>	command as typed
<b>e(depyvar)</b>	name of dependent variable
<b>e(ivar)</b>	variable denoting groups
<b>e(tvar)</b>	variable denoting time within groups
<b>e(wtype)</b>	weight type
<b>e(wexp)</b>	weight expression
<b>e(model)</b>	<b>fe</b>
<b>e(rhotype)</b>	method of estimating $\rho_{\text{par}}$
<b>e(dw)</b>	lbi, if lbi specified
<b>e(properties)</b>	<b>b V</b>
<b>e(predict)</b>	program used to implement predict
<b>e(marginsok)</b>	predictions allowed by <b>margins</b>
<b>e(marginsnotok)</b>	predictions disallowed by <b>margins</b>
<b>e(asbalanced)</b>	factor variables <b>fvset</b> as <b>asbalanced</b>
<b>e(asobserved)</b>	factor variables <b>fvset</b> as <b>asobserved</b>

#### Matrices

<b>e(b)</b>	coefficient vector
<b>e(V)</b>	variance-covariance matrix of the estimators

#### Functions

<b>e(sample)</b>	marks estimation sample
------------------	-------------------------

## Methods and formulas

Consider a linear panel-data model described by (1) and (2). The data can be unbalanced and unequally spaced. Specifically, the dataset contains observations on individual  $i$  at times  $t_{ij}$  for  $j = 1, \dots, n_i$ .

Methods and formulas are presented under the following headings:

### *Estimating $\rho$*

*Transforming the data to remove the AR(1) component*

*The within estimator of the fixed-effects model*

*The Baltagi–Wu GLS estimator*

*The test statistics*

## Estimating $\rho$

The estimate of  $\rho$  is always obtained after removing the group means. Let  $\tilde{y}_{it} = y_{it} - \bar{y}_i$ , let  $\tilde{x}_{it} = x_{it} - \bar{x}_i$ , and let  $\tilde{\epsilon}_{it} = \epsilon_{it} - \bar{\epsilon}_i$ .

Then, except for the `onestep` method, all the estimates of  $\rho$  are obtained by running Stata's `prais` on

$$\tilde{y}_{it} = \tilde{x}_{it}\beta + \tilde{\epsilon}_{it}$$

See [TS] `prais` for the formulas for each of the methods.

When `onestep` is specified, a regression is run on the above equation, and the residuals are obtained. Let  $e_{it_{ij}}$  be the residual used to estimate the error  $\tilde{\epsilon}_{it_{ij}}$ . If  $t_{ij} - t_{i,j-1} > 1$ ,  $e_{it_{ij}}$  is set to zero. Given this series of residuals

$$\hat{\rho}_{\text{onestep}} = \frac{n}{m_c} \frac{\sum_{i=1}^N \sum_{t=2}^T e_{it} e_{i,t-1}}{\sum_{i=1}^N \sum_{t=1}^T e_{it}^2}$$

where  $n$  is the number of nonzero elements in  $e$  and  $m_c$  is the number of consecutive pairs of nonzero  $e_{it}$ s.

## Transforming the data to remove the AR(1) component

After estimating  $\rho$ , Baltagi and Wu (1999) derive a transformation of the data that removes the AR(1) component. Their  $C_i(\rho)$  can be written as

$$y_{it_{ij}}^* = \begin{cases} (1 - \rho^2)^{1/2} y_{it_{ij}} & \text{if } t_{ij} = 1 \\ (1 - \rho^2)^{1/2} \left\{ y_{i,t_{ij}} \frac{1}{(1 - \rho^{2(t_{ij} - t_{i,j-1})})^{1/2}} - y_{i,t_{i,j-1}} \frac{\rho^{(t_{ij} - t_{i,j-1})}}{(1 - \rho^{2(t_{i,j} - t_{i,j-1})})^{1/2}} \right\} & \text{if } t_{ij} > 1 \end{cases}$$

Using the analogous transform on the independent variables generates transformed data without the AR(1) component. Performing simple OLS on the transformed data leaves behind the residuals  $\mu^*$ .

## The within estimator of the fixed-effects model

To obtain the within estimator, we must transform the data that come from the AR(1) transform. For the within transform to remove the fixed effects, the first observation of each panel must be dropped. Specifically, let

$$\begin{aligned}\check{y}_{it_{ij}} &= y_{it_{ij}}^* - \bar{y}_i^* + \bar{\bar{y}}^* & \forall j > 1 \\ \check{\mathbf{x}}_{it_{ij}} &= \mathbf{x}_{it_{ij}}^* - \bar{\mathbf{x}}_i^* + \bar{\bar{\mathbf{x}}}^* & \forall j > 1 \\ \check{\epsilon}_{it_{ij}} &= \epsilon_{it_{ij}}^* - \bar{\epsilon}_i^* + \bar{\bar{\epsilon}}^* & \forall j > 1\end{aligned}$$

where

$$\begin{aligned}\bar{y}_i^* &= \frac{\sum_{j=2}^{n_i-1} y_{it_{ij}}^*}{n_i - 1} \\ \bar{\bar{y}}^* &= \frac{\sum_{i=1}^N \sum_{j=2}^{n_i-1} y_{it_{ij}}^*}{\sum_{i=1}^N n_i - 1} \\ \bar{\mathbf{x}}_i^* &= \frac{\sum_{j=2}^{n_i-1} \mathbf{x}_{it_{ij}}^*}{n_i - 1} \\ \bar{\bar{\mathbf{x}}}^* &= \frac{\sum_{i=1}^N \sum_{j=2}^{n_i-1} \mathbf{x}_{it_{ij}}^*}{\sum_{i=1}^N n_i - 1} \\ \bar{\epsilon}_i^* &= \frac{\sum_{j=2}^{n_i-1} \epsilon_{it_{ij}}^*}{n_i - 1} \\ \bar{\bar{\epsilon}}^* &= \frac{\sum_{i=1}^N \sum_{j=2}^{n_i-1} \epsilon_{it_{ij}}^*}{\sum_{i=1}^N n_i - 1}\end{aligned}$$

The within estimator of the fixed-effects model is then obtained by running OLS on

$$\check{y}_{it_{ij}} = \alpha + \check{\mathbf{x}}_{it_{ij}} \boldsymbol{\beta} + \check{\epsilon}_{it_{ij}}$$

Reported as  $R^2$  within is the  $R^2$  from the above regression.

Reported as  $R^2$  between is  $\left\{ \text{corr}(\bar{\mathbf{x}}_i \hat{\boldsymbol{\beta}}, \bar{y}_i) \right\}^2$ .

Reported as  $R^2$  overall is  $\left\{ \text{corr}(\mathbf{x}_{it} \hat{\boldsymbol{\beta}}, y_{it}) \right\}^2$ .

## The Baltagi–Wu GLS estimator

The residuals  $\mu^*$  can be used to estimate the variance components. Translating the matrix formulas given in [Baltagi and Wu \(1999\)](#) into summations yields the following variance-components estimators:

$$\begin{aligned}\hat{\sigma}_\omega^2 &= \sum_{i=1}^N \frac{(\mu_i^{*\prime} g_i)^2}{(g_i' g_i)} \\ \hat{\sigma}_\epsilon^2 &= \frac{\left[ \sum_{i=1}^N (\mu_i^{*\prime} \mu_i^*) - \sum_{i=1}^N \left\{ \frac{(\mu_i^{*\prime} g_i)^2}{(g_i' g_i)} \right\} \right]}{\sum_{i=1}^N (n_i - 1)} \\ \hat{\sigma}_\mu^2 &= \frac{\left[ \sum_{i=1}^N \left\{ \frac{(\mu_i^{*\prime} g_i)^2}{(g_i' g_i)} \right\} - N \hat{\sigma}_\epsilon^2 \right]}{\sum_{i=1}^N (g_i' g_i)}\end{aligned}$$

where

$$g_i = \left[ 1, \frac{\{1 - \rho^{(t_{i,2} - t_{i,1})}\}}{\{1 - \rho^{2(t_{i,2} - t_{i,1})}\}^{\frac{1}{2}}}, \dots, \frac{\{1 - \rho^{(t_{i,n_i} - t_{i,n_i-1})}\}}{\{1 - \rho^{2(t_{i,n_i} - t_{i,n_i-1})}\}^{\frac{1}{2}}} \right]'$$

and  $\mu_i^*$  is the  $n_i \times 1$  vector of residuals from  $\mu^*$  that correspond to person  $i$ .

Then

$$\hat{\theta}_i = 1 - \left( \frac{\hat{\sigma}_\mu}{\hat{\omega}_i} \right)$$

where

$$\hat{\omega}_i^2 = g_i' g_i \hat{\sigma}_\mu^2 + \hat{\sigma}_\epsilon^2$$

With these estimates in hand, we can transform the data via

$$z_{it_{ij}}^{**} = z_{it_{ij}}^* - \hat{\theta}_i g_{ij} \frac{\sum_{s=1}^{n_i} g_{is} z_{it_{is}}^*}{\sum_{s=1}^{n_i} g_{is}^2}$$

for  $z \in \{y, \mathbf{x}\}$ .

Running OLS on the transformed data  $y^{**}, \mathbf{x}^{**}$  yields the feasible GLS estimator of  $\alpha$  and  $\beta$ .

Reported as  $R^2$  between is  $\left\{ \text{corr}(\bar{\mathbf{x}}_i \hat{\beta}, \bar{y}_i) \right\}^2$ .

Reported as  $R^2$  within is  $\left\{ \text{corr}\{(\mathbf{x}_{it} - \bar{\mathbf{x}}_i) \hat{\beta}, y_{it} - \bar{y}_i\} \right\}^2$ .

Reported as  $R^2$  overall is  $\left\{ \text{corr}(\mathbf{x}_{it} \hat{\beta}, y_{it}) \right\}^2$ .

## The test statistics

The Baltagi–Wu LBI is the sum of terms

$$d_* = d_1 + d_2 + d_3 + d_4$$

where

$$\begin{aligned} d_1 &= \frac{\sum_{i=1}^N \sum_{j=1}^{n_i} \{\tilde{z}_{it_{ij}} - \tilde{z}_{it_{i,j-1}} I(t_{ij} - t_{i,j-1} = 1)\}^2}{\sum_{i=1}^N \sum_{j=1}^{n_i} \tilde{z}_{it_{ij}}^2} \\ d_2 &= \frac{\sum_{i=1}^N \sum_{j=1}^{n_i-1} \tilde{z}_{it_{ij}}^2 \{1 - I(t_{i,j+1} - t_{ij} = 1)\}}{\sum_{i=1}^N \sum_{j=1}^{n_i} \tilde{z}_{it_{ij}}^2} \\ d_3 &= \frac{\sum_{i=1}^N \tilde{z}_{it_{i1}}^2}{\sum_{i=1}^N \sum_{j=1}^{n_i} \tilde{z}_{it_{ij}}^2} \\ d_4 &= \frac{\sum_{i=1}^N \tilde{z}_{it_{in_i}}^2}{\sum_{i=1}^N \sum_{j=1}^{n_i} \tilde{z}_{it_{ij}}^2} \end{aligned}$$

$I()$  is the indicator function that takes the value of 1 if the condition is true and 0 otherwise. The  $\tilde{z}_{it_{i,j-1}}$  are residuals from the within estimator.

Baltagi and Wu (1999) also show that  $d_1$  is the Bhargava et al. Durbin–Watson statistic modified to handle cases of unbalanced panels and unequally spaced data.

## Acknowledgment

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## Also see

- [XT] **xtregar postestimation** — Postestimation tools for xtregar
- [XT] **xtgee** — Fit population-averaged panel-data models by using GEE
- [XT] **xtglss** — Fit panel-data models by using GLS
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtset** — Declare data to be panel data
- [TS] **newey** — Regression with Newey–West standard errors
- [TS] **prais** — Prais–Winsten and Cochrane–Orcutt regression
- [U] **20 Estimation and postestimation commands**

## Postestimation commands

The following postestimation commands are available after `xtregar`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
* <code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

\* `estat ic` is not appropriate after `xtregar, re`.

## predict

### Description for predict

predict creates a new variable containing predictions such as linear predictions and predictions.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

```
predict [type] newvar [if] [in] [, statistic]
```

<i>statistic</i>	Description
Main	
<b>xb</b>	$x_{it}\beta$ , linear prediction; the default
<b>ue</b>	$u_i + e_{it}$ , the combined residual
<b>*u</b>	$u_i$ , the fixed- or random-error component
<b>*e</b>	$e_{it}$ , the overall error component

Unstarred statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample. Starred statistics are calculated only for the estimation sample, even when `if e(sample)` is not specified.

### Options for predict

---

Main	Other
------	-------

---

**xb**, the default, calculates the linear prediction,  $x_{it}\beta$ .

**ue** calculates the prediction of  $u_i + e_{it}$ .

**u** calculates the prediction of  $u_i$ , the estimated fixed or random effect.

**e** calculates the prediction of  $e_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]  
margins [marginlist] , predict(statistic ...) [options]
```

---

*statistic*

Description

<code>xb</code>	$x_{it}b$ , linear prediction; the default
<code>ue</code>	not allowed with <code>margins</code>
<code>u</code>	not allowed with <code>margins</code>
<code>e</code>	not allowed with <code>margins</code>

---

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [R] **margins**.

### Also see

[XT] **xtregar** — Fixed- and random-effects linear models with an AR(1) disturbance

[U] **20 Estimation and postestimation commands**

**xtset** — Declare data to be panel data[Description](#)  
[Options](#)[Quick start](#)  
[Remarks and examples](#)[Menu](#)  
[Stored results](#)[Syntax](#)  
[Also see](#)

## Description

**xtset** manages the panel settings of a dataset. You must **xtset** your data before you can use the other **xt** commands. **xtset panelvar** declares the data in memory to be a panel in which the order of observations is irrelevant. **xtset panelvar timevar** declares the data to be a panel in which the order of observations is relevant. When you specify *timevar*, you can then use [Stata's time-series operators](#) and analyze your data with the **ts** commands without having to **tsset** your data.

**xtset** without arguments displays how the data are currently **xtset**. If the data are set with a *panelvar* and a *timevar*, **xtset** also sorts the data by *panelvar timevar* if a *timevar* was specified. If the data are set with a *panelvar* only, the sort order is not changed.

**xtset, clear** is a rarely used programmer's command to declare that the data are no longer to be considered a panel.

## Quick start

Declare dataset to be panel data with panel identifier *pvar*

```
xtset pvar
```

Indicate that observations are ordered by year, stored in *tvar1*

```
xtset pvar tvar1
```

As above, but indicate that observations are instead made every 2 years

```
xtset pvar tvar1, delta(2)
```

Indicate that observations are made monthly; *tvar2* is not formatted

```
xtset pvar tvar2, monthly
```

As above, and apply **%tm** format to *tvar2*

```
xtset pvar tvar2, format(%tm)
```

## Menu

Statistics > Longitudinal/panel data > Setup and utilities > Declare dataset to be panel data

## Syntax

Declare data to be panel

```
xtset panelvar  
xtset panelvar timevar [ , tsoptions ]
```

Display how data are currently xtset

```
xtset
```

Clear xt settings

```
xtset, clear
```

In the declare syntax, *panelvar* identifies the panels and the optional *timevar* identifies the times within panels. *tsoptions* concern *timevar*.

<i>tsoptions</i>	Description
<i>unitoptions</i>	specify units of <i>timevar</i>
<i>deltaoption</i>	specify length of period of <i>timevar</i>
<i>noquery</i>	suppress summary calculations and output

*noquery* is not shown in the dialog box.

<i>unitoptions</i>	Description
( <i>default</i> )	<i>timevar</i> 's units from <i>timevar</i> 's display format
<i>clocktime</i>	<i>timevar</i> is %tc: 0 = 1jan1960 00:00:00.000, 1 = 1jan1960 00:00:00.001, ...
<i>daily</i>	<i>timevar</i> is %td: 0 = 1jan1960, 1 = 2jan1960, ...
<i>weekly</i>	<i>timevar</i> is %tw: 0 = 1960w1, 1 = 1960w2, ...
<i>monthly</i>	<i>timevar</i> is %tm: 0 = 1960m1, 1 = 1960m2, ...
<i>quarterly</i>	<i>timevar</i> is %tq: 0 = 1960q1, 1 = 1960q2, ...
<i>halfyearly</i>	<i>timevar</i> is %th: 0 = 1960h1, 1 = 1960h2, ...
<i>yearly</i>	<i>timevar</i> is %ty: 1960 = 1960, 1961 = 1961, ...
<i>generic</i>	<i>timevar</i> is %tg: 0 = ?, 1 = ?, ...
<i>format</i> (%fmt)	specify <i>timevar</i> 's format and then apply default rule

In all cases, negative *timevar* values are allowed.

*deltaoption* specifies the period between observations in *timevar* units and may be specified as

<i>deltaoption</i>	Example
<code>delta(#)</code>	<code>delta(1)</code> or <code>delta(2)</code>
<code>delta((exp))</code>	<code>delta((7*24))</code>
<code>delta(# units)</code>	<code>delta(7 days)</code> or <code>delta(15 minutes)</code> or <code>delta(7 days 15 minutes)</code>
<code>delta((exp) units)</code>	<code>delta((2+3) weeks)</code>

Allowed units for `%tc` and `%tC` *timevars* are

seconds	second	secs	sec
minutes	minute	mins	min
hours	hour		
days	day		
weeks	week		

and for all other `%t` *timevars* are

days	day
weeks	week

## Options

*unitoptions* `clocktime`, `daily`, `weekly`, `monthly`, `quarterly`, `halfyearly`, `yearly`, `generic`, and `format(%fmt)` specify the units in which *timevar* is recorded.

*timevar* will usually be a variable that counts 1, 2, ..., and is to be interpreted as first year of survey, second year, ..., or first month of treatment, second month, .... In these cases, you do not need to specify a *unitoption*.

In other cases, *timevar* will be a year variable or the like such as 2001, 2002, ..., and is to be interpreted as year of survey or the like. In those cases, you do not need to specify a *unitoption*.

In other, more complicated cases, *timevar* will be a full-blown `%t` variable; see [D] **Datetime**. If *timevar* already has a `%t` display format assigned to it, you do not need to specify a *unitoption*; `xtset` will obtain the units from the format. If you have not yet bothered to assign the appropriate `%t` format to the `%t` variable, however, you can use the *unitoptions* to tell `xtset` the units. Then `xtset` will set *timevar*'s display format for you. Thus, the *unitoptions* are convenience options; they allow you to skip formatting the time variable. The following all have the same net result:

Alternative 1	Alternative 2	Alternative 3
<code>format t %td</code>	<i>(t not formatted)</i>	<i>(t not formatted)</i>
<code>xtset pid t</code>	<code>xtset pid t, daily</code>	<code>xtset pid t, format(%td)</code>

*timevar* is not required to be a `%t` variable; it can be any variable of your own concocting so long as it takes on only integer values. When you `xtset` a time variable that is not `%t`, the display format does not change unless you specify the *unitoption generic* or use the `format()` option.

`delta()` specifies the period between observations in *timevar* and is commonly used when *timevar* is `%tc`. `delta()` is only sometimes used with the other `%t` formats or with generic time variables.

If `delta()` is not specified, `delta(1)` is assumed. This means that at *timevar* = 5, the previous time is *timevar* = 5 - 1 = 4 and the next time would be *timevar* = 5 + 1 = 6. Lag and lead operators, for instance, would work this way. This would be assumed regardless of the units of *timevar*.

If you specified `delta(2)`, then at `timevar = 5`, the previous time would be `timevar = 5 - 2 = 3` and the next time would be `timevar = 5 + 2 = 7`. Lag and lead operators would work this way. In the observation with `timevar = 5`, `L.income` would be the value of `income` in the observation for which `timevar = 3` and `F.income` would be the value of `income` in the observation for which `timevar = 7`. If you then add an observation with `timevar = 4`, the operators will still work appropriately; that is, at `timevar = 5`, `L.income` will still have the value of `income` at `timevar = 3`.

There are two aspects of `timevar`: its units and its length of period. The `unitoptions` set the units. `delta()` sets the length of period. You are not required to specify one to specify the other. You might have a generic `timevar` but it counts in 12: 0, 12, 24, .... You would skip specifying `unitoptions` but would specify `delta(12)`.

We mentioned that `delta()` is commonly used with `%tc timevars` because Stata's `%tc` variables have units of milliseconds. If `delta()` is not specified and in some model you refer to `L.bp`, you will be referring to the value of `bp` 1 ms ago. Few people have data with periodicity of a millisecond. Perhaps your data are hourly. You could specify `delta(3600000)`. Or you could specify `delta((60*60*1000))`, because `delta()` will allow expressions if you include an extra pair of parentheses. Or you could specify `delta(1 hour)`. They all mean the same thing: `timevar` has periodicity of 3,600,000 ms. In an observation for which `timevar = 1,489,572,000,000` (corresponding to 15mar2007 10:00:00), `L.bp` would be the observation for which `timevar = 1,489,572,000,000 - 3,600,000 = 1,489,568,400,000` (corresponding to 15mar2007 9:00:00).

When you `xtset` the data and specify `delta()`, `xtset` verifies that all the observations follow the specified periodicity. For instance, if you specified `delta(2)`, then `timevar` could contain any subset of `{..., -4, -2, 0, 2, 4, ...}` or it could contain any subset of `{..., -3, -1, 1, 3, ...}`. If `timevar` contained a mix of values, `xtset` would issue an error message. The check is made on each panel independently, so one panel might contain `timevar` values from one set and the next, another, and that would be fine.

`clear`—used in `xtset`, `clear`—makes Stata forget that the data ever were `xtset`. This is a rarely used programmer's option.

The following option is available with `xtset` but is not shown in the dialog box:

`noquery` prevents `xtset` from performing most of its summary calculations and suppresses output.

With this option, only the following results are posted:

<code>r(tdelt)</code>	<code>r(tsfmt)</code>
<code>r(panelvar)</code>	<code>r(unit)</code>
<code>r(timevar)</code>	<code>r(unit1)</code>

## Remarks and examples

`xtset` declares the dataset in memory to be panel data. You need to do this before you can use the other `xt` commands. The storage types of both `panelvar` and `timevar` must be numeric, and both variables must contain integers only.

There are two syntaxes for setting the data:

```
xtset panelvar
xtset panelvar timevar
```

In the first syntax—`xtset panelvar`—the data are set to be a panel and the order of the observations within panel is considered to be irrelevant. For instance, `panelvar` might be country and the observations within might be city.

In the second syntax—`xtset panelvar timevar`—the data are to be a panel and the order of observations within panel are considered ordered by *timevar*. For instance, in data collected from repeated surveying of the same people over various years, *panelvar* might be person and *timevar*, year. When you specify *timevar*, you may then use Stata's time-series operators such as L. and F. (lag and lead) in other commands. The operators will be interpreted as lagged and lead values within panel.

The storage types of both *panelvar* and *timevar* must be numeric, and both variables must contain integers only.

## □ Technical note

In previous versions of Stata there was no `xtset` command. The other `xt` commands instead had the `i(panelvar)` and `t(timevar)` options. Older commands still have those options, but they are no longer documented and, if you specify them, they just perform the `xtset` for you. Thus, do-files that you previously wrote will continue to work. Modern usage, however, is to `xtset` the data first.



## □ Technical note

`xtset` is related to the `tsset` command, which declares data to be time series. One of the syntaxes of `tsset` is `tsset panelvar timevar`, which is identical to one of `xtset`'s syntaxes, namely, `xtset panelvar timevar`. Here they are in fact the same command, meaning that `xtsetting` your data is sufficient to allow you to use the `ts` commands and `tssetting` your data is sufficient to allow you to use the `xt` commands. You do not need to set both, but it will not matter if you do.

`xtset` and `tsset` are different, however, when you set just a *panelvar*—you type `xtset panelvar`—or when you set just a *timevar*—you type `tsset timevar`.



If you `save` your data after `xtset`, the data will be remembered to be a panel and you will not have to `xtset` again.

## ▷ Example 1: Panel data without a time variable

Many panel datasets contain a variable identifying panels but do not contain a time variable. For example, you may have a dataset where each panel is a family, and the observations within panel are family members, or you may have a dataset in which each person made a decision multiple times but the ordering of those decisions is unimportant and perhaps unknown. In this latter case, if the time of the decision were known, we would advise you to `xtset` it. The other `xt` statistical commands do not do something different because *timevar* has been set—they will ignore *timevar* if *timevar* is irrelevant to the statistical method that you are using. You should always set everything that is true about the data.

In any case, let's consider the case where there is no *timevar*. We have data on U.S. states and cities within states:

```
. list state city in 1/10, sepby(state)
```

	state	city
1.	Alabama	Birmingham
2.	Alabama	Mobile
3.	Alabama	Montgomery
4.	Alabama	Huntsville
5.	Alaska	Anchorage
6.	Alaska	Fairbanks
7.	Arizona	Phoenix
8.	Arizona	Tucson
9.	Arkansas	Fayetteville
10.	Arkansas	Fort Smith

Here we do not type **xtset state city** because *city* is not a time variable. Instead, we type **xtset state**:

```
. xtset state
string variables not allowed in varlist;
state is a string variable
r(109);
```

You cannot **xtset** a string variable. We must make a numeric variable from our string variable and **xtset** that. One alternative is

```
. egen statenum = group(state)
. list state statenum in 1/10, sepby(state)
```

	state	statenum
1.	Alabama	1
2.	Alabama	1
3.	Alabama	1
4.	Alabama	1
5.	Alaska	2
6.	Alaska	2
7.	Arizona	3
8.	Arizona	3
9.	Arkansas	4
10.	Arkansas	4

```
. xtset statenum
panel variable: statenum (unbalanced)
```

Perhaps a better alternative is

```
. encode state, gen(st)
. list state st in 1/10, sepby(state)
```

	state	st
1.	Alabama	Alabama
2.	Alabama	Alabama
3.	Alabama	Alabama
4.	Alabama	Alabama
5.	Alaska	Alaska
6.	Alaska	Alaska
7.	Arizona	Arizona
8.	Arizona	Arizona
9.	Arkansas	Arkansas
10.	Arkansas	Arkansas

`encode` (see [D] `encode`) produces a numeric variable with a value label, so when we list the result, new variable `st` looks just like our original. It is, however, numeric:

```
. list state st in 1/10, nolabel sepby(state)
```

	state	st
1.	Alabama	1
2.	Alabama	1
3.	Alabama	1
4.	Alabama	1
5.	Alaska	2
6.	Alaska	2
7.	Arizona	3
8.	Arizona	3
9.	Arkansas	4
10.	Arkansas	4

We can `xtset` new variable `st`:

```
. xtset st
panel variable: st (unbalanced)
```



► Example 2: Panel data with a time variable

Some panel datasets do contain a time variable. Dataset **abdata.dta** contains labor demand data from a panel of firms in the United Kingdom. Here are wage data for the first two firms in the dataset:

```
. use https://www.stata-press.com/data/r16/abdata, clear  
. list id year wage if id==1 | id==2, sepby(id)
```

	id	year	wage
1.	1	1977	13.1516
2.	1	1978	12.3018
3.	1	1979	12.8395
4.	1	1980	13.8039
5.	1	1981	14.2897
6.	1	1982	14.8681
7.	1	1983	13.7784
8.	2	1977	14.7909
9.	2	1978	14.1036
10.	2	1979	14.9534
11.	2	1980	15.491
12.	2	1981	16.1969
13.	2	1982	16.1314
14.	2	1983	16.3051

To declare this dataset as a panel dataset, you type

```
. xtset id year, yearly  
panel variable: id (unbalanced)  
time variable: year, 1976 to 1984  
delta: 1 year
```

The output from **list** shows that the last observations for these two firms are for 1983, but **xtset** shows that for some firms data are available for 1984 as well. If one or more panels contain data for nonconsecutive periods, **xtset** will report that gaps exist in the time variable. For example, if we did not have data for firm 1 for 1980 but did have data for 1979 and 1981, **xtset** would indicate that our data have a gap.

For yearly data, we could omit the **yearly** option and just type **xtset id year** because years are stored and listed just like regular integers.

Having declared our data to be a panel dataset, we can use time-series operators to obtain lags:

```
. list id year wage L.wage if id==1 | id==2, sepby(id)
```

		L.		
	id	year	wage	wage
1.	1	1977	13.1516	.
2.	1	1978	12.3018	13.1516
3.	1	1979	12.8395	12.3018
4.	1	1980	13.8039	12.8395
5.	1	1981	14.2897	13.8039
6.	1	1982	14.8681	14.2897
7.	1	1983	13.7784	14.8681
8.	2	1977	14.7909	.
9.	2	1978	14.1036	14.7909
10.	2	1979	14.9534	14.1036
11.	2	1980	15.491	14.9534
12.	2	1981	16.1969	15.491
13.	2	1982	16.1314	16.1969
14.	2	1983	16.3051	16.1314

L.wage is missing for 1977 in both panels because we have no wage data for 1976. In observation 8, the lag operator did not incorrectly reach back into the previous panel.



## □ Technical note

The terms *balanced* and *unbalanced* are often used to describe whether a panel dataset is missing some observations. If a dataset does not contain a time variable, then panels are considered *balanced* if each panel contains the same number of observations; otherwise, the panels are *unbalanced*.

When the dataset contains a time variable, panels are said to be *strongly balanced* if each panel contains the same time points, *weakly balanced* if each panel contains the same number of observations but not the same time points, and *unbalanced* otherwise.



## ▷ Example 3: Applying time-series formats to the time variable

If our data are observed more than once per year, applying time-series formats to the time variable can improve readability.

We have a dataset consisting of individuals who joined a gym's weight-loss program that began in January 2005 and ended in December 2005. Each participant's weight was recorded once per month. Some participants did not show up for all the monthly weigh-ins, so we do not have all 12 months' records for each person. The first two people's data are

```
. use https://www.stata-press.com/data/r16/gymdata
. list id month wt if id==1 | id==2, sepby(id)
```

	id	month	wt
1.	1	1	145
2.	1	2	144
(output omitted)			
11.	1	11	124
12.	1	12	120
(output omitted)			
13.	2	1	144
14.	2	2	143
(output omitted)			
23.	2	11	122
24.	2	12	118

To set these data, we can type

```
. xtset id month
panel variable: id (unbalanced)
time variable: month, 1 to 12, but with gaps
delta: 1 unit
```

The note “but with gaps” above is no cause for concern. It merely warns us that, within some panels, some time values are missing. We already knew that about our data—some participants did not show up for the monthly weigh-ins.

The rest of this example concerns making output more readable. Month numbers such as 1, 2, ..., 12 are perfectly readable here. In another dataset, where month numbers went to, say 127, they would not be so readable. In such cases, we can make a more readable date—2005m1, 2005m2, ...—by using Stata’s %t variables. For a discussion, see [D] **Datetime**. We will go quickly here. One of the %t formats is %tm—monthly—and it says that 1 means 1960m1. Thus, we need to recode our month variable so that, rather than taking on values from 1 to 12, it takes on values from 540 to 551. Then we can put a %tm format on that variable. Working out 540–551 is subject to mistakes. Stata function tm(2005m1) tells us the %tm month corresponding to January of 2005, so we can type

```
. generate month2 = month + m(2005m1) - 1
. format month2 %tm
```

New variable month2 will work just as well as the original month in an **xtset**, and even a little better, because output will be a little more readable:

```
. xtset id month2
panel variable: id (unbalanced)
time variable: month2, 2005m1 to 2005m12, but with gaps
delta: 1 month
```

By the way, we could have omitted typing **format month2 %tm** and then, rather than typing **xtset id month2**, we would have typed **xtset id month2, monthly**. The **monthly** option specifies that the time variable is %tm. When we did not specify the option, **xtset** determined that it was monthly from the display format we had set.



## ► Example 4: Clock times

We have data from a large hotel in Las Vegas that changes the reservation prices for its rooms hourly. A piece of the data looks like

```
. list in 1/5
```

	roomtype	time	price
1.	1	02.13.2007 08:00	140
2.	1	02.13.2007 09:00	155
3.	1	02.13.2007 10:00	160
4.	1	02.13.2007 11:00	155
5.	1	02.13.2007 12:00	160

The panel variable is `roomtype` and, although you cannot see it from the output above, it takes on 1, 2, ..., 20. Variable `time` is a string variable. The first step in making this dataset `xt` is to translate the string to a numeric variable:

```
. generate double t = clock(time, "MDY hm")
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	1.487e+12
2.	1	02.13.2007 09:00	155	1.487e+12
3.	1	02.13.2007 10:00	160	1.487e+12
4.	1	02.13.2007 11:00	155	1.487e+12
5.	1	02.13.2007 12:00	160	1.487e+12

See [D] Datetime translation for an explanation of what is going on here. `clock()` is the function that converts strings to datetime (%tc) values. We typed `clock(time, "MDY hm")` to convert string variable `time`, and we told `clock()` that the values in `time` were in the order month, day, year, hour, and minute. We stored new variable `t` as a `double` because time values are large and that is required to prevent rounding. Even so, the resulting values `1.487e+12` look rounded, but that is only because of the default display format for new variables. We can see the values better if we change the format:

```
. format t %20.0gc
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	1,486,972,800,000
2.	1	02.13.2007 09:00	155	1,486,976,400,000
3.	1	02.13.2007 10:00	160	1,486,980,000,000
4.	1	02.13.2007 11:00	155	1,486,983,600,000
5.	1	02.13.2007 12:00	160	1,486,987,200,000

Even better would be to change the format to %tc—Stata's clock-time format:

```
. format t %tc
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	13feb2007 08:00:00
2.	1	02.13.2007 09:00	155	13feb2007 09:00:00
3.	1	02.13.2007 10:00	160	13feb2007 10:00:00
4.	1	02.13.2007 11:00	155	13feb2007 11:00:00
5.	1	02.13.2007 12:00	160	13feb2007 12:00:00

We could drop variable `time`. New variable `t` contains the same information as `time` and `t` is better because it is a Stata time variable, the most important property of which being that it is numeric rather than string. We can `xtset` it. Here, however, we also need to specify the length of the periods with `xtset`'s `delta()` option. Stata's time variables are numeric, but they record milliseconds since 01jan1960 00:00:00. By default, `xtset` uses `delta(1)`, and that means the time-series operators would not work as we want them to work. For instance, `L.price` would look back only 1 ms (and find nothing). We want `L.price` to look back 1 hour (3,600,000 ms):

```
. xtset roomtype t, delta(1 hour)
panel variable: roomtype (strongly balanced)
time variable: t, 13feb2007 08:00:00 to 31mar2007 18:00:00
                 but with gaps
delta: 1 hour
. list t price L.price in 1/5
```

		L.	
	t	price	price
1.	13feb2007 08:00:00	140	.
2.	13feb2007 09:00:00	155	140
3.	13feb2007 10:00:00	160	155
4.	13feb2007 11:00:00	155	160
5.	13feb2007 12:00:00	160	155



## ► Example 5: Clock times must be double

In the previous example, it was of vital importance that when we generated the %tc variable `t`,

```
. generate double t = clock(time, "MDY hm")
```

we generated it as a `double`. Let's see what would have happened had we forgotten and just typed `generate t = clock(time, "MDY hm")`. Let's go back and start with the same original data:

```
. list in 1/5
```

	roomtype	time	price
1.	1	02.13.2007 08:00	140
2.	1	02.13.2007 09:00	155
3.	1	02.13.2007 10:00	160
4.	1	02.13.2007 11:00	155
5.	1	02.13.2007 12:00	160

Remember, variable `time` is a string variable, and we need to translate it to numeric. So we translate, but this time we forgot to make the new variable a `double`:

```
. generate t = clock(time, "MDY hm")
```

```
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	1.49e+12
2.	1	02.13.2007 09:00	155	1.49e+12
3.	1	02.13.2007 10:00	160	1.49e+12
4.	1	02.13.2007 11:00	155	1.49e+12
5.	1	02.13.2007 12:00	160	1.49e+12

We see the first difference—`t` now lists as `1.49e+12` rather than `1.487e+12` as it did previously—but this is nothing that would catch our attention. We would not even know that the value is different. Let's continue.

We next put a `%20.0gc` format on `t` to better see the numerical values. In fact, that is not something we would usually do in an analysis. We did that in the example to emphasize to you that the `t` values were really big numbers. We will repeat the exercise just to be complete, but in real analysis, we would not bother.

```
. format t %20.0gc
```

```
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	1,486,972,780,544
2.	1	02.13.2007 09:00	155	1,486,976,450,560
3.	1	02.13.2007 10:00	160	1,486,979,989,504
4.	1	02.13.2007 11:00	155	1,486,983,659,520
5.	1	02.13.2007 12:00	160	1,486,987,198,464

Okay, we see big numbers in `t`. Let's continue.

Next we put a %tc format on t, and that is something we would usually do, and you should always do. You should also list a bit of the data, as we did:

```
. format t %tc
. list in 1/5
```

	roomtype	time	price	t
1.	1	02.13.2007 08:00	140	13feb2007 07:59:40
2.	1	02.13.2007 09:00	155	13feb2007 09:00:50
3.	1	02.13.2007 10:00	160	13feb2007 09:59:49
4.	1	02.13.2007 11:00	155	13feb2007 11:00:59
5.	1	02.13.2007 12:00	160	13feb2007 11:59:58

By now, you should see a problem: the translated datetime values are off by a second or two. That was caused by rounding. Dates and times should be the same, not approximately the same, and when you see a difference like this, you should say to yourself, “The translation is off a little. Why is that?” and then you should think, “Of course, rounding. I bet that I did not create t as a double.”

Let’s assume, however, that you do not do this. You instead plow ahead:

```
. xtset roomtype t, delta(1 hour)
time values with period less than delta() found
r(451);
```

And that is what will happen when you forget to create t as a double. The rounding will cause uneven period, and xtset will complain.

By the way, it is important only that clock times (%tc and %tC variables) be stored as doubles. The other date values %td, %tw, %tm, %tq, %th, and %ty are small enough that they can safely be stored as floats, although forgetting and storing them as doubles does no harm.



## □ Technical note

Stata provides two clock-time formats, %tc and %tC. %tC provides a clock with leap seconds. Leap seconds are occasionally inserted to account for randomness of the earth’s rotation, which gradually slows. Unlike the extra day inserted in leap years, the timing of when leap seconds will be inserted cannot be foretold. The authorities in charge of such matters announce a leap second approximately 6 months before insertion. Leap seconds are inserted at the end of the day, and the leap second is called 23:59:60 (that is, 11:59:60 p.m.), which is then followed by the usual 00:00:00 (12:00:00 a.m.). Most nonastronomers find these leap seconds vexing. The added seconds cause problems because of their lack of predictability—knowing how many seconds there will be between 01jan2012 and 01jan2013 is not possible—and because there are not necessarily 24 hours in a day. If you use a leap second-adjusted clock, most days have 24 hours, but a few have 24 hours and 1 second. You must look at a table to find out.

From a time-series analysis point of view, the nonconstant day causes the most problems. Let’s say that you have data on blood pressure for a set of patients, taken hourly at 1:00, 2:00, . . . , and that you have xtset your data with delta(1 hour). On most days, L24.bp would be blood pressure at the same time yesterday. If the previous day had a leap second, however, and your data were recorded using a leap second-adjusted clock, there would be no observation L24.bp because 86,400 seconds before the current reading does not correspond to an on-the-hour time; 86,401 seconds before the current reading corresponds to yesterday’s time. Thus, whenever possible, using Stata’s %tc encoding rather than %tC is better.

When times are recorded by computers using leap second-adjusted clocks, however, avoiding %tC is not possible. For performing most time-series analysis, the recommended procedure is to map the %tC values to %tc and then xtset those. You must ask yourself whether the process you are studying is based on the clock—the nurse does something at 2 o'clock every day—or the true passage of time—the emitter spits out an electron every 86,400,000 ms.

When dealing with computer-recorded times, first find out whether the computer (and its time-recording software) use a leap second-adjusted clock. If it does, translate that to a %tC value. Then use function cofC() to convert to a %tc value and xtset that. If variable T contains the %tC value,

```
. generate double t = cofC(T)
. format t %tc
. xtset panelvar t, delta(...)
```

Function cofC() moves leap seconds forward: 23:59:60 becomes 00:00:00 of the next day. □

## Stored results

xtset stores the following in r():

### Scalars

r(imin)	minimum panel ID
r(imax)	maximum panel ID
r(tmin)	minimum time
r(tmax)	maximum time
r(tdelta)	delta
r(gaps)	1 if there are gaps, 0 otherwise

### Macros

r(panelvar)	name of panel variable
r(timevar)	name of time variable
r(tdeltas)	formatted delta
r(tmns)	formatted minimum time
r(tmxs)	formatted maximum time
r(tsfmt)	%fmt of time variable
r(unit)	units of time variable: Clock, clock, daily, weekly, monthly, quarterly, halfyearly, yearly, or generic
r(unit1)	units of time variable: C, c, d, w, m, q, h, y, or "
r(balanced)	unbalanced, weakly balanced, or strongly balanced; panels are strongly balanced if they all have the same time values, weakly balanced if same number of observations but different time values, otherwise unbalanced

## Also see

[XT] **xtdescribe** — Describe pattern of xt data

[XT] **xtsum** — Summarize xt data

[TS] **tset** — Declare data to be time-series data

[TS] **tsfill** — Fill in gaps in time variable

**xtstreg** — Random-effects parametric survival models

Description  
Options  
References

Quick start  
Remarks and examples  
Also see

Menu  
Stored results

Syntax  
Methods and formulas

## Description

**xtstreg** fits random-effects parametric survival-time models. The conditional distribution of the response given the random effects is assumed to be an exponential, a Weibull, a lognormal, a loglogistic, or a gamma distribution. **xtstreg** can be used with single- or multiple-record st data.

## Quick start

Declare pvar as the panel variable using **xtset**, and declare data to be survival-time data using **stset**

```
xtset pvar  
stset tvar, failure(fail)
```

Random-effects Weibull survival model with covariates x1 and x2

```
xtstreg x1 x2, distribution(weibull)
```

Use accelerated failure-time metric instead of proportional-hazards metric

```
xtstreg x1 x2, distribution(weibull) time
```

As above, but with panel-level probability weights wvar

```
xtstreg x1 x2 [pw=wvar], distribution(weibull) time
```

Random-effects model with cluster-robust standard errors for panels nested within cvar

```
xtstreg x1 x2, distribution(weibull) vce(cluster cvar)
```

## Menu

Statistics > Longitudinal/panel data > Survival models > Parametric survival models (RE)

## Syntax

`xtstreg [indepvars] [if] [in] [weight], distribution(distname) [options]`

<i>options</i>	Description
<hr/>	
Model	
<u>noconstant</u>	suppress constant term
* <u>distribution</u> ( <i>distname</i> )	specify survival distribution
<u>time</u>	use accelerated failure-time metric
<u>offset</u> ( <i>varname</i> )	include <i>varname</i> in model with coefficient constrained to 1
<u>constraints</u> ( <i>constraints</i> )	apply specified linear constraints
SE/Robust	
<u>vce</u> ( <i>vcetype</i> )	<i>vcetype</i> may be <u>oim</u> , <u>robust</u> , <u>cluster</u> <i>clustvar</i> , <u>bootstrap</u> , or <u>jackknife</u>
Reporting	
<u>level</u> (#)	set confidence level; default is <u>level</u> (95)
<u>nohr</u>	do not report hazard ratios
<u>noshow</u>	do not show st setting information
<u>lrmodel</u>	perform the likelihood-ratio model test instead of the default Wald test
<u>nocnsreport</u>	do not display constraints
<u>tratio</u>	report time ratios
<u>display_options</u>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
Integration	
<u>intmethod</u> ( <i>intmethod</i> )	integration method; <i>intmethod</i> may be <u>mvaghermite</u> (the default) or <u>ghermite</u>
<u>intpoints</u> (#)	use # quadrature points; default is <u>intpoints</u> (12)
Maximization	
<u>maximize_options</u>	control the maximization process; seldom used
<u>startgrid</u> ( <i>numlist</i> )	improve starting value of the random-intercept parameter by performing a grid search
<u>nodisplay</u>	suppress display of header and coefficients
<u>collinear</u>	keep collinear variables
<u>coeflegend</u>	display legend instead of statistics

\* distribution(*distname*) is required.

<i>distname</i>	Description
<code>exponential</code>	exponential survival distribution
<code>loglogistic</code>	loglogistic survival distribution
<code>llogistic</code>	synonym for <code>loglogistic</code>
<code>weibull</code>	Weibull survival distribution
<code>lognormal</code>	lognormal survival distribution
<code>lnormal</code>	synonym for <code>lognormal</code>
<code>gamma</code>	gamma survival distribution

---

You must `stset` your data before using `xtstreg`; see [ST] `stset`.

A panel variable must be specified. Use `xtset`; see [XT] `xtset`.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

*varlist* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by`, `fp`, and `statsby` are allowed; see [U] 11.1.10 Prefix commands.

`fweights`, `iweights`, and `pweights` are allowed; see [U] 11.1.6 weight. Weights must be constant within panel.

`startgrid()`, `nodisplay`, `collinear`, and `coflegend` do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

`noconstant`; see [R] Estimation options.

`distribution(distname)` specifies the survival model to be fit. *distname* is one of the following: `exponential`, `loglogistic`, `llogistic`, `weibull`, `lognormal`, `lnormal`, or `gamma`. This option is required.

`time` specifies that the model be fit in the accelerated failure-time metric rather than in the log relative-hazard metric. This option is valid only for the exponential and Weibull models because these are the only models that have both a proportional-hazards and an accelerated failure-time parameterization. Regardless of metric, the likelihood function is the same, and models are equally appropriate in either metric; it is just a matter of changing interpretation.

`time` must be specified at estimation.

`offset(varname)` specifies that *varname* be included in the fixed-effects portion of the model with the coefficient constrained to be 1.

`constraints(constraints)`; see [R] Estimation options.

### SE/Robust

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`), that are robust to some kinds of misspecification (`robust`), that allow for intragroup correlation (`cluster clustvar`), and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] vce\_options.

Specifying `vce(robust)` is equivalent to specifying `vce(cluster panelvar)`; see *xtstreg and the robust VCE estimator* in Methods and formulas.

## Reporting

`level(#)`; see [R] Estimation options.

`nohr`, which may be specified at estimation or upon redisplaying results, specifies that coefficients rather than exponentiated coefficients be displayed, that is, that coefficients rather than hazard ratios be displayed. This option affects only how coefficients are displayed, not how they are estimated.

This option is valid only for the exponential and Weibull models because they have a natural proportional-hazards parameterization. These two models, by default, report hazards ratios (exponentiated coefficients).

`noshow` prevents `xtstreg` from showing the key `st` variables. This option is rarely used because most users type `stset`, `show` or `stset`, `noshow` to set once and for all whether they want to see these variables mentioned at the top of the output of every `st` command; see [ST] `stset`.

`lrmodel`, `nocnsreport`; see [R] Estimation options.

`tratio` specifies that exponentiated coefficients, which are interpreted as time ratios, be displayed. `tratio` is appropriate only for the loglogistic, lognormal, and gamma models or for the exponential and Weibull models when fit in the accelerated failure-time metric.

`tratio` may be specified at estimation or upon replay.

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fwrap(#)`, `fvwrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] Estimation options.

## Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] Estimation options.

## Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `rtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] Maximize. These options are seldom used.

The following options are available with `xtstreg` but are not shown in the dialog box:

`startgrid(numlist)` performs a grid search to improve the starting value of the random-intercept parameter. No grid search is performed by default unless the starting value is found to be not feasible, in which case `xtstreg` runs `startgrid(0.1 1 10)` and chooses the value that works best. You may already be using a default form of `startgrid()` without knowing it. If you see `xtstreg` displaying Grid node 1, Grid node 2, ... following Grid node 0 in the iteration log, that is `xtstreg` doing a default search because the original starting value was not feasible.

`nodisplay` is for programmers. It suppresses the display of the header and the coefficients.

`collinear`, `coeflegend`; see [R] Estimation options.

## Remarks and examples

`xtstreg` fits random-effects parametric survival-time models. The following discussion relies on the jargon of survival analysis; if you are not familiar with survival-time data or time-to-event data, see *Introduction* in [ST] Survival analysis for an overview of survival analysis in Stata and [ST] Glossary for a glossary of technical terms.

**xtstreg** is suitable only for data that have been **stset** as well as **xtset**. **stset** weights are not used; instead, weights must be specified at estimation. **xtstreg** requires “subjects”, as defined by option **id()** in **stset**, to be nested within panels identified by the *panelvar* specified in **xtset**. **xtstreg** can be used with multiple-record data, but it does not allow delayed entry or gaps.

For a Stata-specific introduction to survival analysis, see [Cleves, Gould, and Marchenko \(2016\)](#). [Rabe-Hesketh and Skrondal \(2012\)](#), chap. 14-15 is a good introductory read on applied longitudinal modeling of survival data.

## ▷ Example 1

In example 11 of [ST] **streg**, we fit a Weibull model with an inverse-Gaussian shared frailty to the recurrence times for catheter-insertion point infection for 38 kidney dialysis patients. In this example, the subjects are the catheter insertions, not the patients themselves. This is a function of how the data were recorded—the onset of risk occurs at the time the catheter is inserted and not, say, at the time of admission of the patient into the study. Thus we have two subjects (insertions) within each panel (patient). Each catheter insertion results in either infection (**infect==1**) or right-censoring (**infect==0**). Here we **stset** the data:

```
. use https://www.stata-press.com/data/r16/catheter  
(Kidney data, McGilchrist and Aisbett, Biometrics, 1991)  
. stset  
-> stset time, failure(infect)  
      failure event:  infect != 0 & infect < .  
obs. time interval:  (0, time]  
exit on or before:  failure  


---

76  total observations  
    0  exclusions  


---

76  observations remaining, representing  
58  failures in single-record/single-failure data  
7,424  total analysis time at risk and under observation  
                                at risk from t =          0  
                                earliest observed entry t =  0  
                                last observed exit t = 562
```

While it is reasonable to assume independence of patients, we would not want to assume that recurrence times within each patient are independent. The model used in [ST] **streg** allowed us to model the correlation by assuming that it was the result of a latent patient-level effect, or frailty.

Here we use `xtstreg` to fit a random-effects Weibull model with normally distributed random effects at the patient level. This is done by defining our panels as patients in the dataset.

```
. xtset patient
      panel variable: patient (balanced)
. xtstreg age female, distribution(weibull)
      failure _d: infect
      analysis time _t: time
Fitting comparison model:
Iteration 0:  log likelihood = -1700989.9
Iteration 1:  log likelihood = -440.1998
Iteration 2:  log likelihood = -336.62162
Iteration 3:  log likelihood = -334.64937
Iteration 4:  log likelihood = -334.57959
Iteration 5:  log likelihood = -334.57944
Iteration 6:  log likelihood = -334.57944

Refining starting values:
Grid node 0:  log likelihood = -336.03903

Fitting full model:
Iteration 0:  log likelihood = -336.03903  (not concave)
Iteration 1:  log likelihood = -333.12188
Iteration 2:  log likelihood = -330.38629
Iteration 3:  log likelihood = -329.89525
Iteration 4:  log likelihood = -329.87946
Iteration 5:  log likelihood = -329.87938
Iteration 6:  log likelihood = -329.87938

Random-effects Weibull PH regression
Group variable: patient
Number of obs      =      76
Number of groups   =       38
Obs per group:
               min =          2
               avg =        2.0
               max =          2

Integration method: mvaghermite
Integration pts.    =         12
Wald chi2(2)        =      10.17
Prob > chi2         =     0.0062
Log likelihood = -329.87938
```

_t	Haz. Ratio	Std. Err.	z	P> z	[95% Conf. Interval]
age	1.007329	.0137828	0.53	0.594	.9806742 1.034708
female	.1910581	.0999004	-3.17	0.002	.0685629 .5324042
_cons	.0073346	.0072307	-4.99	0.000	.0010623 .0506427
/ln_p	.222825	.1386296			-.0488841 .494534
/sigma2_u	.8234583	.4812598			.2619194 2.588902

Note: Estimates are transformed only in the first equation.

Note: \_cons estimates baseline hazard (conditional on zero random effects).

LR test vs. Weibull model: chibar2(01) = 9.40 Prob >= chibar2 = 0.0011

The results are similar to those in [ST] `streg`. The likelihood-ratio test compares the random-effects model with a survival model with fixed effects only. The results support the random-effects model.

For this model, `xtstreg` displays exponentiated coefficients, labeled as hazard ratios. These hazard ratios should be interpreted as “conditional hazard ratios”, that is, conditional on the random effects.

For example, the hazard ratio for `age` is 1.01. This means that according to the model, for a given patient, the hazard would increase 1% with each year of age. However, at the population level,

marginal hazards corresponding to different levels of the covariates are not necessarily proportional; see [example 5](#) in [ME] **mestreg postestimation** for further discussion.

The exponentiated coefficients of covariates that usually remain constant within a panel do not have a natural interpretation as conditional hazard ratios. However, the magnitude of the exponentiated coefficients always gives an idea of the effect of the covariates. In this example, `female` is constant within the panel. The estimated hazard ratio for `female` is 0.19, which indicates that hazard functions for females tend to be smaller than hazard functions for males.



## □ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see whether changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option, and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [\[XT\] quadchk](#) for details and [\[XT\] xtprobit](#) for an example.

Because the `xtstreg` likelihood function is calculated by Gauss–Hermite quadrature, the computations on large problems can be slow. Computation time is roughly proportional to the number of points used for the quadrature.



## Stored results

`xtstreg` stores the following in `e()`:

### Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(k)</code>	number of parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(N_clust)</code>	number of clusters
<code>e(chi2)</code>	$\chi^2$
<code>e(p)</code>	<i>p</i> -value for model test
<code>e(l1_c)</code>	log likelihood, comparison model
<code>e(chi2_c)</code>	$\chi^2$ , comparison model
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

### Macros

<code>e(cmd)</code>	<code>gsem</code>
<code>e(cmd2)</code>	<code>xtstreg</code>
<code>e(cmdline)</code>	command as typed

<code>e(depvar)</code>	
<code>e(wtype)</code>	<code>_t</code> weight type
<code>e(wexp)</code>	weight expression (first-level weights)
<code>e(covariates)</code>	list of covariates
<code>e(ivar)</code>	variable denoting groups
<code>e(model)</code>	model name
<code>e(title)</code>	title in estimation output
<code>e(distribution)</code>	distribution
<code>e(clustvar)</code>	name of cluster variable
<code>e(offset)</code>	offset
<code>e(intmethod)</code>	integration method
<code>e(chi2type)</code>	Wald; type of model $\chi^2$
<code>e(vce)</code>	<i>vcetype</i> specified in <code>vce()</code>
<code>e(vcetype)</code>	title used to label Std. Err.
<code>e(frm2)</code>	hazard or time
<code>e(opt)</code>	type of optimization
<code>e(which)</code>	<code>max</code> or <code>min</code> ; whether optimizer is to perform maximization or minimization
<code>e(ml_method)</code>	type of <code>ml</code> method
<code>e(user)</code>	name of likelihood-evaluator program
<code>e(technique)</code>	maximization technique
<code>e(properties)</code>	<code>b V</code>
<code>e(predict)</code>	program used to implement <code>predict</code>
<code>e(marginsok)</code>	predictions allowed by <code>margins</code>
<code>e(marginsnotok)</code>	predictions disallowed by <code>margins</code>
<code>e(marginswtype)</code>	weight type for <code>margins</code>
<code>e(marginswexp)</code>	weight expression for <code>margins</code>
<code>e(marginsdefault)</code>	default <code>predict()</code> specification for <code>margins</code>
<code>e(asbalanced)</code>	factor variables <code>fvset</code> as <code>asbalanced</code>
<code>e(asobserved)</code>	factor variables <code>fvset</code> as <code>asobserved</code>
 Matrices	
<code>e(b)</code>	coefficient vector
<code>e(Cns)</code>	constraints matrix
<code>e(iolog)</code>	iteration log (up to 20 iterations)
<code>e(gradient)</code>	gradient vector
<code>e(V)</code>	variance-covariance matrix of the estimator
<code>e(V_modelbased)</code>	model-based variance
 Functions	
<code>e(sample)</code>	marks estimation sample

## Methods and formulas

Methods and formulas are presented under the following headings:

*Survival models*  
*xtstreg and the robust VCE estimator*

## Survival models

Survival models have a trivariate response  $(t_0, t, d)$ :

$t_0$  is the starting time under observation  $t_0 \geq 0$ ;

$t$  is the ending time under observation  $t \geq t_0$ ; and

$d$  is an indicator for failure  $d \in \{0, 1\}$ .

You must `stset` your data before using `xtstreg`; see [ST] `stset`. By `stsetting` your data, you define the variables `_t0`, `_t`, and `_d`, which serve as the trivariate response variable.

Let  $i = 1, \dots, n$  panels,  $j = 1, \dots, n_i$ , and  $\nu_i$ s be unobservable panel-level random effects that are independent and identically distributed  $N(0, \sigma_\nu^2)$ .

Two often-used models for adjusting survivor functions for the effects of covariates are the accelerated failure-time (AFT) model and the multiplicative or proportional hazards (PH) model.

In the AFT model, the natural logarithm of the survival time,  $\log t$ , is expressed as a linear function of the covariates; when we incorporate the random effects, this yields the model

$$\log t_{ij} = \mathbf{x}_{ij}\beta + \nu_i + \epsilon_{ij}$$

The  $1 \times p$  row vector  $\mathbf{x}_{ij}$  contains the covariates for the fixed effects, with regression coefficients (fixed effects)  $\beta$ .

The  $\epsilon_{ij}$  are the observation-level errors with density  $\varphi(\cdot)$ . The distributional form of the error term determines the regression model. Five regression models are implemented in **xtstreg** using the AFT parameterization: exponential, gamma, loglogistic, lognormal, and Weibull. The lognormal regression model is obtained by letting  $\varphi(\cdot)$  be the normal density. Similarly, by letting  $\varphi(\cdot)$  be the logistic density, one obtains the loglogistic regression. Setting  $\varphi(\cdot)$  equal to the extreme-value density yields the exponential and the Weibull regression models.

In the PH models fit by **xtstreg**, the covariates have a multiplicative effect on the hazard function

$$h(t_{ij}) = h_0(t_{ij}) \exp(\mathbf{x}_{ij}\beta + \nu_i)$$

for some baseline hazard function  $h_0(t)$ . For the **xtstreg** command,  $h_0(t)$  is assumed to be parametric. The exponential and Weibull models are implemented in **xtstreg** for the PH parameterization. These two models are implemented using both the AFT and PH parameterizations.

The survivor function for a given family is the complement of the cumulative distribution function,  $S(t) = 1 - F(t)$ . The density for a failure at time  $t$  is given by

$$g(t) = \frac{\partial F(t)}{\partial t} = -\frac{\partial S(t)}{\partial t}$$

Some distributions contain ancillary parameters that are not denoted here.

The conditional density for a failure at time  $t$  is

$$g(t|t \geq t_0, d = 1) = g(t)/S(t_0)$$

and the conditional probability of survival without failure up to time  $t$  is

$$P(T \geq t|t \geq t_0, d = 0) = S(t)/S(t_0)$$

The conditional likelihood is given by

$$L(t_0, t, d) = \left\{ \frac{g(t)}{S(t_0)} \right\}^d \left\{ \frac{S(t)}{S(t_0)} \right\}^{1-d}$$

See [Survival distributions](#) in **[SEM] Methods and formulas for gsem** for the specific density function corresponding to each distribution.

Given the panel-level random effect  $\nu_i$ , the conditional distribution of  $\mathbf{t}_i = (t_{i1}, \dots, t_{in_i})'$  given  $\eta_i = (\mathbf{x}_{i1}\beta + \nu_i, \dots, \mathbf{x}_{in_i}\beta + \nu_i)$  for panel  $i$  is

$$f(\mathbf{t}_i|\eta_i) = \prod_{j=1}^{n_i} f(t_{ij}|\eta_{ij})$$

where  $f(t_{ij}|\eta_{ij})$  is the contribution to the likelihood from observation  $ij$ ; that is,

$$f(t_{ij}|\eta_{ij}) = \left\{ \frac{g(t_{ij}|\mathbf{x}_{ij}\beta + \nu_i)}{S(t_{0ij}|\mathbf{x}_{ij}\beta + \nu_i)} \right\}^{d_{ij}} \left\{ \frac{S(t_{ij}|\mathbf{x}_{ij}\beta + \nu_i)}{S(t_{0ij}|\mathbf{x}_{ij}\beta + \nu_i)} \right\}^{1-d_{ij}}$$

where  $g(t|\eta)$  and  $S(t|\eta)$  are, respectively, the density and the survivor function conditional on the linear prediction  $\eta$ .

As mentioned above, **xtstreg** does not allow delayed entry or gaps. Therefore, the first observation for a given subject will have a value of  $t_0 = 0$ , and subsequent spells for the subject must start at the end of the previous spell. That is, if observations  $ij$  and  $i, j+1$  belong to the same subject, then  $t_{0i,j+1} = t_{ij}$ .

Given a normal distribution  $N(0, \sigma_\nu^2)$  for the random effect  $\nu_i$ , the panel-level likelihood  $\mathcal{L}_i$  is given by

$$\mathcal{L}_i(\beta, \sigma_\nu) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{j=1}^{n_i} f(t_{ij}|\mathbf{x}_{ij}\beta + \nu_i) \right\} d\nu_i \quad (1)$$

The integration in (1) has no closed form and thus must be approximated. **xtstreg** offers two approximation methods: mean-variance adaptive Gauss–Hermite quadrature (default) and nonadaptive Gauss–Hermite quadrature. For details on these integration methods, see [SEM] **Methods and formulas for gsem**. To see how panel-level weights are incorporated into the likelihood function, see **Survey data** in [SEM] **Methods and formulas for gsem**.

The log likelihood for the entire dataset is simply the sum of the contributions of the  $n$  individual panels; namely,  $\mathcal{L}(\beta, \sigma_\nu) = \sum_{i=1}^n \mathcal{L}_i(\beta, \sigma_\nu)$ .

Maximization of  $\mathcal{L}(\beta, \sigma_\nu)$  is performed with respect to  $(\beta, \sigma_\nu^2)$ . Parameter estimates are stored in **e(b)** as  $(\hat{\beta}, \hat{\sigma}_\nu^2)$ , with the corresponding variance–covariance matrix stored in **e(V)**.

## xtstreg and the robust VCE estimator

Specifying **vce(robust)** or **vce(cluster clustvar)** causes the Huber/White/sandwich VCE estimator to be calculated for the coefficients estimated in this regression. See [P] **\_robust**, particularly **Introduction** and **Methods and formulas**. Wooldridge (2020) and Arellano (2003) discuss this application of the Huber/White/sandwich VCE estimator. As discussed by Wooldridge (2020), Stock and Watson (2008), and Arellano (2003), specifying **vce(robust)** is equivalent to specifying **vce(cluster panelvar)**, where *panelvar* is the variable that identifies the panels.

Clustering on the panel variable produces a consistent VCE estimator when the disturbances are not identically distributed over the panels or there is serial correlation in  $\epsilon_{it}$ .

The cluster–robust VCE estimator requires that there be many clusters and that the disturbances be uncorrelated across the clusters. The panel variable must be nested within the cluster variable because of the within-panel correlation that is generally induced by the random-effects transform when there is heteroskedasticity or within-panel serial correlation in the idiosyncratic errors.

## References

- Arellano, M. 2003. *Panel Data Econometrics*. Oxford: Oxford University Press.
- Cleves, M. A., W. W. Gould, and Y. V. Marchenko. 2016. *An Introduction to Survival Analysis Using Stata*. Rev. 3rd ed. College Station, TX: Stata Press.
- Rabe-Hesketh, S., and A. Skrondal. 2012. *Multilevel and Longitudinal Modeling Using Stata*. 3rd ed. College Station, TX: Stata Press.
- Stock, J. H., and M. W. Watson. 2008. Heteroskedasticity-robust standard errors for fixed effects panel data regression. *Econometrica* 76: 155–174.
- Wooldridge, J. M. 2020. *Introductory Econometrics: A Modern Approach*. 7th ed. Boston: Cengage.

## Also see

- [XT] **xtstreg postestimation** — Postestimation tools for xtstreg
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xtset** — Declare data to be panel data
- [ME] **mestreg** — Multilevel mixed-effects parametric survival models
- [ST] **streg** — Parametric survival models
- [ST] **stset** — Declare data to be survival-time data
- [U] **20 Estimation and postestimation commands**

**xtstreg postestimation** — Postestimation tools for xtstreg

Postestimation commands	predict	margins	Remarks and examples
Methods and formulas	Also see		

## Postestimation commands

The following postestimation command is of special interest after `xtstreg`:

Command	Description
<code>stcurve</code>	plot the survivor, hazard, and cumulative hazard functions

The following standard postestimation commands are also available:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance-covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from margins (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

## **predict**

### Description for predict

`predict` creates a new variable containing predictions such as linear predictions, mean and median survival times, hazard functions, and standard errors.

### Menu for predict

Statistics > Postestimation

### Syntax for predict

`predict [type] newvar [if] [in] [, statistic nooffset]`

<i>statistic</i>	Description
<hr/>	
Main	
<code>xb</code>	linear prediction; the default
<code>mean</code>	marginal mean survival time
<code>mean0</code>	mean survival time assuming that the random effects are zero
<code>median0</code>	median survival time assuming that the random effects are zero
<code>hazard</code>	marginal hazard
<code>hazard0</code>	hazard assuming that the random effects are zero
<code>surv</code>	marginal predicted survivor function
<code>surv0</code>	predicted survivor function assuming that the random effects are zero
<code>stdp</code>	standard error of the linear prediction

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

### Options for predict

#### Main

`xb`, the default, calculates the linear prediction.

`mean` calculates the mean survival time that is marginal with respect to the random effect, which means that the statistic is calculated by integrating the prediction function with respect to the random effect over its entire support.

`mean0` calculates the mean survival time assuming that all random effects are zero.

`median0` calculates the median survival time assuming that all random effects are zero.

`hazard` calculates the hazard function at `_t0` that is marginal with respect to the random effect, which means that the statistic is calculated by integrating the prediction function with respect to the random effect over its entire support.

`hazard0` calculates the hazard function at `_t0`, assuming that all random effects are zero.

`surv` calculates the predicted survivor function at `_t0` that is marginal with respect to the random effect, which means that the statistic is calculated by integrating the prediction function with respect to the random effect over its entire support.

`surv0` calculates the predicted survivor function at `_t0`, assuming that all random effects are zero.

`stdp` calculates the standard error of the linear prediction.

`nooffset` is relevant only if you specified `offset(varname)` with `xtstreg`. This option modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{ij}\beta$  rather than as  $\mathbf{x}_{ij}\beta + \text{offset}_{ij}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions and mean and median survival times.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

```
margins [marginlist] [, options]
margins [marginlist] , predict(statistic ...) [predict(statistic ...) ...] [options]
```

<i>statistic</i>	Description
<code>mean</code>	marginal mean survival time; the default
<code>mean0</code>	mean survival time conditional on zero random effects
<code>median0</code>	median survival time conditional on zero random effects
<code>hazard</code>	marginal hazard
<code>surv</code>	marginal predicted survivor function
<code>xb</code>	linear predictor for the fixed portion of the model only
<code>hazard0</code>	not allowed with <code>margins</code>
<code>surv0</code>	not allowed with <code>margins</code>
<code>stdp</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

## Remarks and examples

### ▷ Example 1

In example 1 of [XT] **xtstreg**, we analyzed the time to infection of the catheter-insertion point for 38 kidney dialysis patients. We fit the following model:

```
. use https://www.stata-press.com/data/r16/catheter
(Kidney data, McGilchrist and Aisbett, Biometrics, 1991)
. xtset patient
  (output omitted)
. xtstreg age female, distribution(weibull)
  (output omitted)
```

The **predict** command allows us to compute the marginal mean and the mean and median survival time assuming that all random effects are zero:

```
. predict mean, mean
. predict mean0, mean0
. predict median0, median0
```

Here we list the predicted mean and median survival times for the first five patients:

```
. list patient mean mean0 median0 in 1/10, sepby(patient)
```

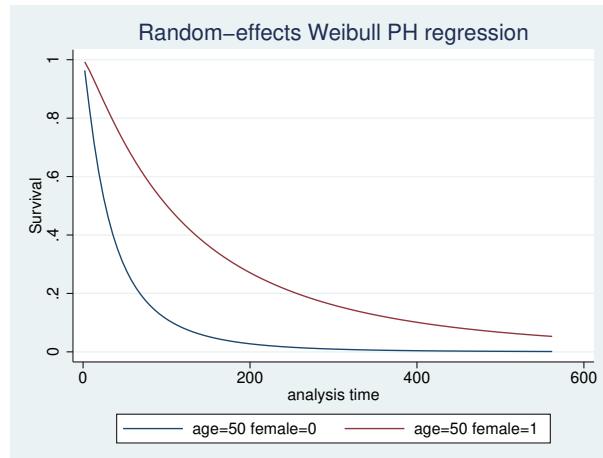
	patient	mean	mean0	median0
1.	1	60.97527	40.39634	32.34459
2.	1	60.97527	40.39634	32.34459
3.	2	204.0082	135.1562	108.217
4.	2	204.0082	135.1562	108.217
5.	3	59.56653	39.46305	31.59731
6.	3	59.56653	39.46305	31.59731
7.	4	224.6581	148.8368	119.1708
8.	4	224.6581	148.8368	119.1708
9.	5	67.7384	44.87694	35.93212
10.	5	67.7384	44.87694	35.93212

This example illustrates that for nonlinear models, the mean computed with the random effects equal to zero is usually not representative of the marginal mean.

**predict** can also compute the predicted survivor function and the predicted hazard function. All of these predictions can be marginal or conditional on the random effects being zero.

Predicted survivor, hazard, or cumulative hazard functions can be visualized with **stcurve**. For example, below we compute marginal predictions for the survivor function for men and women at age 50.

```
. stcurve, survival at1(age=50 female=0) at2(age=50 female=1)
(option marginal assumed)
```



The graph above shows that women who are 50 years old have larger survival probabilities than men of the same age.



## Methods and formulas

`predict newvar` computes the following predictions:

`mean0`:

$$\text{newvar}_{ij} = \int_0^{\infty} \widehat{S}(t|\mathbf{x}_{ij}, u_{ij}) dt$$

`median0`:

$$\text{newvar}_{ij} = \{t : \widehat{S}(t|\mathbf{x}_{ij}, u_{ij}) = 1/2\}$$

`surv0`:

$$\text{newvar}_{ij} = \widehat{S}(t_{ij}|\mathbf{x}_{ij}, u_{ij})$$

`hazard0`:

$$\text{newvar}_{ij} = \widehat{g}(t_{ij}|\mathbf{x}_{ij}, u_{ij}) / \widehat{S}(t_{ij}|\mathbf{x}_{ij}, u_{ij})$$

Here  $\widehat{S}(t|\mathbf{x}_{ij}, u_{ij})$  is the survivor function  $S(t|\mathbf{x}_{ij}\beta + u_{ij})$ , and  $\widehat{g}(t|\mathbf{x}_{ij}, u_{ij})$  is the density  $g(t|\mathbf{x}_{ij}\beta + u_{ij})$  with the parameter estimates substituted in for  $\beta$  and zero substituted for  $u_{ij}$ .

## Also see

[XT] **xtstreg** — Random-effects parametric survival models

[ST] **stcurve** — Plot survivor, hazard, cumulative hazard, or cumulative incidence function

[U] **20 Estimation and postestimation commands**

**xtsum** — Summarize xt data

Description  
Remarks and examples

Quick start  
Stored results

Menu  
Also see

Syntax

## Description

**xtsum**, a generalization of **summarize** (see [R] **summarize**), reports means and standard deviations for panel data; it differs from **summarize** in that it decomposes the standard deviation into between and within components.

## Quick start

Report means and overall, between, and within standard deviations for all numeric variables in **xtset** data

```
xtsum
```

As above, but restrict to v1, v2, and v3

```
xtsum v1 v2 v3
```

As above, but calculate statistics separately for each level of **catvar**

```
bysort catvar: xtsum v1 v2 v3
```

## Menu

Statistics > Longitudinal/panel data > Setup and utilities > Summarize xt data

## Syntax

```
xtsum [varlist] [if]
```

A panel variable must be specified; use `xtset`; see [XT] `xtset`.

`varlist` may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by` is allowed; see [D] `by`.

## Remarks and examples

If you have not read [XT] `xt`, please do so.

`xtsum` provides an alternative to `summarize`. For instance, in the `nlswork` dataset described in [XT] `xt`, `hours` contains the usual hours worked:

```
. use https://www.stata-press.com/data/r16/nlswork
(National Longitudinal Survey. Young Women 14–26 years of age in 1968)
. summarize hours
      Variable |       Obs        Mean    Std. Dev.      Min      Max
                 hours | 28,467  36.55956   9.869623         1      168
. xtsum hours
      Variable |       Mean    Std. Dev.      Min      Max | Observations
      hours   overall | 36.55956   9.869623         1      168 | N = 28467
      between  |          7.846585          1      83.5 | n = 4710
      within   |          7.520712 -2.154726  130.0596 | T-bar = 6.04395
```

`xtsum` provides the same information as `summarize` and more. It decomposes the variable  $x_{it}$  into a between ( $\bar{x}_i$ ) and within ( $x_{it} - \bar{x}_i + \bar{x}$ , the global mean  $\bar{x}$  being added back in make results comparable). The overall and within are calculated over 28,467 person-years of data. The between is calculated over 4,710 persons, and the average number of years a person was observed in the `hours` data is 6.

`xtsum` also reports minimums and maximums. Hours worked last week varied between 1 and (unbelievably) 168. Average hours worked last week for each woman varied between 1 and 83.5. “Hours worked within” varied between -2.15 and 130.1, which is not to say that any woman actually worked negative hours. The within number refers to the deviation from each individual’s average, and naturally, some of those deviations must be negative. Then the negative value is not disturbing but the positive value is. Did some woman really deviate from her average by +130.1 hours? No. In our definition of within, we add back in the global average of 36.6 hours. Some woman did deviate from her average by  $130.1 - 36.6 = 93.5$  hours, which is still large.

The reported standard deviations tell us something that may surprise you. They say that the variation in hours worked last week across women is nearly equal to that observed within a woman over time. That is, if you were to draw two women randomly from our data, the difference in hours worked is expected to be nearly equal to the difference for the same woman in two randomly selected years.

If a variable does not vary over time, its within standard deviation will be zero:

```
. xtsum birth_yr
      Variable |       Mean    Std. Dev.      Min      Max | Observations
      birth_yr overall | 48.08509   3.012837        41      54 | N = 28534
      between  |          3.051795          41      54 | n = 4711
      within   |          0        48.08509  48.08509 | T-bar = 6.05689
```

## Stored results

**xtsum** stores the following in **r()**:

Scalars

<b>r(N)</b>	number of observations
<b>r(n)</b>	number of panels
<b>r(Tbar)</b>	average number of years under observation
<b>r(mean)</b>	mean
<b>r(sd)</b>	overall standard deviation
<b>r(min)</b>	overall minimum
<b>r(max)</b>	overall maximum
<b>r(sd_b)</b>	between standard deviation
<b>r(min_b)</b>	between minimum
<b>r(max_b)</b>	between maximum
<b>r(sd_w)</b>	within standard deviation
<b>r(min_w)</b>	within minimum
<b>r(max_w)</b>	within maximum

## Also see

[XT] **xtdescribe** — Describe pattern of xt data

[XT] **xtab** — Tabulate xt data

**xttab** — Tabulate xt data

Description  
Option

Quick start  
Remarks and examples

Menu  
Stored results

Syntax  
Also see

## Description

`xttab`, a generalization of `tabulate` (see [R] `tabulate oneway`), performs one-way tabulations and decomposes counts into between and within components in panel data.

`xttrans`, another generalization of `tabulate` (see [R] `tabulate oneway`), reports transition probabilities (the change in one categorical variable over time).

## Quick start

Overall, between, and within one-way tabulation of `v1` using `xtset` data

```
xttab v1
```

Report transition probabilities for `v2`

```
xttrans v2
```

Add frequency of transitions

```
xttrans v2, freq
```

As above, but for each level of `catvar`

```
bysort catvar: xttrans v2, freq
```

## Menu

### **xttab**

Statistics > Longitudinal/panel data > Setup and utilities > Tabulate xt data

### **xttrans**

Statistics > Longitudinal/panel data > Setup and utilities > Report transition probabilities

## Syntax

`xtab varname [if]`

`xttrans varname [if] [, freq]`

A panel variable must be specified; use `xtset`; see [XT] `xtset`.

`by` is allowed with `xtab` and `xttrans`; see [D] `by`.

## Option

Main

`freq`, allowed with `xttrans` only, specifies that frequencies as well as transition probabilities be displayed.

## Remarks and examples

If you have not read [XT] `xt`, please do so.

### ▷ Example 1: `xtab`

Using the `nlswork` dataset described in [XT] `xt`, variable `msp` is 1 if a woman is married and her spouse resides with her, and 0 otherwise:

```
. use https://www.stata-press.com/data/r16/nlswork
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xtab msp
```

msp	Overall		Between		Within Percent
	Freq.	Percent	Freq.	Percent	
0	11324	39.71	3113	66.08	62.69
1	17194	60.29	3643	77.33	75.75
Total	28518	100.00	6756	143.41	69.73

(n = 4711)

The overall part of the table summarizes results in terms of person-years. We have 11,324 person-years of data in which `msp` is 0 and 17,194 in which it is 1—in 60.3% of our data, the woman is married with her spouse present. Between repeats the breakdown, but this time in terms of women rather than person-years; 3,113 of our women ever had `msp` 0 and 3,643 ever had `msp` 1, for a grand total of 6,756 ever having either. We have in our data, however, only 4,711 women. This means that there are women who sometimes have `msp` 0 and at other times have `msp` 1.

The within percent tells us the fraction of the time a woman has the specified value of `msp`. If we take the first line, conditional on a woman ever having `msp` 0, 62.7% of her observations have `msp` 0. Similarly, conditional on a woman ever having `msp` 1, 75.8% of her observations have `msp` 1. These two numbers are a measure of the stability of the `msp` values, and, in fact, `msp` 1 is more stable among these younger women than `msp` 0, meaning that they tend to marry more than they divorce. The total within of 69.73% is the normalized between weighted average of the within percents, that is,  $(3113 \times 62.69 + 3643 \times 75.75) / 6756$ . It is a measure of the overall stability of the `msp` variable.

A time-invariant variable will have a tabulation with within percents of 100:

```
. xttab race
```

race	Overall		Between		Within Percent
	Freq.	Percent	Freq.	Percent	
white	20180	70.72	3329	70.66	100.00
black	8051	28.22	1325	28.13	100.00
other	303	1.06	57	1.21	100.00
Total	28534	100.00	4711	100.00	100.00

(n = 4711)



## ▷ Example 2: xttrans

xttrans shows the transition probabilities. In cross-sectional time-series data, we can estimate the probability that  $x_{i,t+1} = v_2$  given that  $x_{it} = v_1$  by counting transitions. For instance

```
. xttrans msp
```

1 if married, spouse present	1 if married, spouse present		Total
	0	1	
0	80.49	19.51	100.00
1	7.96	92.04	100.00
Total	37.11	62.89	100.00

The rows reflect the initial values, and the columns reflect the final values. Each year, some 80% of the msp 0 persons in the data remained msp 0 in the next year; the remaining 20% became msp 1. Although msp 0 had a 20% chance of becoming msp 1 in each year, the msp 1 had only an 8% chance of becoming (or returning to) msp 0. The freq option displays the frequencies that go into the calculation:

```
. xttrans msp, freq
```

1 if married, spouse present	1 if married, spouse present		Total
	0	1	
0	7,697	1,866	9,563
	80.49	19.51	100.00
1	1,133	13,100	14,233
	7.96	92.04	100.00
Total	8,830	14,966	23,796
	37.11	62.89	100.00



## □ Technical note

The transition probabilities reported by `xttrans` are not necessarily the transition probabilities in a Markov sense. `xttrans` counts transitions from each observation to the next once the observations have been put in  $t$  order within  $i$ . It does not normalize for missing periods. `xttrans` does pay attention to missing values of the variable being tabulated, however, and does not count transitions from nonmissing to missing or from missing to nonmissing. Thus if the data are fully rectangularized, `xttrans` produces (inefficient) estimates of the Markov transition matrix. `fillin` will rectangularize datasets; see [D] `fillin`. Thus the Markov transition matrix could be estimated by typing

```
. fillin idcode year  
. xttrans msp  
(output omitted)
```



## Stored results

`xttab` stores the following in `r()`:

Scalars	
	<code>r(n)</code> number of panels
Matrices	
	<code>r(results)</code> results matrix

## Also see

[XT] **xtdescribe** — Describe pattern of xt data

[XT] **xtsum** — Summarize xt data

**xttobit** — Random-effects tobit models

Description	Quick start	Menu	Syntax
Options	Remarks and examples	Stored results	Methods and formulas
References	Also see		

## Description

**xttobit** fits random-effects tobit models for panel data where the outcome variable is censored. Censoring limits may be fixed for all observations or vary across observations. The user can request that a likelihood-ratio test comparing the panel tobit model with the pooled tobit model be conducted at estimation time.

## Quick start

Tobit model of *y* on *x* where *y* is censored at a lower limit of 5 using **xtset** data

```
xttobit y x, ll(5)
```

Add indicators for levels of categorical variable *a*

```
xttobit y x i.a, ll(5)
```

As above, but specify that censoring occurs at 5 and 25

```
xttobit y x i.a, ll(5) ul(25)
```

As above, but where *lower* and *upper* are variables containing the censoring limits

```
xttobit y x i.a, ll(lower) ul(upper)
```

Add likelihood-ratio test comparing the random-effects model with the pooled model

```
xttobit y x i.a, ll(lower) ul(upper) tobit
```

## Menu

Statistics > Longitudinal/panel data > Censored outcomes > Tobit regression (RE)

## Syntax

`xttobit depvar [indepvars] [if] [in] [weight] [, options]`

options	Description
<b>Model</b>	
<code>noconstant</code>	suppress constant term
<code>l1[(varname   #)]</code>	left-censoring variable or limit
<code>u1[(varname   #)]</code>	right-censoring variable or limit
<code>offset(varname)</code>	include <i>varname</i> in model with coefficient constrained to 1
<code>constraints(constraints)</code>	apply specified linear constraints
<b>SE</b>	
<code>vce(vcetype)</code>	<i>vcetype</i> may be <code>oim</code> , <code>bootstrap</code> , or <code>jackknife</code>
<b>Reporting</b>	
<code>level(#)</code>	set confidence level; default is <code>level(95)</code>
<code>tobit</code>	perform likelihood-ratio test comparing against pooled tobit model
<code>lrmodel</code>	perform the likelihood-ratio model test instead of the default Wald test
<code>nocnsreport</code>	do not display constraints
<code>display_options</code>	control columns and column formats, row spacing, line width, display of omitted variables and base and empty cells, and factor-variable labeling
<b>Integration</b>	
<code>intmethod(intmethod)</code>	integration method; <i>intmethod</i> may be <code>mvaghermite</code> (the default) or <code>ghermite</code>
<code>intpoints(#)</code>	use # quadrature points; default is <code>intpoints(12)</code>
<b>Maximization</b>	
<code>maximize_options</code>	control the maximization process; seldom used
<code>collinear</code>	keep collinear variables
<code>coeflegend</code>	display legend instead of statistics

A panel variable must be specified; use `xtset`; see [XT] `xtset`.

*indepvars* may contain factor variables; see [U] 11.4.3 Factor variables.

*depvar* and *indepvars* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

`by`, `fp`, and `statsby` are allowed; see [U] 11.1.10 Prefix commands.

`iweights` are allowed; see [U] 11.1.6 weight. Weights must be constant within panel.

`collinear` and `coeflegend` do not appear in the dialog box.

See [U] 20 Estimation and postestimation commands for more capabilities of estimation commands.

## Options

### Model

`noconstant`; see [R] Estimation options.

`l1[(varname | #)]` and `u1[(varname | #)]` indicate the lower and upper limits for censoring, respectively. Observations with `depvar ≤ l1()` are left-censored; observations with `depvar ≥ u1()` are right-censored; and remaining observations are not censored. You do not have to specify the

censoring values. If you specify `ll`, the lower limit is the minimum of `depvar`. If you specify `ul`, the upper limit is the maximum of `depvar`.

`offset(varname)`, `constraints(constraints)`; see [R] **Estimation options**.

#### SE

`vce(vcetype)` specifies the type of standard error reported, which includes types that are derived from asymptotic theory (`oim`) and that use bootstrap or jackknife methods (`bootstrap`, `jackknife`); see [XT] **vce\_options**.

#### Reporting

`level(#)`; see [R] **Estimation options**.

`tobit` specifies that a likelihood-ratio test comparing the random-effects model with the pooled (tobit) model be included in the output.

`lrmodel`, `nocnsreport`; see [R] **Estimation options**.

`display_options`: `noci`, `nopvalues`, `noomitted`, `vsquish`, `noemptycells`, `baselevels`, `allbaselevels`, `nofvlabel`, `fvwrap(#)`, `fvrapon(style)`, `cformat(%fmt)`, `pformat(%fmt)`, `sformat(%fmt)`, and `nolstretch`; see [R] **Estimation options**.

#### Integration

`intmethod(intmethod)`, `intpoints(#)`; see [R] **Estimation options**.

#### Maximization

`maximize_options`: `difficult`, `technique(algorithm_spec)`, `iterate(#)`, `[no]log`, `trace`, `gradient`, `showstep`, `hessian`, `showtolerance`, `tolerance(#)`, `ltolerance(#)`, `rtolerance(#)`, `nonrtolerance`, and `from(init_specs)`; see [R] **Maximize**. These options are seldom used.

The following options are available with `xttobit` but are not shown in the dialog box:

`collinear`, `coeflegend`; see [R] **Estimation options**.

## Remarks and examples

`xttobit` fits random-effects tobit models. There is no command for a fixed-effects model, because there does not exist a sufficient statistic allowing the fixed effects to be conditioned out of the likelihood.

Consider the linear regression model with panel-level random effects

$$y_{it} = \mathbf{x}_{it}\beta + \nu_i + \epsilon_{it}$$

for  $i = 1, \dots, n$  panels, where  $t = 1, \dots, n_i$ . The random effects,  $\nu_i$ , are i.i.d.,  $N(0, \sigma_\nu^2)$ , and  $\epsilon_{it}$  are i.i.d.  $N(0, \sigma_\epsilon^2)$  independently of  $\nu_i$ .

The observed data,  $y_{it}^o$ , represent possibly censored versions of  $y_{it}$ . If they are left-censored, all that is known is that  $y_{it} \leq y_{it}^o$ . If they are right-censored, all that is known is that  $y_{it} \geq y_{it}^o$ . If they are uncensored,  $y_{it} = y_{it}^o$ . If they are left-censored,  $y_{it}^o$  is determined by `ll()`. If they are right-censored,  $y_{it}^o$  is determined by `ul()`. If they are uncensored,  $y_{it}^o$  is determined by `depvar`.

## ▷ Example 1: Random-effects tobit regression

Using the `nlswork` data described in [XT] `xt`, we fit a random-effects tobit model of adjusted (log) wages. We use the `ul()` option to impose an upper limit on the recorded log of wages.

```
. use https://www.stata-press.com/data/r16/nlswork3
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xttobit ln_wage i.union age grade not_smsa south##c.year, ul(1.9) tobit
(output omitted)

Random-effects tobit regression
Number of obs = 19,224
Uncensored = 12,334
Limits: lower = -inf
Upper = 1.90
Left-censored = 0
Right-censored = 6,890
Group variable: idcode
Number of groups = 4,148
Random effects u_i ~ Gaussian
Obs per group:
min = 1
avg = 4.6
max = 12
Integration method: mvaghermite
Integration pts. = 12
Wald chi2(7) = 2925.68
Prob > chi2 = 0.0000
Log likelihood = -6814.4606
```

ln_wage	Coef.	Std. Err.	z	P> z	[95% Conf. Interval]
1.union	.1430527	.0069718	20.52	0.000	.1293883 .1567171
age	.0099132	.0017516	5.66	0.000	.0064801 .0133464
grade	.0784855	.0022764	34.48	0.000	.0740239 .0829472
not_smsa	-.1339978	.009206	-14.56	0.000	-.1520413 -.1159544
1.south	-.3507188	.0695554	-5.04	0.000	-.4870449 -.2143928
year	-.0008285	.0018371	-0.45	0.652	-.0044292 .0027721
south##c.year					
1	.0031938	.0008606	3.71	0.000	.0015071 .0048805
_cons	.5101956	.1006646	5.07	0.000	.3128966 .7074946
/sigma_u	.3045992	.0048344	63.01	0.000	.2951239 .3140745
/sigma_e	.2488678	.0018254	136.34	0.000	.24529 .2524455
rho	.5996844	.0084095			.583118 .6160734

LR test of sigma\_u=0: chibar2(01) = 6650.63      Prob >= chibar2 = 0.000

The results from a tobit regression can be interpreted as we would those from a linear regression. Because the dependent variable is log transformed, the coefficients can be interpreted in terms of a percentage change. We see, for example, that on average, union members make 14.3% more than nonunion members.

The output also includes the overall and panel-level variance components (labeled `sigma_e` and `sigma_u`, respectively) together with  $\rho$  (labeled `rho`)

$$\rho = \frac{\sigma_\nu^2}{\sigma_\epsilon^2 + \sigma_\nu^2}$$

which is the percent contribution to the total variance of the panel-level variance component.

When `rho` is zero, the panel-level variance component is unimportant, and the panel estimator is not different from the pooled estimator. A likelihood-ratio test of this is included at the bottom of the output. This test formally compares the pooled estimator (tobit) with the panel estimator. In this case, we reject the null hypothesis that there are no panel-level effects.



## □ Technical note

The random-effects model is calculated using quadrature, which is an approximation whose accuracy depends partially on the number of integration points used. We can use the `quadchk` command to see if changing the number of integration points affects the results. If the results change, the quadrature approximation is not accurate given the number of integration points. Try increasing the number of integration points using the `intpoints()` option and run `quadchk` again. Do not attempt to interpret the results of estimates when the coefficients reported by `quadchk` differ substantially. See [XT] `quadchk` for details and [XT] `xtprobit` for an example.

Because the `xttobit` likelihood function is calculated by Gauss–Hermite quadrature, on large problems the computations can be slow. Computation time is roughly proportional to the number of points used for the quadrature.



## Stored results

`xttobit` stores the following in `e()`:

Scalars

<code>e(N)</code>	number of observations
<code>e(N_g)</code>	number of groups
<code>e(N_unc)</code>	number of uncensored observations
<code>e(N_lc)</code>	number of left-censored observations
<code>e(N_rc)</code>	number of right-censored observations
<code>e(N_cd)</code>	number of completely determined observations
<code>e(k)</code>	number of parameters
<code>e(k_eq)</code>	number of equations in <code>e(b)</code>
<code>e(k_eq_model)</code>	number of equations in overall model test
<code>e(k_dv)</code>	number of dependent variables
<code>e(df_m)</code>	model degrees of freedom
<code>e(l1)</code>	log likelihood
<code>e(l1_0)</code>	log likelihood, constant-only model
<code>e(l1_c)</code>	log likelihood, comparison model
<code>e(chi2)</code>	$\chi^2$
<code>e(chi2_c)</code>	$\chi^2$ for comparison test
<code>e(rho)</code>	$\rho$
<code>e(sigma_u)</code>	panel-level standard deviation
<code>e(sigma_e)</code>	standard deviation of $\epsilon_{it}$
<code>e(n_quad)</code>	number of quadrature points
<code>e(g_min)</code>	smallest group size
<code>e(g_avg)</code>	average group size
<code>e(g_max)</code>	largest group size
<code>e(p)</code>	p-value for model test
<code>e(rank)</code>	rank of <code>e(V)</code>
<code>e(rank0)</code>	rank of <code>e(V)</code> for constant-only model
<code>e(ic)</code>	number of iterations
<code>e(rc)</code>	return code
<code>e(converged)</code>	1 if converged, 0 otherwise

## Macros

e(cmd)	xttobit
e(cmdline)	command as typed
e(depvar)	names of dependent variables
e(ivar)	variable denoting groups
e(llopt)	contents of ll()
e(ulopt)	contents of ul()
e(k_aux)	number of auxiliary parameters
e(wtype)	weight type
e(wexp)	weight expression
e(title)	title in estimation output
e(offset1)	offset
e(chi2type)	Wald or LR; type of model $\chi^2$ test
e(chi2_ct)	Wald or LR; type of model $\chi^2$ test corresponding to e(chi2_c)
e(vce)	vctype specified in vce()
e(intmethod)	integration method
e(distrib)	Gaussian; the distribution of the random effect
e(opt)	type of optimization
e(which)	max or min; whether optimizer is to perform maximization or minimization
e(ml_method)	type of ml method
e(user)	name of likelihood-evaluator program
e(technique)	maximization technique
e(properties)	b V
e(predict)	program used to implement predict
e(marginsok)	predictions allowed by margins
e(asbalanced)	factor variables fvset as asbalanced
e(asobserved)	factor variables fvset as asobserved

## Matrices

e(b)	coefficient vector
e(Cns)	constraints matrix
e(ilog)	iteration log
e(gradient)	gradient vector
e(V)	variance-covariance matrix of the estimators

## Functions

e(sample)	marks estimation sample
-----------	-------------------------

## Methods and formulas

Assuming a normal distribution,  $N(0, \sigma_\nu^2)$ , for the random effects  $\nu_i$ , we have the joint (unconditional of  $\nu_i$ ) density of the observed data from the  $i$ th panel

$$f(y_{i1}^o, \dots, y_{in_i}^o | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) = \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_\nu^2}}{\sqrt{2\pi}\sigma_\nu} \left\{ \prod_{t=1}^{n_i} F(y_{it}^o, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i$$

where

$$F(y_{it}^o, \Delta_{it}) = \begin{cases} (\sqrt{2\pi}\sigma_\epsilon)^{-1} e^{-(y_{it}^o - \Delta_{it})^2/(2\sigma_\epsilon^2)} & \text{if } y_{it}^o \in C \\ \Phi\left(\frac{y_{it}^o - \Delta_{it}}{\sigma_\epsilon}\right) & \text{if } y_{it}^o \in L \\ 1 - \Phi\left(\frac{y_{it}^o - \Delta_{it}}{\sigma_\epsilon}\right) & \text{if } y_{it}^o \in R \end{cases}$$

where  $C$  is the set of noncensored observations,  $L$  is the set of left-censored observations,  $R$  is the set of right-censored observations, and  $\Phi()$  is the cumulative normal distribution.

The panel level likelihood  $l_i$  is given by

$$\begin{aligned} l_i &= \int_{-\infty}^{\infty} \frac{e^{-\nu_i^2/2\sigma_{\nu}^2}}{\sqrt{2\pi}\sigma_{\nu}} \left\{ \prod_{t=1}^{n_i} F(y_{it}^o, \mathbf{x}_{it}\beta + \nu_i) \right\} d\nu_i \\ &\equiv \int_{-\infty}^{\infty} g(y_{it}^o, x_{it}, \nu_i) d\nu_i \end{aligned}$$

This integral can be approximated with  $M$ -point Gauss–Hermite quadrature

$$\int_{-\infty}^{\infty} e^{-x^2} h(x) dx \approx \sum_{m=1}^M w_m^* h(a_m^*)$$

This is equivalent to

$$\int_{-\infty}^{\infty} f(x) dx \approx \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} f(a_m^*)$$

where the  $w_m^*$  denote the quadrature weights and the  $a_m^*$  denote the quadrature abscissas. The log likelihood,  $L$ , is the sum of the logs of the panel level likelihoods  $l_i$ .

The default approximation of the log likelihood is by adaptive Gauss–Hermite quadrature, which approximates the panel level likelihood with

$$l_i \approx \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} g(y_{it}^o, x_{it}, \sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i)$$

where  $\hat{\sigma}_i$  and  $\hat{\mu}_i$  are the adaptive parameters for panel  $i$ . Therefore, with the definition of  $g(y_{it}^o, x_{it}, \nu_i)$ , the total log likelihood is approximated by

$$\begin{aligned} L &\approx \sum_{i=1}^n w_i \log \left[ \sqrt{2\hat{\sigma}_i} \sum_{m=1}^M w_m^* \exp\{(a_m^*)^2\} \frac{\exp\{-(\sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i)^2/2\sigma_{\nu}^2\}}{\sqrt{2\pi}\sigma_{\nu}} \right. \\ &\quad \left. \prod_{t=1}^{n_i} F(y_{it}^o, x_{it}\beta + \sqrt{2\hat{\sigma}_i}a_m^* + \hat{\mu}_i) \right] \end{aligned} \tag{1}$$

where  $w_i$  is the user-specified weight for panel  $i$ ; if no weights are specified,  $w_i = 1$ .

The default method of adaptive Gauss–Hermite quadrature is to calculate the posterior mean and variance and use those parameters for  $\hat{\mu}_i$  and  $\hat{\sigma}_i$  by following the method of [Naylor and Smith \(1982\)](#), further discussed in [Skrondal and Rabe-Hesketh \(2004\)](#). We start with  $\hat{\sigma}_{i,0} = 1$  and  $\hat{\mu}_{i,0} = 0$ , and the posterior means and variances are updated in the  $k$ th iteration. That is, at the  $k$ th iteration of the optimization for  $l_i$  we use

$$l_{i,k} \approx \sum_{m=1}^M \sqrt{2\hat{\sigma}_{i,k-1}} w_m^* \exp\{(a_m^*)^2\} g(y_{it}^o, x_{it}, \sqrt{2\hat{\sigma}_{i,k-1}}a_m^* + \hat{\mu}_{i,k-1})$$

Letting

$$\tau_{i,m,k-1} = \sqrt{2}\hat{\sigma}_{i,k-1}a_m^* + \hat{\mu}_{i,k-1}$$

$$\hat{\mu}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1}) \frac{\sqrt{2}\hat{\sigma}_{i,k-1}w_m^* \exp\{(a_m^*)^2\}g(y_{it}^o, x_{it}, \tau_{i,m,k-1})}{l_{i,k}}$$

and

$$\hat{\sigma}_{i,k} = \sum_{m=1}^M (\tau_{i,m,k-1})^2 \frac{\sqrt{2}\hat{\sigma}_{i,k-1}w_m^* \exp\{(a_m^*)^2\}g(y_{it}^o, x_{it}, \tau_{i,m,k-1})}{l_{i,k}} - (\hat{\mu}_{i,k})^2$$

and this is repeated until  $\hat{\mu}_{i,k}$  and  $\hat{\sigma}_{i,k}$  have converged for this iteration of the maximization algorithm. This adaptation is applied on every iteration until the log-likelihood change from the preceding iteration is less than a relative difference of 1e-6; after this, the quadrature parameters are fixed.

The log likelihood can also be calculated by nonadaptive Gauss–Hermite quadrature if the `intmethod(ghermite)` option is specified. For nonadaptive Gauss–Hermite quadrature, the following formula for the log likelihood is used in place of (1).

$$\begin{aligned} L &= \sum_{i=1}^n w_i \log \left\{ \Pr(y_{i1}, \dots, y_{in_i} | \mathbf{x}_{i1}, \dots, \mathbf{x}_{in_i}) \right\} \\ &\approx \sum_{i=1}^n w_i \log \left[ \frac{1}{\sqrt{\pi}} \sum_{m=1}^M w_m^* \prod_{t=1}^{n_i} F \left\{ y_{it}^o, \mathbf{x}_{it} \boldsymbol{\beta} + \sqrt{2}\sigma_\nu a_m^* \right\} \right] \end{aligned}$$

Both quadrature formulas require that the integrated function be well approximated by a polynomial of degree equal to the number of quadrature points. Panel size can affect whether

$$\prod_{t=1}^{n_i} F(y_{it}^o, \mathbf{x}_{it} \boldsymbol{\beta} + \nu_i)$$

is well approximated by a polynomial. As panel size and  $\rho$  increase, the quadrature approximation can become less accurate. For large  $\rho$ , the random-effects model can also become unidentified. Adaptive quadrature gives better results for correlated data and large panels than nonadaptive quadrature; however, we recommend that you use the `quadchk` command (see [XT] `quadchk`) to verify the quadrature approximation used in this command, whichever approximation you choose.

## References

- Naylor, J. C., and A. F. M. Smith. 1982. Applications of a method for the efficient computation of posterior distributions. *Journal of the Royal Statistical Society, Series C* 31: 214–225.
- Pendergast, J. F., S. J. Gange, M. A. Newton, M. J. Lindstrom, M. Palta, and M. R. Fisher. 1996. A survey of methods for analyzing clustered binary response data. *International Statistical Review* 64: 89–118.
- Skrondal, A., and S. Rabe-Hesketh. 2004. *Generalized Latent Variable Modeling: Multilevel, Longitudinal, and Structural Equation Models*. Boca Raton, FL: Chapman & Hall/CRC.

## Also see

- [XT] **xttobit postestimation** — Postestimation tools for xttobit
- [XT] **quadchk** — Check sensitivity of quadrature approximation
- [XT] **xteintreg** — Extended random-effects interval regression
- [XT] **xtintreg** — Random-effects interval-data regression models
- [XT] **xtreg** — Fixed-, between-, and random-effects and population-averaged linear models
- [XT] **xtset** — Declare data to be panel data
- [ME] **metobit** — Multilevel mixed-effects tobit regression
- [R] **tobit** — Tobit regression
- [U] **20 Estimation and postestimation commands**

**xttobit postestimation** — Postestimation tools for xttobit

Postestimation commands  
Methods and formulas

[predict](#)  
[Also see](#)

[margins](#)

Remarks and examples

## Postestimation commands

The following postestimation commands are available after `xttobit`:

Command	Description
<code>contrast</code>	contrasts and ANOVA-style joint tests of estimates
<code>estat ic</code>	Akaike's and Schwarz's Bayesian information criteria (AIC and BIC)
<code>estat summarize</code>	summary statistics for the estimation sample
<code>estat vce</code>	variance–covariance matrix of the estimators (VCE)
<code>estimates</code>	cataloging estimation results
<code>forecast</code>	dynamic forecasts and simulations
<code>hausman</code>	Hausman's specification test
<code>lincom</code>	point estimates, standard errors, testing, and inference for linear combinations of coefficients
<code>lrtest</code>	likelihood-ratio test
<code>margins</code>	marginal means, predictive margins, marginal effects, and average marginal effects
<code>marginsplot</code>	graph the results from <code>margins</code> (profile plots, interaction plots, etc.)
<code>nlcom</code>	point estimates, standard errors, testing, and inference for nonlinear combinations of coefficients
<code>predict</code>	predictions, residuals, influence statistics, and other diagnostic measures
<code>predictnl</code>	point estimates, standard errors, testing, and inference for generalized predictions
<code>pwcompare</code>	pairwise comparisons of estimates
<code>test</code>	Wald tests of simple and composite linear hypotheses
<code>testnl</code>	Wald tests of nonlinear hypotheses

# predict

## Description for predict

`predict` creates a new variable containing predictions such as linear predictions, standard errors, probabilities, and expected values.

## Menu for predict

Statistics > Postestimation

## Syntax for predict

```
predict [type] newvar [if] [in] [, statistic nooffset]
```

statistic	Description
<hr/>	
Main	
<code>xb</code>	linear prediction; the default
<code>stdp</code>	standard error of the linear prediction
<code>stdf</code>	standard error of the linear forecast
<code>pr(a,b)</code>	$\Pr(a < y < b)$ , marginal with respect to the random effect
<code>e(a,b)</code>	$E(y   a < y < b)$ , marginal with respect to the random effect
<code>ystar(a,b)</code>	$E(y^*)$ , $y^* = \max\{a, \min(y, b)\}$ , marginal with respect to the random effect

These statistics are available both in and out of sample; type `predict ... if e(sample) ...` if wanted only for the estimation sample.

where  $a$  and  $b$  may be numbers or variables;  $a$  missing ( $a \geq .$ ) means  $-\infty$ , and  $b$  missing ( $b \geq .$ ) means  $+\infty$ ; see [\[U\] 12.2.1 Missing values](#).

## Options for predict

### Main

`xb`, the default, calculates the linear prediction  $\mathbf{x}_{it}\beta$  using the estimated fixed effects (coefficients) in the model. This is equivalent to fixing all random effects in the model to their theoretical (prior) mean value of zero.

`stdp` calculates the standard error of the linear prediction. It can be thought of as the standard error of the predicted expected value or mean for the observation's covariate pattern. The standard error of the prediction is also referred to as the standard error of the fitted value.

`stdf` calculates the standard error of the linear forecast. This is the standard error of the point prediction for 1 observation. It is commonly referred to as the standard error of the future or forecast value. By construction, the standard errors produced by `stdf` are always larger than those produced by `stdp`; see [Methods and formulas](#) in [\[R\] regress](#).

`pr(a,b)` calculates estimates of  $\Pr(a < y < b | \mathbf{x} = \mathbf{x}_{it})$ , which is the probability that  $y$  would be observed in the interval  $(a, b)$ , given the current values of the predictors,  $\mathbf{x}_{it}$ . The predictions are calculated marginally with respect to the random effect. That is, the random effect is integrated out of the prediction function. In the discussion that follows, these two conditions are implied.

$a$  and  $b$  may be specified as numbers or variable names;  $lb$  and  $ub$  are variable names;

`pr(20,30)` calculates  $\Pr(20 < y < 30)$ ;

`pr(lb,ub)` calculates  $\Pr(lb < y < ub)$ ; and

`pr(20,ub)` calculates  $\Pr(20 < y < ub)$ .

$a$  missing ( $a \geq .$ ) means  $-\infty$ ; `pr(.,30)` calculates  $\Pr(-\infty < y < 30)$ ;

`pr(lb,30)` calculates  $\Pr(-\infty < y < 30)$  in observations for which  $lb \geq .$

(and calculates  $\Pr(lb < y < 30)$  elsewhere).

$b$  missing ( $b \geq .$ ) means  $+\infty$ ; `pr(20,.)` calculates  $\Pr(+\infty > y > 20)$ ;

`pr(20,ub)` calculates  $\Pr(+\infty > y > 20)$  in observations for which  $ub \geq .$

(and calculates  $\Pr(20 < y < ub)$  elsewhere).

`e(a,b)` calculates estimates of  $E(y | a < y < b, \mathbf{x} = \mathbf{x}_{it})$ , which is the expected value of  $y$  conditional on  $y$  being in the interval  $(a, b)$ , meaning that  $y$  is truncated.  $a$  and  $b$  are specified as they are for `pr()`. The predictions are calculated marginally with respect to the random effect. That is, the random effect is integrated out of the prediction function.

`ystar(a,b)` calculates estimates of  $E(y^* | \mathbf{x} = \mathbf{x}_{it})$ , where  $y^* = a$  if  $y \leq a$ ,  $y^* = b$  if  $y \geq b$ , and  $y^* = y$  otherwise, meaning that  $y^*$  is the censored version of  $y$ .  $a$  and  $b$  are specified as they are for `pr()`. The predictions are calculated marginally with respect to the random effect. That is, the random effect is integrated out of the prediction function.

`nooffset` is relevant only if you specify `offset(varname)` for **xttobit**. It modifies the calculations made by `predict` so that they ignore the offset variable; the linear prediction is treated as  $\mathbf{x}_{it}\beta$  rather than  $\mathbf{x}_{it}\beta + \text{offset}_{it}$ .

## margins

### Description for margins

`margins` estimates margins of response for linear predictions, probabilities, and expected values.

### Menu for margins

Statistics > Postestimation

### Syntax for margins

`margins [marginlist] [, options]`

`margins [marginlist], predict(statistic ...) [predict(statistic ...) ...] [options]`

<i>statistic</i>	Description
<code>xb</code>	linear prediction, the default
<code>pr(a,b)</code>	$\Pr(a < y < b)$ , marginal with respect to the random effect
<code>e(a,b)</code>	$E(y   a < y < b)$ , marginal with respect to the random effect
<code>ystar(a,b)</code>	$E(y^*)$ , $y^* = \max\{a, \min(y, b)\}$ , marginal with respect to the random effect
<code>stdp</code>	not allowed with <code>margins</code>
<code>stdf</code>	not allowed with <code>margins</code>

Statistics not allowed with `margins` are functions of stochastic quantities other than `e(b)`.

For the full syntax, see [\[R\] margins](#).

## Remarks and examples

### ▷ Example 1: Average marginal probabilities at specified covariate values

In example 1 of [\[XT\] xttobit](#), we fit a random-effects model of wages. Say that we want to know how union membership status affects the probability that a worker's wage will be "low", where low means a log wage that is less than the 20th percentile of all observations in our dataset. First, we use `centile` to find the 20th percentile of `ln_wage`:

```
. use https://www.stata-press.com/data/r16/nlswork3
(National Longitudinal Survey. Young Women 14-26 years of age in 1968)
. xttobit ln_wage i.union age grade not_smsa south##c.year, ul(1.9)
(output omitted)
. centile ln_wage, centile(20)
```

Variable	Obs	Percentile	Centile	— Binom. Interp. —	
				[95% Conf. Interval]	
ln_wage	28,534	20	1.301507	1.297063	1.308635

Now, we use `margins` to obtain the effect of union status on the probability that the log of wages is in the bottom 20% of women. Given the results from `centile`, that corresponds to the log of wages being below 1.30. We evaluate the effect for two groups: 1) women age 30 living in the south in 1988 who graduated from high school but had no more schooling and 2) the same group of women who instead graduated from college (`grade=16`).

			Number of obs = 19,224		
Average marginal effects					
Model VCE : OIM					
Expression : Pr(ln_wage<1.30), predict(pr(.,1.30))					
dy/dx w.r.t. : 1.union					
1._at : union = 0					
age = 30					
grade = 12					
south = 1					
year = 88					
2._at : union = 0					
age = 30					
grade = 16					
south = 1					
year = 88					
	Delta-method		[95% Conf. Interval]		
	dy/dx	Std. Err.	z	P> z	
0.union	(base outcome)				
1.union	<u>_at</u>	1	-.0992088	.0057424	-17.28
	<u>_at</u>	2	-.0374347	.0033407	-11.21

Note: dy/dx for factor levels is the discrete change from the base level.

For the first group of women, according to our fitted model, being in a union lowers the probability of being classified as a low-wage worker by almost 10 percentage points. Being a college graduate attenuates this effect to just above 3.7 percentage points.



## Methods and formulas

The following uses the notation introduced in [Remarks and examples](#) of [XT] `xttobit`.

The marginal probability that  $y_{it}$  is observed in the interval  $(\ell\ell_{it}, u\ell_{it})$ , obtained by specifying the option `pr(a,b)`, is calculated as

$$\begin{aligned} \text{pr}(\ell\ell_{it}, u\ell_{it}) &= \Pr(\ell\ell_{it} < \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} < u\ell_{it}) \\ &= \Phi\left(\frac{u\ell_{it} - \mathbf{x}_{it}\hat{\boldsymbol{\beta}}}{\hat{\sigma}}\right) - \Phi\left(\frac{\ell\ell_{it} - \mathbf{x}_{it}\hat{\boldsymbol{\beta}}}{\hat{\sigma}}\right) \end{aligned} \quad (1)$$

where  $\hat{\sigma}$  is the square root of the estimated marginal variance of the linear predictor,  $\sqrt{\hat{\sigma}_\epsilon^2 + \hat{\sigma}_\nu^2}$ .

The `e(a,b)` option computes the expected value of  $y_{it}$  conditional on  $y_{it}$  being in the interval  $(\ell\ell_{it}, u\ell_{it})$ , that is, when  $y_{it}$  is truncated. The expected value is calculated as

$$\begin{aligned} e(\ell\ell_{it}, u\ell_{it}) &= E(\mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} \mid \ell\ell_{it} < \mathbf{x}_{it}\boldsymbol{\beta} + \nu_i + \epsilon_{it} < u\ell_{it}) \\ &= \mathbf{x}_{it}\hat{\boldsymbol{\beta}} - \hat{\sigma} \frac{\phi\left(\frac{u\ell_{it}-\mathbf{x}_{it}\hat{\boldsymbol{\beta}}}{\hat{\sigma}}\right) - \phi\left(\frac{\ell\ell_{it}-\mathbf{x}_{it}\hat{\boldsymbol{\beta}}}{\hat{\sigma}}\right)}{\Phi\left(\frac{u\ell_{it}-\mathbf{x}_{it}\hat{\boldsymbol{\beta}}}{\hat{\sigma}}\right) - \Phi\left(\frac{\ell\ell_{it}-\mathbf{x}_{it}\hat{\boldsymbol{\beta}}}{\hat{\sigma}}\right)} \end{aligned} \quad (2)$$

where  $\phi$  is the normal density and  $\Phi$  is the cumulative normal distribution.

You can also compute the expected value of  $y_{it}$ , where  $y_{it}$  is assumed censored at  $\ell\ell_{it}$  and  $u\ell_{it}$  by specifying the option `ystar(a,b)`. This expected value is

$$y_{it}^* = \begin{cases} \ell\ell_{it} & \text{if } y_{it} \leq \ell\ell_{it} \\ \mathbf{x}_{it}\boldsymbol{\beta} + \epsilon_{it} & \text{if } \ell\ell_{it} < y_{it} < u\ell_{it} \\ u\ell_{it} & \text{if } y_{it} \geq u\ell_{it} \end{cases}$$

This computation can be expressed in several ways, but the most intuitive formulation involves a combination of (1) and (2):

$$E(y_{it}^*) = \text{pr}(-\infty, \ell\ell_{it})\ell\ell_{it} + \text{pr}(\ell\ell_{it}, u\ell_{it})e(\ell\ell_{it}, u\ell_{it}) + \text{pr}(u\ell_{it}, +\infty)u\ell_{it}$$

## Also see

[XT] **xttobit** — Random-effects tobit models

[U] **20 Estimation and postestimation commands**

**xtunitroot** — Panel-data unit-root tests[Description](#)[Options](#)[Acknowledgments](#)[Quick start](#)[Remarks and examples](#)[References](#)[Menu](#)[Stored results](#)[Also see](#)[Syntax](#)[Methods and formulas](#)

## Description

`xtunitroot` performs a variety of tests for unit roots (or stationarity) in panel datasets. The Levin–Lin–Chu (2002), Harris–Tzavalis (1999), Breitung (2000; Breitung and Das 2005), Im–Pesaran–Shin (2003), and Fisher-type (Choi 2001) tests have as the null hypothesis that all the panels contain a unit root. The Hadri (2000) Lagrange multiplier (LM) test has as the null hypothesis that all the panels are (trend) stationary. The top of the output for each test makes explicit the null and alternative hypotheses. Options allow you to include panel-specific means (fixed effects) and time trends in the model of the data-generating process.

## Quick start

Levin–Lin–Chu test that each series `y` within panels contains a unit root using `xtset` data  
`xtunitroot llc y`

As above, but specify 4 lags for the augmented Dickey–Fuller regressions

```
xtunitroot llc y, lags(4)
```

Harris–Tzavalis unit-root test including a time trend

```
xtunitroot ht y, trend
```

Breitung unit-root test with 4 lags to prewhiten the series

```
xtunitroot breitung y, lags(4)
```

Im–Pesaran–Shin unit-root test for the demeaned series `y`

```
xtunitroot ips y, demean
```

Philips–Perron unit-root test of `y` with 1 lag for prewhitening

```
xtunitroot fisher y, pperron lags(1)
```

Hadri Lagrange multiplier stationarity test using Bartlett's kernel with 1 lag to estimate long-run variance

```
xtunitroot hadri y, kernel(bartlett)
```

## Menu

Statistics > Longitudinal/panel data > Unit-root tests

## Syntax

*Levin–Lin–Chu test*

```
xtunitroot llc varname [if] [in] [, LLC_options]
```

*Harris–Tzavalis test*

```
xtunitroot ht varname [if] [in] [, HT_options]
```

*Breitung test*

```
xtunitroot breitung varname [if] [in] [, Breitung_options]
```

*Im–Pesaran–Shin test*

```
xtunitroot ips varname [if] [in] [, IPS_options]
```

*Fisher-type tests (combining p-values)*

```
xtunitroot fisher varname [if] [in], {dfuller|pperron} lags(#) [Fisher_options]
```

*Hadri Lagrange multiplier stationarity test*

```
xtunitroot hadri varname [if] [in] [, Hadri_options]
```

LLC_options	Description
<u>trend</u>	include a time trend
<u>noconstant</u>	suppress panel-specific means
<u>demean</u>	subtract cross-sectional means
<u>lags</u> ( <i>lag_spec</i> )	specify lag structure for augmented Dickey–Fuller (ADF) regressions
<u>kernel</u> ( <i>kernel_spec</i> )	specify method to estimate long-run variance

*lag\_spec* is either a nonnegative integer or one of `aic`, `bic`, or `hqic` followed by a positive integer.

*kernel\_spec* takes the form *kernel* *maxlags*, where *kernel* is one of `bartlett`, `parzen`, or `quadraticspectral` and *maxlags* is either a positive number or one of `nwest` or `llc`.

HT_options	Description
<u>trend</u>	include a time trend
<u>noconstant</u>	suppress panel-specific means
<u>demean</u>	subtract cross-sectional means
<u>altt</u>	make small-sample adjustment to <i>T</i>

Breitung_options	Description
<u>trend</u>	include a time trend
<u>noconstant</u>	suppress panel-specific means
<u>demean</u>	subtract cross-sectional means
<u>robust</u>	allow for cross-sectional dependence
<u>lags</u> (#)	specify lag structure for prewhitening

<i>IPS_options</i>	Description
<u>trend</u>	include a time trend
<u>demean</u>	subtract cross-sectional means
<u>lags(lag_spec)</u>	specify lag structure for ADF regressions

*lag\_spec* is either a nonnegative integer or one of `aic`, `bic`, or `hqic` followed by a positive integer.

<i>Fisher_options</i>	Description
* <u>dfuller</u>	use ADF unit-root tests
* <u>pperron</u>	use Phillips–Perron unit-root tests
* <u>lags(#)</u>	specify lag structure for prewhitening
<u>demean</u>	subtract cross-sectional means
<u>dfuller_opts</u>	any options allowed by the <code>dfuller</code> command
<u>pperron_opts</u>	any options allowed by the <code>pperron</code> command

\* Either `dfuller` or `pperron` is required.

\* `lags(#)` is required.

<i>Hadri_options</i>	Description
<u>trend</u>	include a time trend
<u>demean</u>	subtract cross-sectional means
<u>robust</u>	allow for cross-sectional dependence
<u>kernel(kernel_spec)</u>	specify method to estimate long-run variance

*kernel\_spec* takes the form *kernel* [ # ], where *kernel* is one of `bartlett`, `parzen`, or `quadraticspectral` and # is a positive number.

*varname* may contain time-series operators; see [U] 11.4.4 Time-series varlists.

## Options

### LLC\_options

`trend` includes a linear time trend in the model that describes the process by which the series is generated.

`noconstant` suppresses the panel-specific mean term in the model that describes the process by which the series is generated. Specifying `noconstant` imposes the assumption that the series has a mean of zero for all panels.

`demean` requests that `xtunitroot` first subtract the cross-sectional averages from the series. When specified, for each time period `xtunitroot` computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

`lags(lag_spec)` specifies the lag structure to use for the ADF regressions performed in computing the test statistic.

Specifying `lags(#)` requests that # lags of the series be used in the ADF regressions. The default is `lags(1)`.

Specifying `lags(aic #)` requests that the number of lags of the series be chosen such that the Akaike information criterion (AIC) for the regression is minimized. `xtunitroot llc` will fit ADF regressions with 1 to `#` lags and choose the regression for which the AIC is minimized. This process is done for each panel so that different panels may use ADF regressions with different numbers of lags.

Specifying `lags(bic #)` is just like specifying `lags(aic #)`, except that the Bayesian information criterion (BIC) is used instead of the AIC.

Specifying `lags(hqic #)` is just like specifying `lags(aic #)`, except that the Hannan–Quinn information criterion is used instead of the AIC.

`kernel(kernel_spec)` specifies the method used to estimate the long-run variance of each panel's series. `kernel_spec` takes the form `kernel maxlags`. `kernel` is one of `bartlett`, `parzen`, or `quadraticspectral`. `maxlags` is a number, `nwest` to request the Newey and West (1994) bandwidth selection algorithm, or `llc` to request the lag truncation algorithm in Levin, Lin, and Chu (2002).

Specifying, for example, `kernel(bartlett 3)` requests the Bartlett kernel with 3 lags.

Specifying `kernel(bartlett nwest)` requests the Bartlett kernel with the maximum number of lags determined by the Newey and West bandwidth selection algorithm.

Specifying `kernel(bartlett llc)` requests the Bartlett kernel with a maximum lag determined by the method proposed in Levin, Lin, and Chu's (2002) article:

$$\text{maxlags} = \text{int}\left(3.21T^{1/3}\right)$$

where  $T$  is the number of observations per panel. This is the default.

## HT\_options

`trend` includes a linear time trend in the model that describes the process by which the series is generated.

`noconstant` suppresses the panel-specific mean term in the model that describes the process by which the series is generated. Specifying `noconstant` imposes the assumption that the series has a mean of zero for all panels.

`demean` requests that `xtunitroot` first subtract the cross-sectional averages from the series. When specified, for each time period `xtunitroot` computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

`altt` requests that `xtunitroot` use  $T - 1$  instead of  $T$  in the formulas for the mean and variance of the test statistic under the null hypothesis. When the number of time periods,  $T$ , is small (less than 10 or 15), the test suffers from severe size distortions when fixed effects or time trends are included; in these cases, using `altt` results in much improved size properties at the expense of significantly less power.

## Breitung\_options

`trend` includes a linear time trend in the model that describes the process by which the series is generated.

`noconstant` suppresses the panel-specific mean term in the model that describes the process by which the series is generated. Specifying `noconstant` imposes the assumption that the series has a mean of zero for all panels.

**demean** requests that **xtunitroot** first subtract the cross-sectional averages from the series. When specified, for each time period **xtunitroot** computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

**robust** requests a variant of the test that is robust to cross-sectional dependence.

**lags(#)** specifies the number of lags used to remove higher-order autoregressive components of the series. The Breitung test assumes the data are generated by an AR(1) process; for higher-order processes, the first-differenced and lagged-level data are replaced by the residuals from regressions of those two series on the first # lags of the first-differenced data. The default is to not perform this prewhitening step.

## IPS\_options

**trend** includes a linear time trend in the model that describes the process by which the series is generated.

**demean** requests that **xtunitroot** first subtract the cross-sectional averages from the series. When specified, for each time period **xtunitroot** computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

**lags(lag\_spec)** specifies the lag structure to use for the ADF regressions performed in computing the test statistic. With this option, **xtunitroot** reports Im, Pesaran, and Shin's (2003)  $W_{t\text{-bar}}$  statistic that is predicated on  $T$  going to infinity first, followed by  $N$  going to infinity. By default, no lags are included, and **xtunitroot** instead reports Im, Pesaran, and Shin's  $\tilde{t}\text{-bar}$  and  $Z_{\tilde{t}\text{-bar}}$  statistics that assume  $T$  is fixed while  $N$  goes to infinity, as well as the  $t\text{-bar}$  statistic and exact critical values that assume both  $N$  and  $T$  are fixed.

Specifying **lags(#)** requests that # lags of the series be used in the ADF regressions. By default, no lags are included.

Specifying **lags(aic #)** requests that the number of lags of the series be chosen such that the AIC for the regression is minimized. **xtunitroot llc** will fit ADF regressions with 1 to # lags and choose the regression for which the AIC is minimized. This process is done for each panel so that different panels may use ADF regressions with different numbers of lags.

Specifying **lags(bic #)** is just like specifying **lags(aic #)**, except that the BIC is used instead of the AIC.

Specifying **lags(hqic #)** is just like specifying **lags(aic #)**, except that the Hannan–Quinn information criterion is used instead of the AIC.

If you specify **lags(0)**, then **xtunitroot** reports the  $W_{t\text{-bar}}$  statistic instead of the  $Z_{t\text{-bar}}$ , and  $t\text{-bar}$  statistics.

## Fisher\_options

**dfuller** requests that **xtunitroot** conduct ADF unit-root tests on each panel by using the **dfuller** command. You must specify either the **dfuller** or the **pperron** option.

**pperron** requests that **xtunitroot** conduct Phillips–Perron unit-root tests on each panel by using the **pperron** command. You must specify either the **pperron** or the **dfuller** option.

**lags(#)** specifies the number of lags used to remove higher-order autoregressive components of the series. The Fisher test assumes the data are generated by an AR(1) process; for higher-order processes, the first-differenced and lagged-level data are replaced by the residuals from regressions of those two series on the first # lags of the first-differenced data. **lags(#)** is required.

`demean` requests that `xtunitroot` first subtract the cross-sectional averages from the series. When specified, for each time period `xtunitroot` computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

`dfuller_opts` are any options accepted by the `dfuller` command, including `noconstant`, `trend`, `drift`, and `lags()`. Because `xtunitroot` calls `dfuller` quietly, the `dfuller` option `regress` has no effect. See [TS] `dfuller`.

`pperron_opts` are any options accepted by the `pperron` command, including `noconstant`, `trend`, and `lags()`. Because `xtunitroot` calls `pperron` quietly, the `pperron` option `regress` has no effect. See [TS] `pperron`.

## Hadri\_options

`trend` includes a linear time trend in the model that describes the process by which the series is generated.

`demean` requests that `xtunitroot` first subtract the cross-sectional averages from the series. When specified, for each time period `xtunitroot` computes the mean of the series across panels and subtracts this mean from the series. Levin, Lin, and Chu suggest this procedure to mitigate the impact of cross-sectional dependence.

`robust` requests a variant of the test statistic that is robust to heteroskedasticity across panels.

`kernel(kernel_spec)` requests a variant of the test statistic that is robust to serially correlated errors. `kernel_spec` specifies the method used to estimate the long-run variance of each panel's series. `kernel_spec` takes the form `kernel [#]`. Three kernels are supported: `bartlett`, `parzen`, and `quadraticspectral`.

Specifying, for example, `kernel(bartlett 3)` requests the Bartlett kernel with 3 lags.

If # is not specified, then 1 lag is used.

## Remarks and examples

Remarks are presented under the following headings:

- [Overview](#)
- [Levin–Lin–Chu test](#)
- [Harris–Tsavalis test](#)
- [Breitung test](#)
- [Im–Pesaran–Shin test](#)
- [Fisher-type tests](#)
- [Hadri LM test](#)

## Overview

We consider a simple panel-data model with a first-order autoregressive component:

$$y_{it} = \rho_i y_{i,t-1} + \mathbf{z}'_{it} \boldsymbol{\gamma}_i + \epsilon_{it} \quad (1)$$

where  $i = 1, \dots, N$  indexes panels;  $t = 1, \dots, T_i$  indexes time;  $y_{it}$  is the variable being tested; and  $\epsilon_{it}$  is a stationary error term. The  $\mathbf{z}_{it}$  term can represent panel-specific means, panel-specific means and a time trend, or nothing, depending on the options specified to `xtunitroot`. By default,  $\mathbf{z}_{it} = 1$ , so that the term  $\mathbf{z}'_{it} \boldsymbol{\gamma}_i$  represents panel-specific means (fixed effects). If `trend` is specified,

$\mathbf{z}'_{it} = (1, t)$  so that  $\mathbf{z}'_{it}\gamma_i$  represents panel-specific means and linear time trends. For tests that allow it, specifying `noconstant` omits the  $\mathbf{z}'_{it}\gamma_i$  term. The Im–Pesaran–Shin (`xtunitroot ips`) and Fisher-type (`xtunitroot fisher`) tests allow unbalanced panels, while the remaining tests require balanced panels so that  $T_i = T$  for all  $i$ .

Panel unit-root tests are used to test the null hypothesis  $H_0: \rho_i = 1$  for all  $i$  versus the alternative  $H_a: \rho_i < 1$ . Depending on the test,  $H_a$  may hold, for one  $i$ , a fraction of all  $i$  or all  $i$ ; the output of the respective test precisely states the alternative hypothesis. Equation (1) is often written as

$$\Delta y_{it} = \phi_i y_{i,t-1} + \mathbf{z}'_{it}\gamma_i + \epsilon_{it} \quad (1')$$

so that the null hypothesis is then  $H_0: \phi_i = 0$  for all  $i$  versus the alternative  $H_a: \phi_i < 0$ .

The Hadri LM test for panel stationarity instead assumes the null hypothesis that all panels are stationary versus the alternative that at least some of the panels contain unit roots. We discuss the Hadri LM test in detail later, though for now our remarks focus on tests whose null hypothesis is that the panels contain unit roots.

The various panel unit-root tests implemented by `xtunitroot` differ in several key aspects. First, the Levin–Lin–Chu (`xtunitroot llc`), Harris–Tsavalis (`xtunitroot ht`), and Breitung (`xtunitroot breitung`) tests make the simplifying assumption that all panels share the same autoregressive parameter so that  $\rho_i = \rho$  for all  $i$ . The other tests implemented by `xtunitroot`, however, allow the autoregressive parameter to be panel specific. [Maddala and Wu \(1999\)](#) provide an example of testing whether countries’ economic growth rates converge to a long-run value. Imposing the restriction that  $\rho_i = \rho$  for all  $i$  implies that the rate of convergence would be the same for all countries, an implication that is too restrictive in practice.

Second, the various tests make differing assumptions about the rates at which the number of panels,  $N$ , and the number of time periods,  $T$ , tend to infinity or whether  $N$  or  $T$  is fixed. For microeconomic panels of firms, for example, increasing the sample size would involve gathering data on more firms while holding the number of time periods fixed; here  $N$  tends to infinity whereas  $T$  is fixed. In a macroeconomic analysis of OECD countries, one would typically assume that  $N$  is fixed whereas  $T$  tends to infinity.

Related to the previous point, the size of one’s sample will in large part determine which test is most appropriate in a given situation. If a dataset has a small number of panels and a large number of time periods, then a panel unit-root test that assumes that  $N$  is fixed or that  $N$  tends to infinity at a slower rate than  $T$  will likely perform better than one that is designed for cases where  $N$  is large.

[Hlouskova and Wagner \(2006\)](#) provide a good overview of the types of panel unit-root tests available with `xtunitroot`, and they present exhaustive Monte Carlo simulations examining the tests’ performance. [Baltagi \(2013, chap. 12\)](#) also concisely discusses the tests implemented by `xtunitroot`.

The following table summarizes some of the key differences among the various tests:

Test	Options	Asymptotics	$\rho$ under $H_a$	Panels
LLC	<code>noconstant</code>	$\sqrt{N}/T \rightarrow 0$	common	balanced
LLC		$N/T \rightarrow 0$	common	balanced
LLC	<code>trend</code>	$N/T \rightarrow 0$	common	balanced
HT	<code>noconstant</code>	$N \rightarrow \infty$ , $T$ fixed	common	balanced
HT		$N \rightarrow \infty$ , $T$ fixed	common	balanced
HT	<code>trend</code>	$N \rightarrow \infty$ , $T$ fixed	common	balanced
Breitung	<code>noconstant</code>	$(T, N) \rightarrow_{\text{seq}} \infty$	common	balanced
Breitung		$(T, N) \rightarrow_{\text{seq}} \infty$	common	balanced
Breitung	<code>trend</code>	$(T, N) \rightarrow_{\text{seq}} \infty$	common	balanced
IPS		$N \rightarrow \infty$ , $T$ fixed or $N$ and $T$ fixed	panel-specific	unbalanced
IPS	<code>trend</code>	$N \rightarrow \infty$ , $T$ fixed or $N$ and $T$ fixed	panel-specific	unbalanced
IPS	<code>lags()</code>	$(T, N) \rightarrow_{\text{seq}} \infty$	panel-specific	unbalanced
IPS	<code>trend lags()</code>	$(T, N) \rightarrow_{\text{seq}} \infty$	panel-specific	unbalanced
Fisher-type		$T \rightarrow \infty$ , $N$ finite or infinite	panel-specific	unbalanced
Hadri LM		$(T, N) \rightarrow_{\text{seq}} \infty$	(not applicable)	balanced
Hadri LM	<code>trend</code>	$(T, N) \rightarrow_{\text{seq}} \infty$	(not applicable)	balanced

The first column identifies the test procedure, where we use LLC to denote the Levin–Lin–Chu test, HT to denote the Harris–Tsavalis test, and IPS to denote the Im–Pesaran–Shin test. The second column indicates the deterministic components included in (1) or (1'). The column labeled “Asymptotics” indicates the behavior of the number of panels,  $N$ , and time periods,  $T$ , required for the test statistic to have a well-defined asymptotic distribution. For example, the LLC test without the `noconstant` option requires that  $T$  grow at a faster rate than  $N$  so that  $N/T$  approaches zero; with the `noconstant` option, we need only for  $T$  to grow faster than the square root of  $N$  (so  $T$  could grow more slowly than  $N$ ).

The HT tests and the IPS tests without accommodations for serial correlation assume that the number of time periods,  $T$ , is fixed, whereas  $N$  tends to infinity; xtunitroot also reports critical values for the IPS tests that are valid in finite samples (where  $N$  and  $T$  are fixed).

Many of the tests are justified using sequential limit theory, which we denote as  $(T, N) \rightarrow_{\text{seq}} \infty$ . First, the time dimension goes to infinity, and then the number of panels goes to infinity. As a practical matter, these tests work best with “large”  $T$  and at least “moderate”  $N$ . See Phillips and Moon (2000) for an introduction to asymptotics that depend on both  $N$  and  $T$  and their relation to nonstationary panels. Phillips and Moon (1999) contains a more technical discussion of “multi-indexed” asymptotics.

The fourth column refers to the parameter  $\rho_i$  in (1) and  $\phi_i$  in (1'). As we mentioned previously, some tests assume that all panels have the same autoregressive parameter under the alternative hypothesis of stationarity (denoted “common” in the table), while others allow for panel-specific autoregressive

parameters (denoted “panel-specific” in the table). The Hadri LM tests are not framed in terms of an equation like (1) or (1'), so the distinction based on  $\rho$  is not applicable.

The final column indicates whether the panel dataset must be strongly balanced, meaning each panel has the same number of observations covering the same time span. Except for the Fisher tests, all the tests require that there be no gaps in any panel's series.

We now discuss each test in turn.

## Levin–Lin–Chu test

The starting point for the Levin–Lin–Chu (LLC) test is (1') with the restriction that all panels share a common autoregressive parameter. In a regression model like (1),  $\epsilon_{it}$  is likely to be plagued by serial correlation, so to mitigate this problem, LLC augment the model with additional lags of the dependent variable:

$$\Delta y_{it} = \phi y_{i,t-1} + \mathbf{z}'_{it} \gamma_i + \sum_{j=1}^p \theta_{ij} \Delta y_{i,t-j} + u_{it} \quad (2)$$

The number of lags,  $p$ , can be specified using the `lags()` option, or you can have `xtunitroot llc` select the number of lags that minimizes one of several information criteria. The LLC test assumes that  $\epsilon_{it}$  is independently distributed across panels and follows a stationary invertible autoregressive moving-average process for each panel. By including sufficient lags of  $\Delta y_{i,t}$  in (2),  $u_{it}$  will be white noise; the test does not require  $u_{it}$  to have the same variance across panels.

Under the null hypothesis of a unit root,  $y_{it}$  is nonstationary, so a standard OLS regression  $t$  statistic for  $\phi$  will have a nonstandard distribution that depends in part on the specification of the  $\mathbf{z}_{it}$  term. Moreover, the inclusion of a fixed-effect term in a dynamic model like (2) causes the OLS estimate of  $\phi$  to be biased toward zero; see [Nickell \(1981\)](#). The LLC method produces a bias-adjusted  $t$  statistic, which the authors denote as  $t_\delta^*$ , that has an asymptotically normal distribution.

The LLC test without panel-specific intercepts or time trends, requested by specifying the `noconstant` option with `xtunitroot llc`, is justified asymptotically if  $\sqrt{N}/T \rightarrow 0$ , allowing the time dimension  $T$  to grow more slowly than the cross-sectional dimension  $N$ ; [LLC \(2002\)](#) mention that this assumption is particularly relevant for panel datasets typically encountered in microeconomic applications.

If model (2) includes panel-specific means (the default for `xtunitroot llc`) or time trends (requested with the `trend` option), then you must assume that  $N/T \rightarrow 0$  for the  $t_\delta^*$  statistic to have an asymptotically standard normal distribution. This implies that the time dimension,  $T$ , must grow faster than the cross-sectional dimension,  $N$ , a situation more plausible with macroeconomic datasets.

[LLC \(2002\)](#) recommend using their test with panels of “moderate” size, which they describe as having between 10 and 250 panels and 25 to 250 observations per panel. [Baltagi \(2013, sec. 12.2.3\)](#) mentions that the requirement  $N/T \rightarrow 0$  implies that  $N$  should be small relative to  $T$ .

## □ Technical note

Panel unit-root tests have frequently been used to test the purchasing power parity (PPP) hypothesis. We use a PPP dataset to illustrate the `xtunitroot` command, but understanding PPP is not required to understand how these tests are applied. Here we outline PPP and explain how to test it using panel unit-root tests; uninterested readers can skip the remainder of this technical note. Our discussion and examples are motivated by those in [Oh \(1996\)](#) and [Patterson \(2000, chap. 13\)](#). Also see [Rogoff \(1996\)](#) for a broader introduction to PPP.

The PPP hypothesis is based on the Law of One Price, which stipulates that the price of a tradable good will be the same everywhere. Absolute PPP stipulates that the nominal exchange rate,  $E$ , is

$$E = \frac{P}{P^*}$$

where  $P$  is the price of a basket of goods in the home country and  $P^*$  is the price of the same basket in the foreign country. The exchange rate,  $E$ , indicates the price of a foreign currency in terms of our “home” currency or, equivalently, how many units of the home currency are needed to buy one unit of the foreign currency.

Now consider the real exchange rate,  $\lambda$ , which tells us the prices of goods and services—things we actually consume—in a foreign country relative to their prices at home. We have

$$\lambda = \frac{EP^*}{P} \quad (3)$$

$\lambda$  in general does not equal unity for many reasons, including the fact that not all goods are tradable across countries (haircuts being the textbook example), trade barriers such as tariffs and quotas, differences among countries in how price indices are constructed, and the Harrod–Balassa–Samuelson effect, which links productivity and price levels; see [Obstfeld and Rogoff \(1996, 210–216\)](#).

Taking logs of both sides of (3), we have

$$y \equiv \ln\lambda = \ln E + \ln P^* - \ln P$$

PPP holds only if the real exchange rate reverts to its equilibrium value over time. Thus, to test for PPP, we test whether  $y$  contains a unit root. If  $y$  does contain a unit root, we reject PPP.

The dataset `pennxrate.dta` contains real exchange-rate data based on the Penn World Table version 6.2 ([Heston, Summers, and Aten 2006](#)). The data are a balanced panel consisting of 151 countries observed over 34 years, from 1970 through 2003. The United States was treated as the domestic country and is therefore not included. The variable `lnrxrate` contains the log of the real exchange rate and is the variable on which we conduct panel unit-root tests in the examples.

Two indicator variables are included in the dataset as well. The variable `oecd` flags 27 countries aside from the United States that are members of the Organisation for Economic Co-operation and Development (OECD). (The Czech Republic and the Slovak Republic are excluded because they did not become independent countries until 1993.) The variable `g7` flags the six countries aside from the United States that are members of the Group of Seven (G7) nations.

□

## ▷ Example 1

The dataset `pennxrate.dta` contains real exchange-rate data for a panel of countries observed over 34 years. Here we use the LLC test to determine whether the series `lnrxrate`, the log of real exchange rates, contains a unit root for six nations that are currently in the G7 group of advanced economies. We do not have any reason to believe `lnrxrate` should exhibit a global trend, so we do not include the `trend` option.

Looking at (2), we have no a priori knowledge of the number of lags,  $p$ , needed to ensure that  $u_{it}$  is white noise, so we let `xtunitroot` choose the number of lags for each panel by minimizing the AIC, subject to a maximum of 10 lags.

We type

```
. use https://www.stata-press.com/data/r16/pennxrate
. xtunitroot llc lnrxrate if g7, lags(aic 10)
Levin-Lin-Chu unit-root test for lnrxrate

```

---

Ho: Panels contain unit roots	Number of panels = 6
Ha: Panels are stationary	Number of periods = 34
AR parameter: Common	Asymptotics: N/T -> 0
Panel means: Included	
Time trend: Not included	
ADF regressions: 1.00 lags average (chosen by AIC)	
LR variance: Bartlett kernel, 10.00 lags average (chosen by LLC)	

---

	Statistic	p-value
Unadjusted t	-6.7538	
Adjusted t*	-4.0277	0.0000

---

The header of the output summarizes the exact specification of the test and dataset. Because we did not specify the `noconstant` option, the test allowed for panel-specific means. On average,  $p = 1$  lag of the dependent variable of (2) were included as regressors in the ADF regressions. By default, `xtunitroot` estimated the long-run variance of  $\Delta \ln rxrate_{it}$  by using a Bartlett kernel with an average of 10 lags.

The LLC bias-adjusted test statistic  $t_\delta^* = -4.0277$  is significantly less than zero ( $p < 0.00005$ ), so we reject the null hypothesis of a unit-root [that is, that  $\phi = 0$  in (2)] in favor of the alternative that `lnrxrate` is stationary (that is, that  $\phi < 0$ ). This conclusion supports the PPP hypothesis.

Labeled “Unadjusted t” in the output is a conventional  $t$  statistic for testing  $H_0: \phi = 0$ . When the model does not include panel-specific means or trends, this test statistic has a standard normal limiting distribution and its  $p$ -value is shown in the output; the unadjusted statistic,  $t_\delta$ , diverges to negative infinity if trends or panel-specific constants are included, so a  $p$ -value is not displayed in those cases.

Because the G7 economies have many similarities, our results could be affected by cross-sectional correlation in real exchange rates; O’Connell’s (1998) results showed that the LLC test exhibits severe size distortions in the presence of cross-sectional correlation. LLC (2002) suggested removing cross-sectional averages from the data to help control for this correlation. We can do this by specifying the `demean` option to `xtunitroot`:

. xtunitroot llc lnrxrate if g7, lags(aic 10) demean	
Levin-Lin-Chu unit-root test for lnrxrate	
Ho: Panels contain unit roots	Number of panels = 6
Ha: Panels are stationary	Number of periods = 34
AR parameter: Common	Asymptotics: N/T -> 0
Panel means: Included	
Time trend: Not included	Cross-sectional means removed
ADF regressions: 1.50 lags average (chosen by AIC)	
LR variance: Bartlett kernel, 10.00 lags average (chosen by LLC)	
Statistic	p-value
Unadjusted t	-5.5473
Adjusted t*	-2.0813
	0.0187

Once we control for cross-sectional correlation by removing cross-sectional means, we can no longer reject the null hypothesis of a unit root at the 1% significance level, though we can reject at the 5% level.



Here we chose the number of lags based on the AIC criterion in an admission that we do not know the true number of lags to include in (2). However, the test statistics are derived under the assumption that the lag order,  $p$ , is known. If we happen to choose the wrong number of lags, then the distribution of the test statistic will depart from its expected distribution that assumes  $p$  is known.

## Harris–Tsavalis test

In many datasets, particularly in microeconomics, the time dimension,  $T$ , is small, so tests whose asymptotic properties are established by assuming that  $T$  tends to infinity can lead to incorrect inference. HT (1999) derived a unit-root test that assumes that the time dimension,  $T$ , is fixed. Their simulation results suggest that the test has favorable size and power properties for  $N$  greater than 25, and they report (p. 213) that power improves faster as  $T$  increases for a given  $N$  than when  $N$  increases for a given  $T$ .

The HT test statistic is based on the OLS estimator,  $\rho$ , in the regression model

$$y_{it} = \rho y_{i,t-1} + \mathbf{z}'_{it} \boldsymbol{\gamma}_i + \epsilon_{it} \quad (4)$$

where the term  $\mathbf{z}'_{it} \boldsymbol{\gamma}_i$  allows for panel-specific means and trends and was discussed in [Overview](#). Harris and Tsavalis assume that  $\epsilon_{it}$  is independent and identically distributed (i.i.d.) normal with constant variance across panels. Because of the bias induced by the inclusion of the panel means and time trends in this model, the expected value of the OLS estimator is not equal to unity under the null hypothesis. Harris and Tsavalis derived the mean and standard error of  $\hat{\rho}$  for (4) under the null hypothesis  $H_0: \rho = 1$  when neither panel-specific means nor time trends are included (requested with the `noconstant` option), when only panel-specific means are included (the default), and when both panel-specific means and time trends are included (requested with the `trend` option). The asymptotic distribution of the test statistic is justified as  $N \rightarrow \infty$ , so you should have a relatively large number of panels when using this test. Notice that, like the LLC test, the HT test assumes that all panels share the same autoregressive parameter.

## ► Example 2

Because the HT test is designed for cases where  $N$  is relatively large, here we test whether the series `lnrxrate` contains a unit root using all 151 countries in our dataset. We will again remove cross-sectional means to help control for contemporaneous correlation. We type

<code>. xtunitroot ht lnrxrate, demean</code>		
Harris-Tzavalis unit-root test for <code>lnrxrate</code>		
Ho: Panels contain unit roots	Number of panels = 151	
Ha: Panels are stationary	Number of periods = 34	
AR parameter: Common	Asymptotics: $N \rightarrow \text{Infinity}$	
Panel means: Included	T Fixed	
Time trend: Not included	Cross-sectional means removed	
Statistic	z	p-value
rho	0.8184	-13.1239
		0.0000

Here we strongly reject the null hypothesis of a unit root, again finding support for PPP. The point estimate of  $\rho$  in (4) is 0.8184, and the  $z$  statistic is -13.12. □

Can we directly compare the results from the LLC and HT tests? We used a subset of the data for the LLC test but used all the data for the HT test. That leads to the obvious answer that no, our results are not entirely comparable. However, a more subtle issue regarding the asymptotic properties of the tests also warrants caution when comparing results.

The LLC test assumes that  $N/T \rightarrow 0$ , so  $N$  should be small relative to  $T$ . Moreover, with our exchange-rate dataset, we are much more likely to be able to add more years of data rather than add more countries, because the number of countries in the world is for the most part fixed. Hence, assuming  $T$  grows faster than  $N$  is certainly plausible.

On the other hand, the HT test assumes that  $T$  is fixed whereas  $N$  goes to infinity. Is that assumption plausible for our dataset? As we just mentioned,  $T$  likely grows faster than  $N$  here, so using a test that assumes  $T$  is fixed whereas  $N$  grows is hard to justify with our dataset.

In short, when selecting a panel unit-root test, you must consider the relative sizes of  $N$  and  $T$  and the relative speeds at which they tend to infinity or whether either  $N$  or  $T$  is fixed.

## Breitung test

Both the LLC and HT tests take the approach of first fitting a regression model and subsequently adjusting the autoregressive parameter or its  $t$  statistic to compensate for the bias induced by having a dynamic regressor and fixed effects in the model. The Breitung (2000; Breitung and Das 2005) test takes a different tact, adjusting the data before fitting a regression model so that bias adjustments are not needed.

In the LLC test, additional lags of the dependent variable could be included in (2) to control for serial correlation. The Breitung procedure instead allows for a prewhitening of the series before computing the test. If the `trend` option is not specified, we regress  $\Delta y_{it}$  and  $y_{i,t-1}$  on  $\Delta y_{i,t-1}, \dots, \Delta y_{i,t-p}$  and use the residuals from those regressions in place of  $\Delta y_{i,t}$  and  $y_{i,t-1}$  in computing the test. You specify the number of lags,  $p$ , to use by specifying `lags(#)`. If the `trend` option is specified, then the Breitung method uses a different prewhitening procedure that involves fitting only one (instead of two) preliminary regressions; see *Methods and formulas* for details.

Monte Carlo simulations by Breitung (2000) show that bias-corrected statistics such as LLC's  $t_\delta^*$  suffer from low power, particularly against alternative hypotheses with autoregressive parameters near one and when panel-specific effects are included. In contrast, the Breitung (2000) test statistic exhibits much higher power in these cases. Moreover, the Breitung test has good power even with small datasets ( $N = 25$ ,  $T = 25$ ), though the power of the test appears to deteriorate when  $T$  is fixed and  $N$  is increased.

The Breitung test assumes that the error term  $\epsilon_{it}$  is uncorrelated across both  $i$  and  $t$ . `xtunitroot breitung` optionally also reports a version of the statistic based on Breitung and Das (2005) that is robust to cross-sectional correlation.

## ▷ Example 3

Here we test whether `lnrxrate` contains a unit root for the subset of 27 OECD countries in our dataset. We will use the `robust` option to obtain a test statistic that is robust to cross-sectional correlation, so we will not subtract the cross-sectional means via the `demean` option. We type

```
. xtunitroot breitung lnrxrate if oecd, robust
Breitung unit-root test for lnrxrate

```

---

Ho: Panels contain unit roots	Number of panels = 27
Ha: Panels are stationary	Number of periods = 34
AR parameter: Common	Asymptotics: T,N -> Infinity
Panel means: Included	sequentially
Time trend: Not included	Prewhitening: Not performed

---

	Statistic	p-value
lambda*	-1.6794	0.0465

---

\* Lambda robust to cross-sectional correlation

We can reject the null of a unit root at the 5% level but not at the 1% level.



## Im–Pesaran–Shin test

All the tests we have discussed thus far assume that all panels share a common autoregressive parameter,  $\rho$ . Cultural, institutional, and other factors make such an assumption tenuous for both macro- and microeconometric panel datasets. IPS (2003) developed a set of tests that relax the assumption of a common autoregressive parameter. Moreover, the IPS test does not require balanced datasets, though there cannot be gaps within a panel. The starting point for the IPS test is a set of Dickey–Fuller regressions of the form

$$\Delta y_{it} = \phi_i y_{i,t-1} + \mathbf{z}'_{it} \gamma_i + \epsilon_{it} \quad (5)$$

Notice that here  $\phi$  is panel-specific, indexed by  $i$ , whereas in (2),  $\phi$  is constant. Im, Pesaran, and Shin assume that  $\epsilon_{it}$  is independently distributed normal for all  $i$  and  $t$ , and they allow  $\epsilon_{it}$  to have heterogeneous variances  $\sigma_i^2$  across panels.

As described by Maddala and Wu (1999), one way to view the key difference between the IPS and LLC tests is that here we fit (5) to each panel separately and average the resulting  $t$  statistics, whereas in the LLC test we pool the data before fitting an equation such as (2) (thus we impose a common autoregressive parameter) and compute a test statistic based on the pooled regression results.

Under the null hypothesis that all panels contain a unit root, we have  $\phi_i = 0$  for all  $i$ . The alternative is that the fraction of panels that follow stationary processes is nonzero; that is, as  $N$  tends to infinity, the fraction  $N_1/N$  converges to a nonzero value, where  $N_1$  is the number of panels that are stationary.

Whether you allow for serially correlated errors determines the test statistics produced, and because there are substantive differences in the output, we consider the serially uncorrelated and serially correlated cases separately. First, we consider the serially uncorrelated case, which `xtunitroot` assumes when you do not specify the `lags()` option.

The IPS test allowing for heterogeneous panels with serially uncorrelated errors assumes that the number of time periods,  $T$ , is fixed; `xtunitroot ips` produces statistics both for the case where  $N$  is fixed and for the case where  $N \rightarrow \infty$ . Under the null hypothesis of a unit root, the usual  $t$  statistic,  $t_i$ , for testing  $H_0: \phi_i = 0$  in (5) does not have a mean of zero. For the case where  $N$  is fixed, IPS used simulation to tabulate “exact” critical values for the average of the  $t_i$  statistics when the dataset is balanced; these critical values are not available with unbalanced datasets. The critical values are “exact” only when the error term is normally distributed and when  $T$  corresponds to one of the sample sizes used in their simulation studies. For other values of  $T$ , `xtunitroot ips` linearly interpolates the values in IPS (2003, table 2).

For the case where  $N \rightarrow \infty$ , they used simulation to tabulate the mean and variance of  $t_i$  for various values of  $T$  under the null hypothesis and showed that a bias-adjusted average of the  $t_i$ 's has a standard normal limiting distribution. We illustrate the test with an example.

## ▷ Example 4

Here we test whether `lnrxrate` contains a unit root for the subset of OECD countries. We type

		Number of panels = 27				
		Number of periods = 34				
		Asymptotics: T,N -> Infinity				
		sequentially				
		Cross-sectional means removed				
Ho: All panels contain unit roots						
Ha: Some panels are stationary						
AR parameter: Panel-specific						
Panel means: Included						
Time trend: Not included						
ADF regressions: No lags included						
		Fixed-N exact critical values				
		Statistic	p-value	1%	5%	10%
t-bar		-3.1327		-1.810	-1.730	-1.680
t-tilde-bar		-2.5771				
Z-t-tilde-bar		-7.3911	0.0000			

As with the other unit-root tests available with `xtunitroot`, the header of the output contains a summary of the dataset's dimensions and the null and alternative hypotheses. First, consider the statistic labeled `t-bar`, which IPS denote as  $t\text{-bar}_{NT}$ . This statistic is appropriate when you assume that both  $N$  and  $T$  fixed; exact critical values reported in IPS (2003) are reported immediately to its right. Here, because  $t\text{-bar}_{NT}$  is less than even its 1% critical value, we strongly reject the null hypothesis that all series contain a unit root in favor of the alternative that a nonzero fraction of the panels represent stationary processes.

The statistic labeled `t-tilde-bar` is IPS's  $\tilde{t}\text{-bar}_{NT}$  statistic and is similar to the  $t\text{-bar}_{NT}$  statistic, except that a different estimator of the Dickey–Fuller regression error variance is used. A standardized version of this statistic,  $Z_{\tilde{t}\text{-bar}}$ , is labeled `Z-t-tilde-bar` in the output and has an asymptotic standard

normal distribution. Here the *p*-value corresponding to *Z-t-tilde-bar* is essentially zero, so we strongly reject the null that all series contain a unit root.



## □ Technical note

Just as the  $Z_{\tilde{t}\text{-bar}}$  statistic corresponds to  $\tilde{t}\text{-bar}_{NT}$ , IPS present a  $Z_{t\text{-bar}}$  statistic corresponding to  $t\text{-bar}_{NT}$ . However, the  $Z_{t\text{-bar}}$  statistic does not have an asymptotic normal distribution, and so it is not presented in the output.  $Z_{t\text{-bar}}$  is available in the stored results as `r(zt)`.



When serial correlation is present, we augment the Dickey–Fuller regression with further lags of the dependent variable:

$$\Delta y_{it} = \phi_i y_{i,t-1} + \mathbf{z}'_{it} \boldsymbol{\gamma}_i + \sum_{j=1}^p \Delta y_{i,t-j} + \epsilon_{it} \quad (6)$$

where the number of lags,  $p$ , is specified using the `lags()` option, and if the `trend` option is specified, we also include a time trend with panel-specific slope. You can either specify a number or have `xtunitroot` choose the number of lags for each panel by minimizing an information criterion. Here `xtunitroot` produces the IPS  $W_{t\text{-bar}}$  statistic, which has an asymptotically standard normal distribution as  $T \rightarrow \infty$  followed by  $N \rightarrow \infty$ . As a practical matter, this means you should have a reasonably large number of both time periods and panels to use this test.

Part of the computation of the  $W_{t\text{-bar}}$  statistic involves retrieving expected values and variances of the  $t$  statistic for  $\beta_i$  in (6) in table 3 of IPS (2003). Because expected values have not been computed beyond  $p = 8$  lags in (6), you cannot request more than 8 lags in the `lags()` option.

## ▷ Example 5

We again test whether `lnrxrate` contains a unit root for the subset of OECD countries, except we allow for serially correlated errors. We will choose the number of lags for the ADF regressions by minimizing the AIC criterion, subject to a maximum of 8 lags. We type

```
. xtunitroot ips lnrxrate if oecd, lags(aic 8) demean
Im-Pesaran-Shin unit-root test for lnrxrate

```

---

Ho: All panels contain unit roots	Number of panels = 27
Ha: Some panels are stationary	Number of periods = 34
AR parameter: Panel-specific	Asymptotics: T,N -> Infinity
Panel means: Included	sequentially
Time trend: Not included	Cross-sectional means removed
ADF regressions: 1.48 lags average (chosen by AIC)	

---

	Statistic	p-value
W-t-bar	-7.3075	0.0000



## Fisher-type tests

In our discussion of the IPS test, we intimated that the test statistics could be viewed as averages of bias-adjusted  $t$  statistics for each panel. As [Maddala and Wu \(1999, 635\)](#) describe the IPS test, “... the IPS test is a way of combining the evidence on the unit-root hypothesis from the  $N$  unit-root tests performed on the  $N$  cross-section units.” Fisher-type panel unit-root tests make this approach explicit.

Meta-analysis, frequently used in biostatistics and medical sciences, is the combination of results from multiple studies designed to test a similar hypothesis in order to yield a more decisive conclusion. One type of meta-analysis, first proposed by R. A. Fisher, combines the  $p$ -values from independent tests to obtain an overall test statistic and is frequently called a Fisher-type test. See [Whitehead \(2002, sec. 9.8\)](#) for an introduction. In the context of panel data unit-root tests, we perform a unit-root test on each panel’s series separately, then combine the  $p$ -values to obtain an overall test of whether the panel series contains a unit root.

`xtunitroot fisher` performs either ADF or Phillips–Perron unit-root tests on each panel depending on whether you specify the `dfuller` or `pperron` option. The actual tests are conducted by the `dfuller` and `pperron` commands, and you can specify to `xtunitroot fisher` any options those commands take; see [\[TS\] dfuller](#) and [\[TS\] pperron](#).

`xtunitroot fisher` combines the  $p$ -values from the panel-specific unit-root tests using the four methods proposed by [Choi \(2001\)](#). Three of the methods differ in whether they use the inverse  $\chi^2$ , inverse-normal, or inverse-logit transformation of  $p$ -values, and the fourth is a modification of the inverse  $\chi^2$  transformation that is suitable for when  $N$  tends to infinity. The inverse-normal and inverse-logit transformations can be used whether  $N$  is finite or infinite.

The null hypothesis being tested by `xtunitroot fisher` is that all panels contain a unit root. For a finite number of panels, the alternative is that at least one panel is stationary. As  $N$  tends to infinity, the number of panels that do not have a unit root should grow at the same rate as  $N$  under the alternative hypothesis.

### ▷ Example 6

Here we test for a unit root in `lnrxrate` using all 151 countries in our sample. We will use the ADF test. As before, we do not include a trend in real exchange rates and will therefore not specify the `trend` option. However, because the mean real exchange rate for any country is nonzero, we will specify the `drift` option. We will use two lags in the ADF regressions, and we will remove cross-sectional means by using `demean`. We type

. xtunitroot fisher lnrxrate, dfuller drift lags(2) demean			
Fisher-type unit-root test for lnrxrate			
Based on augmented Dickey-Fuller tests			
Ho: All panels contain unit roots	Number of panels =	151	
Ha: At least one panel is stationary	Number of periods =	34	
AR parameter: Panel-specific	Asymptotics: T -> Infinity		
Panel means: Included	Cross-sectional means removed		
Time trend: Not included	ADF regressions: 2 lags		
Drift term: Included			
	Statistic	p-value	
Inverse chi-squared(302)	P	975.9130	0.0000
Inverse normal	Z	-19.6183	0.0000
Inverse logit t(759)	L*	-20.9768	0.0000
Modified inv. chi-squared	Pm	27.4211	0.0000

P statistic requires number of panels to be finite.  
Other statistics are suitable for finite or infinite number of panels.

All four of the tests strongly reject the null hypothesis that all the panels contain unit roots. Choi's (2001) simulation results suggest that the inverse normal  $Z$  statistic offers the best trade-off between size and power, and he recommends using it in applications. We have observed that the inverse logit  $L^*$  test typically agrees with the  $Z$  test. Under the null hypothesis,  $Z$  has a standard normal distribution and  $L^*$  has a  $t$  distribution with  $5N + 4$  degrees of freedom. Low values of  $Z$  and  $L^*$  cast doubt on the null hypothesis.

When the number of panels is finite, the inverse  $\chi^2$   $P$  test is applicable; this statistic has a  $\chi^2$  distribution with  $2N$  degrees of freedom, and large values are cause to reject the null hypothesis. Under the null hypothesis, as  $T \rightarrow \infty$  followed by  $N \rightarrow \infty$ ,  $P$  tends to infinity so that  $P$  has a degenerate limiting distribution. For large panels, Choi (2001) therefore proposes the modified inverse  $\chi^2$   $P_m$  test which converges to a standard normal distribution; a large value of  $P_m$  casts doubt on the null hypothesis. Choi's simulation results do not reveal a specific value of  $N$  over which  $P_m$  should be preferred to  $P$ , though he mentions that  $N = 100$  is still too small for  $P_m$  to have an approximately normal distribution.



## Hadri LM test

All the tests we have discussed so far take as the null hypothesis that the series contains a unit root. Classical statistical methods are designed to reject the null hypothesis only when the evidence against the null is sufficiently overwhelming. However, because unit-root tests typically are not very powerful against alternative hypotheses of somewhat persistent but stationary processes, reversing roles and testing the null hypothesis of stationarity against the alternative of a unit root is appealing. For pure time series, the KPSS test of Kwiatkowski et al. (1992) is one such test.

The Hadri (2000) LM test uses panel data to test the null hypothesis that the data are stationary versus the alternative that at least one panel contains a unit root. The test is designed for cases with large  $T$  and moderate  $N$ . The motivation for the test is straightforward. Suppose we include a panel-specific time trend (using the `trend` option with `xtunitroot hadri`) and write our series,  $y_{it}$ , as

$$y_{it} = r_{it} + \beta_{it} t + \epsilon_{it}$$

where  $r_{it}$  is a random walk,

$$r_{it} = r_{i,t-1} + u_{it}$$

and  $\epsilon_{it}$  and  $u_{it}$  are zero-mean i.i.d. normal errors. If the variance of  $u_{it}$  were zero, then  $r_{it}$  would collapse to a constant;  $y_{it}$  would therefore be trend stationary. Using this logic, the Hadri LM test tests the hypothesis

$$H_0: \lambda = \frac{\sigma_u^2}{\sigma_\epsilon^2} = 0 \quad \text{versus} \quad H_a: \lambda > 0$$

Two options to `xtunitroot hadri` allow you to relax the assumption that  $\epsilon_{it}$  is i.i.d., though normality is still required. You can specify the `robust` option to obtain a variant of the test that is robust to heteroskedasticity across panels, or you can specify `kernel()` to obtain a variant that is robust to serial correlation and heteroskedasticity. Asymptotically, the Hadri LM test is justified as  $T \rightarrow \infty$  followed by  $N \rightarrow \infty$ . As a practical matter, [Hadri \(2000\)](#) recommends this test for “large”  $T$  and “moderate”  $N$ .

## ▷ Example 7

We now test the null hypothesis that `lnrxrate` is stationary for the subset of OECD countries. To control for serial correlation, we will use a Bartlett kernel with 5 lags. We type

```
. xtunitroot hadri lnrxrate if oecd, kernel(bartlett 5) demean
Hadri LM test for lnrxrate
-----
Ho: All panels are stationary          Number of panels =      27
Ha: Some panels contain unit roots    Number of periods =     34
Time trend: Not included             Asymptotics: T, N -> Infinity
Heteroskedasticity: Robust           sequentially
LR variance: Bartlett kernel, 5 lags Cross-sectional means removed
-----
                           Statistic      p-value
-----  
z                      9.6473       0.0000
```

We strongly reject the null hypothesis that all panels’ series are stationary in favor of the alternative that at least one of them contains a unit root. In contrast, the previous examples generally rejected the null hypothesis that all series contain unit roots in favor of the alternative that at least some are stationary. For cautionary remarks on the use of panel unit-root tests in the examination of PPP, see, for example, [Banerjee, Marcellino, and Osbat \(2005\)](#). In short, our results are qualitatively quite similar to those reported in the literature, though [Banerjee, Marcellino, and Osbat](#) argue that because of cross-unit cointegration and long-run relationships among countries, panel unit-root tests quite often reject the null hypothesis even when true.



## Stored results

`xtunitroot llc` stores the following in `r()`:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(sig_adj)</code>	standard deviation adjustment
<code>r(mu_adj)</code>	mean adjustment
<code>r(delta)</code>	pooled estimate of $\delta$
<code>r(se_delta)</code>	pooled standard error of $\widehat{\delta}$
<code>r(Var_ep)</code>	variance of whitened differenced series
<code>r(sbar)</code>	mean of ratio of long-run to innovation standard deviations
<code>r(ttilde)</code>	observations per panel after lagging and differencing
<code>r(td)</code>	unadjusted $t_\delta$ statistic
<code>r(p_td)</code>	$p$ -value for $t_\delta$
<code>r(tds)</code>	adjusted $t_\delta^*$ statistic
<code>r(p_tds)</code>	$p$ -value for $t_\delta^*$
<code>r(hac_lags)</code>	lags used in HAC variance estimator
<code>r(hac_lagm)</code>	average lags used in HAC variance estimator
<code>r(adf_lags)</code>	lags used in ADF regressions
<code>r(adf_lagm)</code>	average lags used in ADF regressions

Macros

<code>r(test)</code>	<code>llc</code>
<code>r(hac_kernel)</code>	kernel used in HAC variance estimator
<code>r(hac_method)</code>	HAC lag-selection algorithm
<code>r(adf_method)</code>	ADF regression lag-selection criterion
<code>r(demean)</code>	demean, if the data were demeaned
<code>r(deterministics)</code>	noconstant, constant, or trend

`xtunitroot ht` stores the following in `r()`:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(rho)</code>	estimated $\rho$
<code>r(Var_rho)</code>	variance of $\rho$ under $H_0$
<code>r(mean_rho)</code>	mean of $\rho$ under $H_0$
<code>r(z)</code>	$z$ statistic
<code>r(p)</code>	$p$ -value

Macros

<code>r(test)</code>	<code>ht</code>
<code>r(demean)</code>	demean, if the data were demeaned
<code>r(deterministics)</code>	noconstant, constant, or trend
<code>r(altt)</code>	altt, if altt was specified

**xtunitroot breitung** stores the following in **r()**:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(lambda)</code>	test statistic $\lambda$
<code>r(lrobust)</code>	robust test statistic $\lambda_R$
<code>r(p)</code>	<i>p</i> -value for $\lambda$
<code>r(p_lrobust)</code>	<i>p</i> -value for $\lambda_R$
<code>r(lags)</code>	lags used for prewhitening

Macros

<code>r(test)</code>	<code>breitung</code>
<code>r(demean)</code>	demean, if the data were demeaned
<code>r(robust)</code>	robust, if specified
<code>r(deterministics)</code>	noconstant, constant, or trend

**xtunitroot ips** stores the following in **r()**:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(tbar)</code>	test statistic $t\bar{bar}_{NT}$
<code>r(cv_10)</code>	exact 10% critical value for $t\bar{bar}_{NT}$
<code>r(cv_5)</code>	exact 5% critical value for $t\bar{bar}_{NT}$
<code>r(cv_1)</code>	exact 1% critical value for $t\bar{bar}_{NT}$
<code>r(zt)</code>	test statistic $Z_{t\bar{bar}}$
<code>r(ttildebar)</code>	test statistic $t\bar{bar}_{NT}$
<code>r(ztildebar)</code>	test statistic $Z_{\sim t\bar{bar}}$
<code>r(p_ztildebar)</code>	<i>p</i> -value for $Z_{\sim t\bar{bar}}$
<code>r(wtbar)</code>	test statistic $W_{t\bar{bar}}$
<code>r(p_wtbar)</code>	<i>p</i> -value for $W_{t\bar{bar}}$
<code>r(lags)</code>	lags used in ADF regressions
<code>r(lagm)</code>	average lags used in ADF regressions

Macros

<code>r(test)</code>	<code>ips</code>
<code>r(demean)</code>	demean, if the data were demeaned
<code>r(adf_method)</code>	ADF regression lag-selection criterion
<code>r(deterministics)</code>	constant or trend

**xtunitroot fisher** stores the following in **r()**:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(P)</code>	inverse $\chi^2$ $P$ statistic
<code>r(df_P)</code>	$P$ statistic degrees of freedom
<code>r(p_P)</code>	$p$ -value for $P$ statistic
<code>r(L)</code>	inverse logit $L$ statistic
<code>r(df_L)</code>	$L$ statistic degrees of freedom
<code>r(p_L)</code>	$p$ -value for $L$ statistic
<code>r(Z)</code>	inverse normal $Z$ statistic
<code>r(p_Z)</code>	$p$ -value for $Z$ statistic
<code>r(Pm)</code>	modified inverse $\chi^2$ $P_m$ statistic
<code>r(p_Pm)</code>	$p$ -value for $P_m$ statistic

Macros

<code>r(test)</code>	<b>fisher</b>
<code>r(urtest)</code>	<b>dfuller</b> or <b>pperron</b>
<code>r(options)</code>	options passed to <b>dfuller</b> or <b>pperron</b>
<code>r(demean)</code>	demean, if the data were demeaned

**xtunitroot hadri** stores the following in **r()**:

Scalars

<code>r(N)</code>	number of observations
<code>r(N_g)</code>	number of groups
<code>r(N_t)</code>	number of time periods
<code>r(var)</code>	variance of $z$ under $H_0$
<code>r(mu)</code>	mean of $z$ under $H_0$
<code>r(z)</code>	test statistic $z$
<code>r(p)</code>	$p$ -value for $z$
<code>r(lags)</code>	lags used for HAC variance

Macros

<code>r(test)</code>	<b>hadri</b>
<code>r(demean)</code>	demean, if the data were demeaned
<code>r(robust)</code>	robust, if specified
<code>r(kernel)</code>	kernel used for HAC variance
<code>r(deterministics)</code>	constant or trend

## Methods and formulas

Methods and formulas are presented under the following headings:

- [Levin–Lin–Chu test](#)
- [Harris–Tsavalis test](#)
- [Breitung test](#)
  - [Breitung test without trend](#)
  - [Breitung test with trend](#)
- [Im–Pesaran–Shin test](#)
- [Fisher-type tests](#)
- [Hadri LM test](#)

We consider a simple panel-data model with a first-order autoregressive component:

$$y_{it} = \rho_i y_{i,t-1} + \mathbf{z}'_{it} \boldsymbol{\gamma}_i + \epsilon_{it}$$

where  $i = 1, \dots, N$  indexes panels and  $t = 1, \dots, T$  indexes time. For the IPS, Fisher-type, and Hadri LM tests, we instead have  $t = 1, \dots, T_i$ , because they do not require balanced panels.  $\epsilon_{it}$  is a zero-mean error term; we discuss the assumptions about  $\epsilon_{it}$  for each test below. Here we use  $N$  to denote the number of panels, not the total number of observations. By default,  $\mathbf{z}_{it} = 1$ , so that the term  $\mathbf{z}'_{it} \gamma_i$  represents panel-specific means (fixed effects). If `noconstant` is specified,  $\mathbf{z}'_{it} \gamma_i$  vanishes. If `trend` is specified,  $\mathbf{z}'_{it} = (1, t)$  so that  $\mathbf{z}'_{it} \gamma_i$  represents panel-specific means and linear time trends.

## Levin–Lin–Chu test

The starting point for the LLC test is the regression model

$$\Delta y_{it} = \phi y_{i,t-1} + \mathbf{z}'_{it} \gamma_i + \sum_{j=1}^{p_i} \theta_{ij} \Delta y_{i,t-j} + u_{it} \quad (7)$$

In (1'), LLC assume  $\epsilon_{it}$  is independently distributed across panels and follows a stationary invertible process so that with sufficient lags of  $\Delta y_{it}$  included in (7),  $u_{it}$  will be white noise with potentially heterogeneous variance across panels. If `lags(#)` is specified with `xtunitroot llc`, then we set  $p_i = #$  for all panels  $i = 1, \dots, N$ . Otherwise, we fit (7) for each panel individually for lags  $1 \dots p^{\max}$  and choose the lag length,  $p_i$ , that minimizes the information criterion requested by the user. During this step, we restrict estimation to the subset of observations that are valid when  $p^{\max}$  lags are included. Information criteria are defined as follows:

$$\begin{aligned} \text{AIC} &= (-2 \ln L + 2k)/M \\ \text{BIC} &= (-2 \ln L + k \ln M)/M \\ \text{HQIC} &= (-2 \ln L + 2k \ln \ln M)/M \end{aligned}$$

where  $\ln L$  is the log likelihood assuming Gaussian errors,  $M = T - p^{\max} - 2$ , and  $k$  is the number of parameters in (7).

With the lag orders,  $p_i$ , in hand, the test proceeds in three main steps, the first of which is to use panel-by-panel OLS regressions to obtain the orthogonalized residuals

$$\hat{e}_{it} = \Delta y_{it} - \sum_{j=1}^{p_i} \hat{\theta}_{ij} \Delta y_{ij} - \mathbf{z}'_{it} \hat{\gamma}_i \quad (8)$$

and

$$\hat{v}_{i,t-1} = y_{i,t-1} - \sum_{j=1}^{p_i} \tilde{\theta}_{ij} \Delta y_{ij} - \mathbf{z}_{it} \tilde{\gamma}_i \quad (9)$$

To control for panel-level heterogeneity, compute

$$\tilde{e}_{it} = \hat{e}_{it}/\hat{\sigma}_{\epsilon i} \quad \text{and} \quad \tilde{v}_{i,t-1} = \hat{v}_{i,t-1}/\hat{\sigma}_{\epsilon i}$$

where

$$\hat{\sigma}_{\epsilon i}^2 = \frac{1}{T - p_i - 1} \sum_{t=p_i}^T \left( \hat{e}_{it} - \hat{\delta}_i \hat{v}_{i,t-1} \right)^2$$

and  $\hat{\delta}_i$  is the OLS coefficient from a regression of  $\hat{e}_{it}$  on  $\hat{v}_{i,t-1}$ . If time trends are included (by specifying the `trend` option), then a linear time trend is included in regressions (7), (8), and (9).

In the second step, we estimate the ratio of long-run to short-run variances. Under the null hypothesis of a unit root, the long-run variance of the model without panel-specific intercepts or time trends ( $z_{it} = \{\emptyset\}$ ) can be estimated as

$$\hat{\sigma}_{yi}^2 = \frac{1}{T-1} \sum_{t=2}^T \Delta y_{it}^2 + \frac{2}{T-1} \sum_{j=1}^m K(j, m) \left( \sum_{t=j+2}^T \Delta y_{it} \Delta y_{i,t-j} \right)$$

where  $m$  is the maximum number of lags and  $K(j, m)$  is the kernel weight function. Define  $z = j/(m+1)$ . If *kernel* is `bartlett`, then

$$K(j, m) = \begin{cases} 1-z & 0 \leq z \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

If *kernel* is `parzen`, then

$$K(j, m) = \begin{cases} 1 - 6z^2 + 6z^3 & 0 \leq z \leq 0.5 \\ 2(1-z)^3 & 0.5 < z \leq 1 \\ 0 & \text{otherwise} \end{cases}$$

If *kernel* is `quadraticspectral`, then

$$K(j, m) = \begin{cases} 1 & z = 0 \\ 3\{\sin(\theta)/\theta - \cos(\theta)\}/\theta^2 & \text{otherwise} \end{cases}$$

where  $\theta = 6\pi z/5$ . If the user requests automatic bandwidth (lag) selection using the Newey–West algorithm, then we use the method documented in [Methods and formulas](#) of [R] `ivregress` with  $\mathbf{z}_i = \mathbf{h} = 1$ . If automatic lag selection with the LLC algorithm is chosen, then  $m = \text{int}(3.21T^{1/3})$ .

If panel-specific intercepts are included (by not specifying `noconstant`), then in the formula for  $\hat{\sigma}_{yi}^2$  we replace  $\Delta y_{it}$  with  $\Delta y_{it} - \bar{\Delta y}_{it}$ , where  $\bar{\Delta y}_{it}$  is the panel-level mean of  $\Delta y_{it}$  for panel  $i$ . Let  $\hat{s}_i = \hat{\sigma}_{yi}/\hat{\sigma}_{\epsilon i}$ , and denote  $\hat{S}_N = N^{-1} \sum_i \hat{s}_i$ .

In the third step, we run the OLS regression

$$\tilde{e}_{it} = \delta v_{i,t-1} + \tilde{\epsilon}_{it}$$

Called the “Basic test statistic” in the output of `xtunitroot llc` is the standard  $t$  statistic for  $\delta$  computed as

$$t_\delta = \hat{\delta}/\text{se}_{(\hat{\delta})}$$

where

$$\text{se}_{(\hat{\delta})} = \widehat{\sigma}_\epsilon \left( \sum_{i=1}^N \sum_{t=p_i+2}^T \tilde{v}_{i,t-1}^2 \right)^{-1/2}$$

$$\widehat{\sigma}_\epsilon^2 = \frac{1}{N\tilde{T}} \sum_{i=1}^N \sum_{t=p_i+2}^T (\tilde{e}_{it} - \delta \tilde{v}_{i,t-1})^2$$

and  $\tilde{T} = T - \bar{p} - 1$  with  $\bar{p}$  the average of  $p_1, \dots, p_N$ .

The adjusted test statistic is then computed as

$$t_\delta^* = \frac{t_\delta - N\tilde{T}\widehat{S}_N \text{se}_{(\hat{\delta})} \mu_T^*}{\sigma_{\tilde{T}}^*}$$

where  $\mu_T^*$  and  $\sigma_{\tilde{T}}^*$  are obtained by linearly interpolating the values in LLC (2002, table 2).  $t_\delta^*$  is asymptotically  $N(0, 1)$ , with very negative values casting doubt on  $H_0$ . If `noconstant` is specified, then the asymptotic properties hold as  $\sqrt{N}/T \rightarrow \infty$ . Otherwise,  $T$  must grow at a faster rate so that  $N/T \rightarrow \infty$ .

## Harris–Tsavalis test

The starting point for the HT test is (4), where  $\epsilon_{it}$  is assumed to be i.i.d. normal with constant variance across panels. Denote by  $\hat{\rho}$  the least-squares estimate of  $\rho$ .

HT show that  $\sqrt{N}(\hat{\rho} - \mu) \xrightarrow{D} N(0, \sigma^2)$  as  $N \rightarrow \infty$  with  $T$  fixed, where  $\mu$  and  $\sigma^2$  depend on the specification of the deterministic component:

	Option	$\mu$	$\sigma^2$
<code>noconstant</code>		1	$\frac{2}{T(T-1)}$
<code>none</code>		$1 - \frac{3}{T+1}$	$\frac{3(17T^2 - 20T + 17)}{5(T-1)(T+1)^3}$
<code>trend</code>		$1 - \frac{15}{2(T+2)}$	$\frac{15(193T^2 - 728T + 1147)}{112(T+2)^3(T-2)}$

## Breitung test

Suppose the data are generated by an AR(1) process so that we can express  $y_{it}$  as

$$y_{it} = \mathbf{z}'_{it} \gamma_i + x_{it}$$

where

$$x_{it} = \alpha_1 x_{i,t-1} + \alpha_2 x_{i,t-2} + \epsilon_{it}$$

where  $\epsilon_{it}$  is an error term. A prewhitening step is available to correct for serial correlation. The nonrobust version assumes that  $\epsilon_{it}$  is uncorrelated across panels, whereas the robust version allows for the panels to be contemporaneously correlated with covariance matrix  $\Omega$ .

Under the null hypothesis that  $y_{it}$  contains a unit root, that is, that  $y_{it}$  is difference stationary,  $\alpha_1 + \alpha_2 = 1$ . Under the alternative that  $y_{it}$  is stationary,  $\alpha_1 + \alpha_2 < 1$ . Some of the time indices and summation limits of the formulas below appear more complex than those in Breitung (2000) and Breitung and Das (2005) because our formulas make explicit the loss of observations because of the prewhitening step.

### Breitung test without trend

Let  $y_{i,t}^\ell = y_{i,t-1} - y_{i,p+1}$  unless `noconstant` is specified, in which case let  $y_{i,t}^\ell = y_{i,t-1}$ . If the `lags()` option is specified with `xtunitroot breitung`, then we replace  $\Delta y_{it}$  and  $y_{i,t}^\ell$  in the following description with the residuals from running regressions of  $\Delta y_{it}$  and  $y_{i,t}^\ell$  on  $\Delta y_{i,t-1}, \dots, \Delta y_{i,t-p}$ , where  $p$  is the lag order specified in `lags()`.

Define

$$\sigma_i^2 = \frac{1}{T-p-2} \sum_{t=p+2}^T (\Delta y_{it})^2$$

Then

$$\lambda = \frac{\sum_{i=1}^N \sum_{t=p+2}^T y_{it}^\ell \cdot \Delta y_{it} / \sigma_i^2}{\sqrt{\sum_{i=1}^N \sum_{t=p+2}^T (y_{it}^\ell)^2 / \sigma_i^2}}$$

$\lambda$  is asymptotically distributed  $N(0, 1)$  as  $T \rightarrow \infty$  followed by  $N \rightarrow \infty$ ; small values of  $\lambda$  cast doubt on  $H_0$ .

For the robust version of the test statistic, let

$$\phi = \frac{\sum_{i=1}^N \sum_{t=p+2}^T y_{it}^\ell \cdot \Delta y_{it} / \sigma_i^2}{\sum_{i=1}^N \sum_{t=p+2}^T (y_{it}^\ell)^2 / \sigma_i^2}$$

and define  $u_{it} = \Delta y_{it} - \phi y_{it}^\ell$ . Let  $\mathbf{u}_i = (u_{i,p+2}, \dots, u_{iT})'$  and let the  $N \times N$  matrix  $\Omega$  have typical element  $\mathbf{u}_i' \mathbf{u}_j / (T-p-2)$ . Let  $\Delta \mathbf{y}_t = (\Delta y_{1t}, \dots, \Delta y_{Nt})'$  and  $\mathbf{y}_t^\ell = (y_{1,t-1}, \dots, y_{N,t-1})'$ . Then

$$\lambda_{\text{robust}} = \frac{\sum_{t=p+2}^T (\Delta \mathbf{y}_t)' \mathbf{y}_t^\ell}{\sum_{t=p+2}^T (\mathbf{y}_t^\ell)' \Omega \mathbf{y}_t^\ell}$$

For  $\Omega$  to be positive definite, we must have  $T-p-1 \geq N$ . As a practical matter, for  $\Omega$  to have good finite-sample properties, we need  $T \gg N$ .  $\lambda_{\text{robust}}$  is asymptotically distributed  $N(0, 1)$  as  $T \rightarrow \infty$  followed by  $N \rightarrow \infty$ ; very negative values of  $\lambda_{\text{robust}}$  cast doubt on  $H_0$ .

### Breitung test with trend

Let  $p$  denote the number of lags requested in the `lags()` option. We fit the regression

$$\Delta y_{it} = \alpha_{i0} + \sum_{j=1}^p \alpha_{ij} \Delta y_{i,t-j} + \nu_{it}$$

and compute the  $1 \times (T-p-1)$  vectors  $\Delta \mathbf{u}_i$  and  $\mathbf{u}_i^\ell$  with typical elements

$$\Delta u_{is} = \Delta y_{is} - \sum_{j=1}^p \hat{\alpha}_{ij} \Delta y_{i,s-j}$$

and

$$u_{is}^\ell = y_{i,s-1} - \sum_{j=1}^p \hat{\alpha}_{ij} y_{i,s-j-1}$$

for  $s = 1, \dots, T - p - 1$ . Let

$$\sigma_i^2 = \frac{1}{T-p-2} \sum_{s=1}^{T-p-1} (\Delta u_{is} - \bar{\Delta u}_i) \Delta u_{is}$$

where  $\bar{\Delta u}_i$  is the mean of  $\Delta u_{is}$  over  $s$ . Let  $\Delta v_i$  and  $v_i^\ell$  denote  $1 \times (T - p - 1)$  vectors with typical elements

$$\Delta v_{is} = \sqrt{\frac{T-p-s-1}{T-p-s}} \left( \Delta u_{is} - \frac{1}{T-p-s-1} \sum_{j=s+1}^{T-p-1} \Delta u_{ij} \right)$$

and

$$v_{is}^\ell = u_{is}^\ell - u_{i1}^\ell - (T-p-1)\bar{\Delta u}_i$$

Now

$$\lambda = \frac{\sum_{i=1}^N \sum_{s=1}^{T-p-1} v_{is}^\ell \Delta v_{is} / \sigma_i^2}{\sqrt{\sum_{i=1}^N \sum_{s=1}^{T-p-1} (v_{is}^\ell)^2 / \sigma_i^2}}$$

$\lambda$  is asymptotically distributed  $N(0, 1)$  as  $T \rightarrow \infty$  followed by  $N \rightarrow \infty$ ; very negative values of  $\lambda$  cast doubt on  $H_0$ . The computation of the robust form of the statistic proceeds in a fashion entirely analogous to the case without trend.

## Im–Pesaran–Shin test

Write the model as

$$\Delta y_{it} = \phi_i y_{i,t-1} + \mathbf{z}'_{it} \gamma_i + \epsilon_{it}$$

where  $\epsilon_{it}$  is independently distributed normal for all  $i$  and  $t$  with panel-specific variance  $\sigma_i^2$ . Denote  $\Delta \mathbf{y}_i = (\Delta y_{i2}, \dots, \Delta y_{iT})'$  and  $\mathbf{y}_{i,-1} = (y_{i1}, \dots, y_{iT-1})'$ . Note that to be consistent with the notation used in the rest of this documentation, we start the time index at  $t = 1$  instead of  $t = 0$  as in IPS (2003). Also let  $\tau_T$  be a conformable vector of ones,  $\mathbf{M}_\tau = \mathbf{I} - \tau_T (\tau'_T \tau_T)^{-1} \tau'_T$ ,  $\mathbf{X}_i = (\tau_T, \mathbf{y}_{i,-1})$ , and  $\mathbf{M}_{X_i} = \mathbf{I} - \mathbf{X}_i (\mathbf{X}'_i \mathbf{X}_i)^{-1} \mathbf{X}'_i$ .

First, we consider the case of no serial correlation, where the user does not specify the `lags()` option. Then

$$\tilde{t}\text{-bar}_{NT} = \frac{1}{N} \sum_{i=1}^N \tilde{t}_{iT}$$

where

$$\tilde{t}_{iT} = \frac{\Delta \mathbf{y}'_i \mathbf{M}_\tau \mathbf{y}_{i,-1}}{\tilde{\sigma}_{iT} (\mathbf{y}'_{i,-1} \mathbf{M}_\tau \mathbf{y}_{i,-1})^{1/2}}$$

and

$$\tilde{\sigma}_{iT}^2 = \frac{\Delta \mathbf{y}'_i \mathbf{M}_\tau \Delta \mathbf{y}_i}{T-1}$$

Also

$$t\text{-bar}_{NT} = \frac{1}{N} \sum_{i=1}^N t_{iT}$$

where

$$t_{iT} = \frac{\Delta \mathbf{y}'_i \mathbf{M}_\tau \mathbf{y}_{i,-1}}{\widehat{\sigma}_{iT} (\mathbf{y}'_{i,-1} \mathbf{M}_\tau \mathbf{y}_{i,-1})^{1/2}}$$

and

$$\tilde{\sigma}_{iT}^2 = \frac{\Delta \mathbf{y}'_i \mathbf{M}_{X_i} \Delta \mathbf{y}_i}{T-1}$$

Now

$$Z_{\tilde{t}\text{-bar}} = \frac{\sqrt{N} \left\{ \tilde{t}\text{-bar}_{NT} - N^{-1} \sum_{i=1}^N E(\tilde{t}_{T_i}) \right\}}{\sqrt{N^{-1} \sum_i \text{Var}(\tilde{t}_{T_i})}}$$

where  $E(\tilde{t}_{T_i})$  and  $\text{Var}(\tilde{t}_{T_i})$  are obtained by linearly interpolating the values shown in IPS (2003, table 1).  $Z_{\tilde{t}\text{-bar}}$  has a standard normal limiting distribution for fixed  $T$  and  $N \rightarrow \infty$ ; very negative values cast doubt on  $H_0$ . Similarly,

$$Z_{t\text{-bar}} = \frac{\sqrt{N} \left\{ t\text{-bar}_{NT} - N^{-1} \sum_i E(t_{T_i}) \right\}}{\sqrt{N^{-1} \sum_i \text{Var}(t_{T_i})}}$$

If the `lags()` option is specified, then we fit the ADF regressions

$$\Delta y_{it} = \phi_i y_{i,t-1} + \mathbf{z}'_{it} \boldsymbol{\gamma}_i + \sum_{j=1}^{p_i} \rho_{ij} \Delta y_{i,t-j} + \epsilon_i t$$

In matrix form, we can write this more compactly as

$$\Delta \mathbf{y}_i = \phi_i \mathbf{y}_{i,-1} + \mathbf{Q}_i \boldsymbol{\theta}_i + \epsilon_i$$

where  $\mathbf{Q}_i = (\tau_t, \Delta \mathbf{y}_{i,-1}, \dots, \Delta \mathbf{y}_{i,-p_i})$  and  $\boldsymbol{\theta}_i = (\alpha_i, \rho_{i1}, \dots, \rho_{ip_i})'$ . Then

$$t\text{-bar}_{NT} = \frac{1}{N} \sum_{i=1}^N t_{iT}(p_i)$$

where

$$t_{iT}(p_i) = \frac{\sqrt{T-p_i-2} (\mathbf{y}'_{i,-1} \mathbf{M}_{Q_i} \Delta \mathbf{y}_i)}{(\mathbf{y}'_{i,-1} \mathbf{M}_{Q_i} \mathbf{y}_{i,-1})^{1/2} (\Delta \mathbf{y}'_{i,-1} \mathbf{M}_{Q_i} \Delta \mathbf{y}_{i,-1})^{1/2}}$$

where  $\mathbf{M}_{Q_i} = \mathbf{I} - \mathbf{Q}_i (\mathbf{Q}'_i \mathbf{Q}_i)^{-1} \mathbf{Q}'_i$ ,  $\mathbf{M}_{X_i} = \mathbf{I} - \mathbf{X}_i (\mathbf{X}'_i \mathbf{X}_i)^{-1} \mathbf{X}'_i$ , and  $\mathbf{X}_i = (\mathbf{y}_{i,-1}, \mathbf{Q}_i)$ . Finally,

$$\mathbf{W}_{t\text{-bar}}(p) = \frac{\sqrt{N} \left[ t\text{-bar}_{NT} - N^{-1} \sum_{i=1}^N E \{ t_{iT}(p_i) \} \right]}{\sqrt{N^{-1} \sum_{i=1}^N \text{Var} \{ t_{iT}(p_i) \}}}$$

where  $E \{ t_{iT}(p_i) \}$  and  $\text{Var} \{ t_{iT}(p_i) \}$  are obtained by linearly interpolating the values shown in IPS (2003, table 3).  $\mathbf{W}_{t\text{-bar}}(p)$  has a standard normal limiting distribution as  $T \rightarrow \infty$  followed by  $N \rightarrow \infty$ ; very negative values cast doubt on  $H_0$ .

## Fisher-type tests

We use `dfuller` or `pperron` to perform unit-root tests on each panel; denote the  $p$ -value for the respective test on the  $i$ th panel as  $p_i$ . All of these tests are predicated on  $T \rightarrow \infty$  so that the unit-root test for each panel is consistent. The  $P$  test is for finite  $N$ ; the other tests are valid whether  $N$  is finite or infinite. Then

$$P = -2 \sum_{i=1}^N \ln(p_i)$$

$P \sim \chi^2(2N)$  and large values cast doubt on  $H_0$ .

$$Z = \frac{1}{\sqrt{N}} \sum_{i=1}^N \Phi^{-1}(p_i)$$

where  $\Phi^{-1}()$  is the inverse of the standard normal cumulative distribution function.  $Z \sim N(0, 1)$ ; very negative values of  $Z$  cast doubt on  $H_0$ .

$$L = \sum_{i=1}^N \ln \left( \frac{p_i}{1 - p_i} \right)$$

$L^* = \sqrt{k}L \sim t(5N + 4)$  where

$$k = \frac{3(5N + 4)}{\pi^2 N(5N + 2)}$$

Very negative values of  $L^*$  cast doubt on  $H_0$ . Finally,

$$P_m = -\frac{1}{\sqrt{N}} \sum_{i=1}^N \{ \ln(p_i) + 1 \}$$

$P_m \sim N(0, 1)$ ; very positive values of  $P_m$  cast doubt on  $H_0$ .

## Hadri LM test

As discussed in the main text, the Hadri LM test can be viewed as a test of  $H_0 : \sigma_u^2/\sigma_\epsilon^2 = 0$ , where both  $u_{it}$  and  $\epsilon_{it}$  are normally distributed random errors.

Let  $\hat{\epsilon}_{it}$  denote the residuals from a regression of  $y_{it}$  on a panel-specific intercept or a panel-specific intercept and time trend if `trend` is specified. Then

$$\widehat{\text{LM}} = \frac{\frac{1}{N} \sum_i \frac{1}{T^2} \sum_t S_{it}^2}{\widehat{\sigma}_\epsilon^2} \tag{10}$$

where

$$S_{it} = \sum_{j=1}^t \hat{\epsilon}_{ij}$$

and

$$\widehat{\sigma}_\epsilon^2 = \frac{1}{NT'} \sum_{i=1}^N \sum_{t=1}^T \hat{\epsilon}_{it}^2$$

where  $T' = T - 2$  if `trend` is specified and  $T' = T - 1$  otherwise. Then

$$Z = \frac{\sqrt{N} (\widehat{\text{LM}} - \mu)}{\sigma}$$

where  $\mu = 1/15$  and  $\sigma^2 = 11/6300$  if `trend` is specified and  $\mu = 1/6$  and  $\sigma^2 = 1/45$  otherwise.  $Z \sim N(0, 1)$  asymptotically as  $T \rightarrow \infty$  followed by  $N \rightarrow \infty$ . Very positive values of  $Z$  cast doubt on  $H_0$ . If `robust` is specified, then we instead use

$$\widehat{\text{LM}} = \frac{1}{N} \sum_{i=1}^N \left( \frac{\sum_{t=1}^T S_{it}^2}{T^2 \widehat{\sigma}_{\epsilon,i}^2} \right)$$

where we calculate  $\widehat{\sigma}_{\epsilon,i}^2$  individually for each panel:

$$\widehat{\sigma}_{\epsilon,i}^2 = \frac{1}{T'} \sum_{t=1}^{T'} \widehat{\epsilon}_{it}^2$$

If `kernel()` is specified, then we use (10) with

$$\widehat{\sigma}_{\epsilon}^2 = \frac{1}{N} \sum_{i=1}^N \left\{ \frac{1}{T} \sum_{t=p+1}^T \widehat{\epsilon}_{it}^2 + \frac{2}{T} \sum_{j=1}^m K(j, m) \sum_{t=j+1}^T \widehat{\epsilon}_{it} \widehat{\epsilon}_{i,t-j} \right\}$$

where  $m$  is the maximum number of lags and  $K(\cdot, \cdot)$  is the kernel function defined previously.

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## Also see

- [XT] **xtcointtest** — Panel-data cointegration tests
- [TS] **dfglss** — DF-GLS unit-root test
- [TS] **dfuller** — Augmented Dickey–Fuller unit-root test
- [TS] **pperron** — Phillips–Perron unit-root test

# Glossary

**Arellano–Bond estimator.** The Arellano–Bond estimator is a generalized method of moments (GMM) estimator for linear dynamic panel-data models that uses lagged levels of the endogenous variables as well as first differences of the exogenous variables as instruments. The Arellano–Bond estimator removes the panel-specific heterogeneity by first-differencing the regression equation.

**autoregressive process.** In autoregressive processes, the current value of a variable is a linear function of its own past values and a white-noise error term. For panel data, a first-order autoregressive process, denoted as an AR(1) process, is  $y_{it} = \rho y_{i,t-1} + \epsilon_{it}$ , where  $i$  denotes panels,  $t$  denotes time, and  $\epsilon_{it}$  is white noise.

**balanced data.** A longitudinal or panel dataset is said to be balanced if each panel has the same number of observations. See also *weakly balanced* and *strongly balanced*.

**between estimator.** The between estimator is a panel-data estimator that obtains its estimates by running OLS on the panel-level means of the variables. This estimator uses only the between-panel variation in the data to identify the parameters, ignoring any within-panel variation. For it to be consistent, the between estimator requires that the panel-level means of the regressors be uncorrelated with the panel-specific heterogeneity terms.

**canonical link.** Corresponding to each family of distributions in a generalized linear model is a canonical link function for which there is a sufficient statistic with the same dimension as the number of parameters in the linear predictor. The use of canonical link functions provides the GLM with desirable statistical properties, especially when the sample size is small.

**conditional fixed-effects model.** In general, including panel-specific dummies to control for fixed effects in nonlinear models results in inconsistent estimates. For some nonlinear models, the fixed-effect term can be removed from the likelihood function by conditioning on a sufficient statistic. For example, the conditional fixed-effect logit model conditions on the number of positive outcomes within each panel.

**conditional hazard function.** In the context of random-effects survival models, the conditional hazard function is the hazard function computed conditionally on the random effects. Even within the same covariate pattern, the conditional hazard function varies among individuals who belong to different random-effects clusters.

**conditional hazard ratio.** In the context of random-effects survival models, the conditional hazard ratio is the ratio of two conditional hazard functions evaluated at different values of the covariates. Unless stated differently, the denominator corresponds to the conditional hazard function at baseline, that is, with all the covariates set to zero.

**correlation structure.** A correlation structure is a set of assumptions imposed on the within-panel variance–covariance matrix of the errors in a panel-data model. See [[XT](#)] `xtgee` for examples of different correlation structures.

**cross-sectional data.** Cross-sectional data refers to data collected over a set of individuals, such as households, firms, or countries sampled from a population at a given point in time.

**cross-sectional time-series data.** Cross-sectional time-series data is another name for panel data. The term *cross-sectional time-series data* is sometimes reserved for datasets in which a relatively small number of panels were observed over many periods. See also *panel data*.

**disturbance term.** The disturbance term encompasses any shocks that occur to the dependent variable that cannot be explained by the conditional (or deterministic) portion of the model.

**dynamic model.** A dynamic model is one in which prior values of the dependent variable or disturbance term affect the current value of the dependent variable.

**endogenous variable.** An endogenous variable is a regressor that is correlated with the unobservable error term. Equivalently, an endogenous variable is one whose values are determined by the equilibrium or outcome of a structural model.

**error-components model.** The error-components model is another name for the random-effects model. See also *random-effects model*.

**exogenous variable.** An exogenous variable is a regressor that is not correlated with any of the unobservable error terms in the model. Equivalently, an exogenous variable is one whose values change independently of the other variables in a structural model.

**fixed-effects model.** The fixed-effects model is a model for panel data in which the panel-specific errors are treated as fixed parameters. These parameters are panel-specific intercepts and therefore allow the conditional mean of the dependent variable to vary across panels. The linear fixed-effects estimator is consistent, even if the regressors are correlated with the fixed effects. See also *random-effects model*.

**generalized estimating equations (GEE).** The method of generalized estimating equations is used to fit population-averaged panel-data models. GEE extends the GLM method by allowing the user to specify a variety of different within-panel correlation structures.

**generalized linear model.** The generalized linear model is an estimation framework in which the user specifies a distributional family for the dependent variable and a link function that relates the dependent variable to a linear combination of the regressors. The distribution must be a member of the exponential family of distributions. The generalized linear model encompasses many common models, including linear, probit, and Poisson regression.

**idiosyncratic error term.** In longitudinal or panel-data models, the idiosyncratic error term refers to the observation-specific zero-mean random-error term. It is analogous to the random-error term of cross-sectional regression analysis.

**instrumental variables.** Instrumental variables are exogenous variables that are correlated with one or more of the endogenous variables in a structural model. The term *instrumental variable* is often reserved for those exogenous variables that are not included as regressors in the model.

**instrumental-variables (IV) estimator.** An instrumental variables estimator uses instrumental variables to produce consistent parameter estimates in models that contain endogenous variables. IV estimators can also be used to control for measurement error.

**interval data.** Interval data are data in which the true value of the dependent variable is not observed. Instead, all that is known is that the value lies within a given interval.

**link function.** In a generalized linear model, the link function relates a linear combination of predictors to the expected value of the dependent variable. In a linear regression model, the link function is simply the identity function.

**longitudinal data.** Longitudinal data is another term for panel data. See also *panel data*.

**negative binomial regression model.** The negative binomial regression model is for applications in which the dependent variable represents the number of times an event occurs. The negative binomial regression model is an alternative to the Poisson model for use when the dependent variable is overdispersed, meaning that the variance of the dependent variable is greater than its mean.

**overidentifying restrictions.** The order condition for model identification requires that the number of exogenous variables excluded from the model be at least as great as the number of endogenous regressors. When the number of excluded exogenous variables exceeds the number of endogenous regressors, the model is overidentified, and the validity of the instruments can then be checked via a test of overidentifying restrictions.

**panel data.** Panel data are data in which the same units were observed over multiple periods. The units, called panels, are often firms, households, or patients who were observed at several points in time. In a typical panel dataset, the number of panels is large, and the number of observations per panel is relatively small.

**panel-corrected standard errors (PCSEs).** The term *panel-corrected standard errors* refers to a class of estimators for the variance–covariance matrix of the OLS estimator when there are relatively few panels with many observations per panel. PCSEs account for heteroskedasticity, autocorrelation, or cross-sectional correlation.

**Poisson regression model.** The Poisson regression model is used when the dependent variable represents the number of times an event occurs. In the Poisson model, the variance of the dependent variable is equal to the conditional mean.

**pooled estimator.** A pooled estimator ignores the longitudinal or panel aspect of a dataset and treats the observations as if they were cross-sectional.

**population-averaged model.** A population-averaged model is used for panel data in which the parameters measure the effects of the regressors on the outcome for the average individual in the population. The panel-specific errors are treated as uncorrelated random variables drawn from a population with zero mean and constant variance, and the parameters measure the effects of the regressors on the dependent variable after integrating over the distribution of the random effects.

**predetermined variable.** A predetermined variable is a regressor in which its contemporaneous and future values are not correlated with the unobservable error term but past values are correlated with the error term.

**prewhiten.** To prewhiten is to apply a transformation to a time series so that it becomes white noise.

**production function.** A production function describes the maximum amount of a good that can be produced, given specified levels of the inputs.

**quadrature.** Quadrature is a set of numerical methods to evaluate a definite integral.

**random-coefficients model.** A random-coefficients model is a panel-data model in which group-specific heterogeneity is introduced by assuming that each group has its own parameter vector, which is drawn from a population common to all panels.

**random-effects model.** A random-effects model for panel data treats the panel-specific errors as uncorrelated random variables drawn from a population with zero mean and constant variance. The regressors must be uncorrelated with the random effects for the estimates to be consistent. See also *fixed-effects model*.

**regressand.** The regressand is the variable that is being explained or predicted in a regression model. Synonyms include dependent variable, left-hand-side variable, and *endogenous variable*.

**regressor.** Regressors are variables in a regression model used to predict the regressand. Synonyms include independent variable, right-hand-side variable, explanatory variable, predictor variable, and *exogenous variable*.

**robust standard errors.** Robust standard errors, also known as Huber/White or Taylor linearization standard errors, are based on the sandwich estimator of variance. Robust standard errors can be

interpreted as representing the sample-to-sample variability of the parameter estimates, even when the model is misspecified. See also [semirobust standard errors](#).

**semirobust standard errors.** Semirobust standard errors are closely related to robust standard errors and can be interpreted as representing the sample-to-sample variability of the parameter estimates, even when the model is misspecified, as long as the mean structure of the model is specified correctly. See also [robust standard errors](#).

**sequential limit theory.** The sequential limit theory is a method of determining asymptotic properties of a panel-data statistic in which one index, say,  $N$ , the number of panels, is held fixed, while  $T$ , the number of time periods, goes to infinity, providing an intermediate limit. Then one obtains a final limit by studying the behavior of this intermediate limit as the other index ( $N$  here) goes to infinity.

**strongly balanced.** A longitudinal or panel dataset is said to be strongly balanced if each panel has the same number of observations and the observations for different panels were all made at the same times.

**unbalanced data.** A longitudinal or panel dataset is said to be unbalanced if each panel does not have the same number of observations. See also [weakly balanced](#) and [strongly balanced](#).

**weakly balanced.** A longitudinal or panel dataset is said to be weakly balanced if each panel has the same number of observations but the observations for different panels were not all made at the same times.

**white noise.** A variable  $u_t$  represents a white-noise process if the mean of  $u_t$  is zero, the variance of  $u_t$  is  $\sigma^2$ , and the covariance between  $u_t$  and  $u_s$  is zero for all  $s \neq t$ .

**within estimator.** The within estimator is a panel-data estimator that removes the panel-specific heterogeneity by subtracting the panel-level means from each variable and then performing ordinary least squares on the demeaned data. The within estimator is used in fitting the linear fixed-effects model.

# **Subject and author index**

See the [combined subject index](#) and the [combined author index](#) in the *Glossary and Index*.