Instrumental Variables

Understanding IV

MIXTAPE SESSIONS

Roadmap

Subtlties of the Validity Condition

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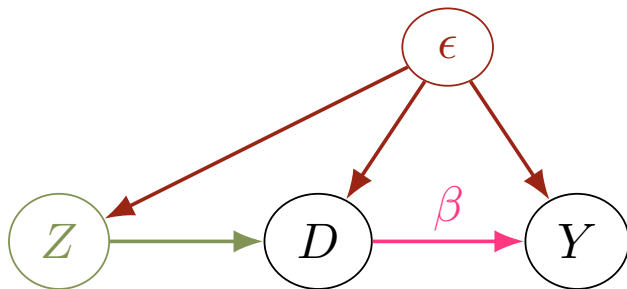
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- More modern IV texts take care to distinguish between these two conceptually distinct requirements...
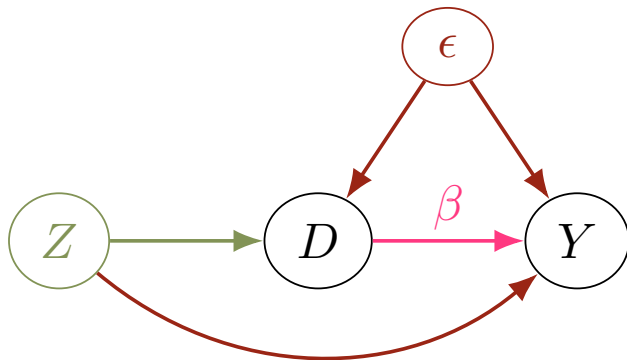
A Valid Instrument
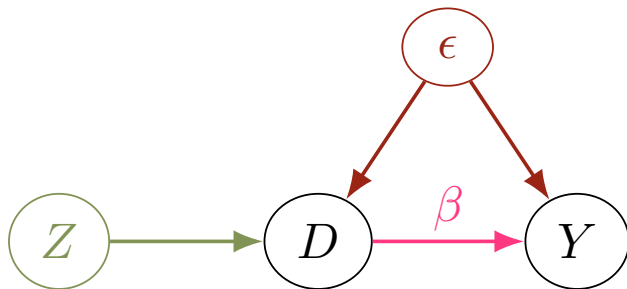
A Violation of As-Good-As-Random Assignment

A Violation of Exclusion

Where do IVs Come From?

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"Gold standard" IV: a randomized offer to participate in a program, with D_i recording program participation

- Exclusion restriction likely to hold for any Y_i, by construction
- Relevance almost guaranteed (provided people want the program!)

Example

Charter School Lotteries

Abdulkadiroglu et al. (2016) are interested in whether going to a "charter" middle school increases standardized test scores

- Charter students tend to score better, but we worry about selection
- History of doubting educational inputs, since Coleman (1966)

Example

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We study a particular charter (UP Academy), which is "takeover"

- Two offer IVs: "immediate" (on lottery night) and from a waitlist

Lottery IV Estimates of UP Test Score Effects

TABLE 8—LOTTERY IV ESTIMATES OF UP EFFECTS

| | | Comparison group mean (1) | OLS (2) | 2SLS | | |
| | | | | First stage | | |
				Immediate offer (3)	Waitlist offer (4)	Enrollment effect (5)
Panel A. All grades (Sixth through eighth)	Math (N = 2,202)	0.059	0.301 (0.022)	0.760 (0.063)	0.562 (0.067)	0.270 (0.056)
	ELA (N = 2,205)	0.103	0.148 (0.020)	0.759 (0.063)	0.562 (0.067)	0.118 (0.051)

Where do IVs Come From?

Without appealing to literal randomization, we may credibly argue Z_i is as-good-as-randomly assigned conditional on some $\mathbf{W}_i$

- Such "natural experiments" rely on a selection-on-observables argument (for Z_i, instead D_i)

- Still worry about exclusion: Z_i cannot affect Y_i except through D_i

Example

Quarter-of-Birth

Angrist and Krueger (1991) famously estimate labor market returns to schooling with a creative IV: student quarter-of-birth

- Compulsory schooling requirements prevent students from dropping before the day they turn 16 (used to be more binding)
- Fixed school start dates mean students who drop out at 16 get more or less schooling depending on their birth date

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- Compulsory schooling requirements prevent students from dropping before the day they turn 16 (used to be more binding)
- Fixed school start dates mean students who drop out at 16 get more or less schooling depending on their birth date
- Quarter-of-birth seems quasi-randomly assigned — is it excludable? See Buckles and Hungerman (2013)…

The Quarter-of-Birth Natural Experiment: Visualized

A. Average Education by Quarter of Birth (first stage)
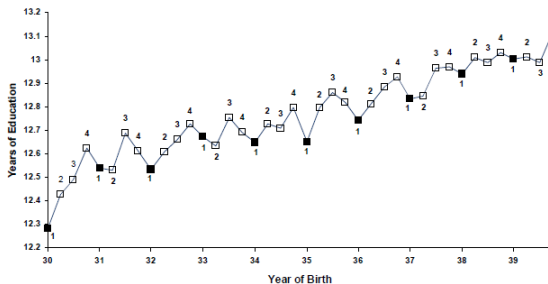
B. Average Weekly Wage by Quarter of Birth (reduced form)
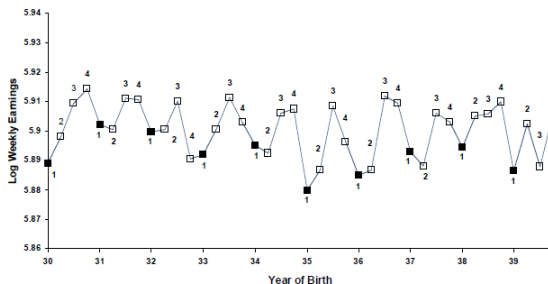
Quarter-of-Birth IV Estimates of Returns to Schooling

Table 4.1.1: 2SLS estimates of the economic returns to schooling

	OLS		2SLS			
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Years of education	0.075	0.072	0.103	0.112	0.106	0.108
	(0.0004)	(0.0004)	(0.024)	(0.021)	(0.026)	(0.019)
Covariates:						
9 year of birth dummies		✓			✓	✓
50 state of birth dummies		✓			✓	✓
Instruments:			dummy for QOB=1	dummy for QOB=1 or QOB=2	dummy for QOB=1	full set of QOB dummies

Where do IVs Come From?

We might also combine IV + difference-in-differences identification

- E.g. instrument with $Z_i \times Post_t$, controlling for Z_i and $Post_t$ FEs

- This requires two parallel trends assumptions, for the RF and FS

- Still need to worry about the exclusion restriction, as always

Example

Charter School Takeovers

In Abdulkadiroglu et al. (2016), we complement the lottery analysis of takeover charters with an instrumented diff-in-diff analysis
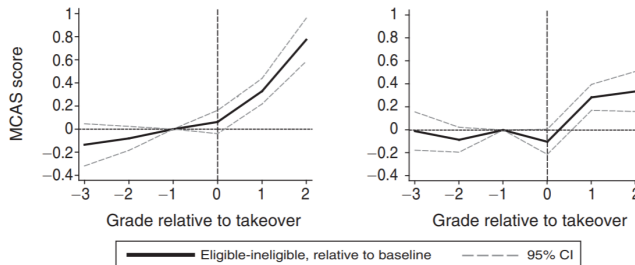
- Students enrolled in the "legacy" public school were eligible for being "grandfathered" into UP, without having to apply to the charter
- We compare their trends in test scores & enrollment to a matched comparison group of observably-similar students at other schools

Grandfathering IV: Visualized

Panel A. Score levels
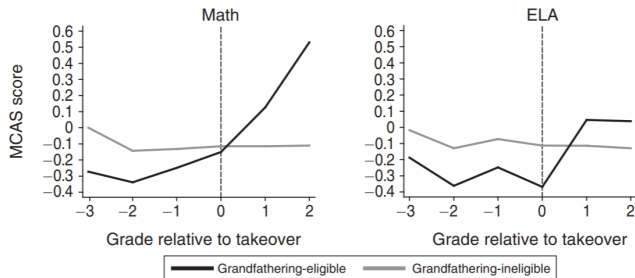
Panel B. Score DD

Grandfathering IV Estimates of UP Test Score Effects

		Comparison group mean (1)	OLS (2)	2SLS	
				First stage (3)	Enrollment effect (4)
Panel A. All grades (Seventh through eighth)	Math (N = 1,543)	−0.233	0.400 (0.032)	1.051 (0.040)	0.321 (0.039)
	ELA (N = 1,539)	−0.214	0.296 (0.035)	1.040 (0.041)	0.394 (0.044)

Roadmap

Just-Identified IV

Tthe Stata `ivregress`/`ivreg2` commands (or `fixest::feols` in R) allows for controls and multiple treatments / instruments

- When # treatment = # instruments, we say the IV is "just-identified":

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$$Y_i = \beta D_i + \mathbf{W}_i'\boldsymbol{\gamma} + \varepsilon_i \text{ (second stage)}$$

$$D_i = \pi Z_i + \mathbf{W}_i'\boldsymbol{\mu} + \eta_i \text{ (first stage)}$$

where $\mathbf{W}_i$ includes a constant.

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The reduced form is:

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- Can use Frisch-Waugh-Lovell to "partial out" $\mathbf{W}_i$ from Y_i, X_i, D_i, and so get back to an IV regression without controls

Overidentification

Sometimes we have more than one instrument $Z_{i\ell}$, for $\ell = 1, \ldots, L$.

This leads to an "overidentified" IV regression:

$$Y_i = \beta D_i + \mathbf{W}_i'\boldsymbol{\gamma} + \varepsilon_i \quad \text{(second stage)}$$

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where $\mathbf{Z}_i = [Z_{i1}, \ldots, Z_{iL}]'$. Reduced form: $Y_i = \mathbf{Z}_i'\boldsymbol{\rho} + \mathbf{W}_i'\boldsymbol{\kappa} + \nu_i$

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Overidentification can yield tests of IV validity

- Intuitively, 2SLS checks whether all the $Z_{i\ell}$ yields the same IV
  estimate, which is sensible in a constant-effects model...

Putting the "2S" in "2SLS"

You'll notice I haven't actually defined 2SLS beyond the simple case

- Before we had $\beta^{IV} = \frac{Cov(Z_i, Y_i)}{Cov(Z_i, D_i)}$ leading to $\widehat{\beta}^{IV} = \frac{\widehat{Cov}(Z_i, Y_i)}{\widehat{Cov}(Z_i, D_i)}$
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- First regress D_i on all instruments $Z_{i\ell}$ and controls W_{ik}
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The proof of this follows from some (simple) linear algebra

- Intuitively, regressing Y_i on $\widehat{\pi}^{OLS} Z_i$ gives a scaled RF:

$$\widehat{\beta}^{IV} = \frac{\widehat{\rho}^{OLS}}{\widehat{\pi}^{OLS}}$$

Avoid Manual 2SLS!

Although easy, you should never do such "manual 2SLS" yourself!

- Your point estimates will be right, but your SEs won't be!

- Also might forget to include some controls in the second stage, etc

Just let Stata/R do everything for you...

2SLS Done Right

```
IV (2SLS) estimation


Estimates efficient for homoskedasticity only
Statistics robust to heteroskedasticity

                                              Number of obs =         69
                                              F(  2,   66) =        5.16
                                              Prob > F     =     0.0083
Total (centered) SS   =  576796958.9          Centered R2  =    -2.5922
Total (uncentered) SS =  3183192639           Uncentered R2 =    0.3491
Residual SS           =  2071965250           Root MSE     =       5480
```

price	Coef.	Robust Std. Err.	z	P>|z|	[95% Conf. Interval]
mpg	1404.283	1499.569	0.94	0.349	-1534.819 4343.384
weight	10.38214	8.57869	1.21	0.226	-6.431778 27.19607
_cons	-55229.89	57542.19	-0.96	0.337	-168010.5 57550.73

```
Underidentification test (Kleibergen-Paap rk LM statistic):          1.200
                                            Chi-sq(1) P-val =       0.2734


Weak identification test (Cragg-Donald Wald F statistic):            1.459
                         (Kleibergen-Paap rk Wald F statistic):      1.083
Stock-Yogo weak ID test critical values: 10% maximal IV size       16.38
                                         15% maximal IV size        8.96
                                         20% maximal IV size        6.66
                                         25% maximal IV size        5.53
Source: Stock-Yogo (2005).  Reproduced by permission.
NB: Critical values are for Cragg-Donald F statistic and i.i.d. errors.


Hansen J statistic (overidentification test of all instruments):    0.000
                                        (equation exactly identified)


Instrumented:        mpg
Included instruments: weight
Excluded instruments: rep78
```

```
clear all
sysuse auto

ivreg2 price (mpg=rep78) weight, r
```

Roadmap

Weak Instruments

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- In this case the second-stage SEs will be large and the 2SLS estimate will tend to be biased towards the corresponding OLS

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Much made of this over the years, but Angrist and Kolesár (2022) argue recently that we shouldn't worry too much

- The SE increase tends to be large enough to "cover up" the bias
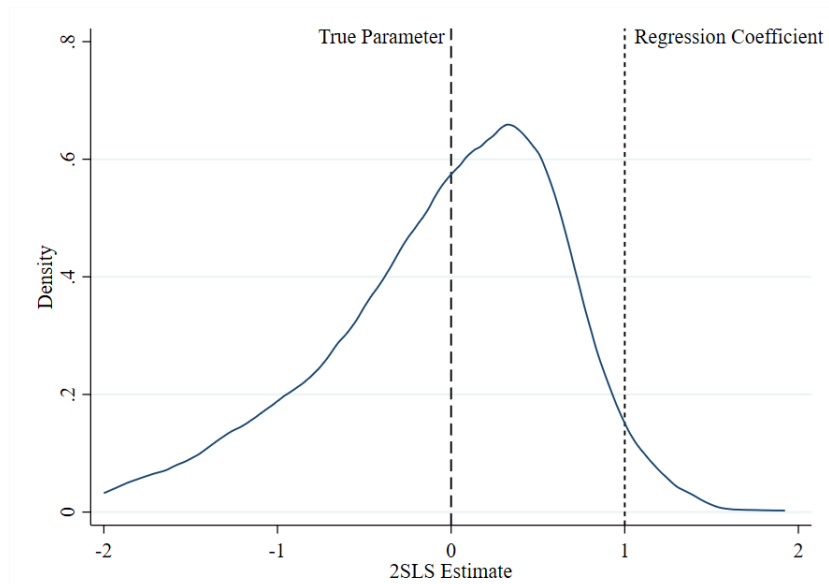- Just-id. 2SLS is "approximately median-unbiased"

Weak Instruments: Visualized

Monte Carlo: $Y_i = \varepsilon_i$, $D_i = \Pi Z_i + \eta_i$: $\Pi = Var(\varepsilon_i) = Var(\eta_i) = 1$
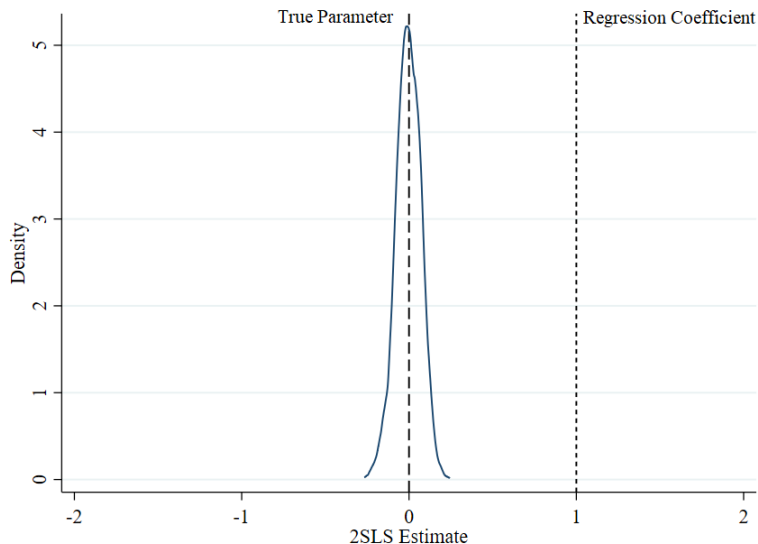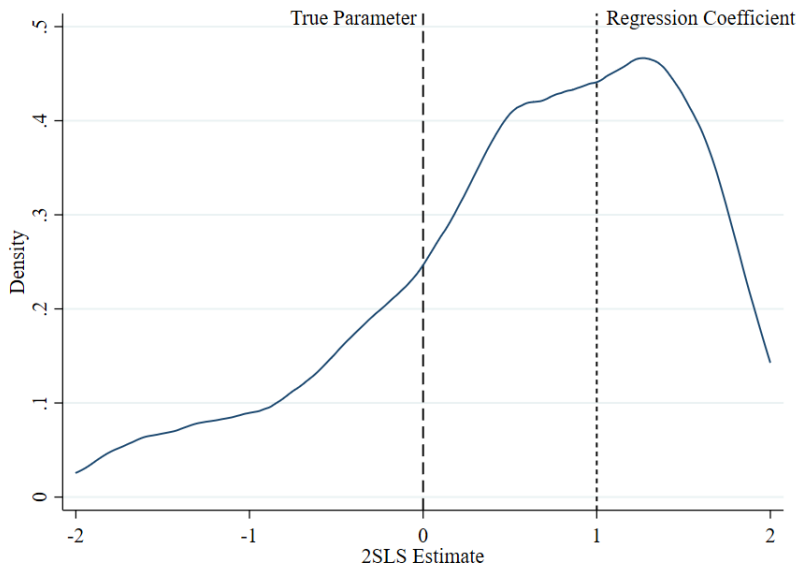
Weak Instruments: Visualized

Monte Carlo: $Y_i = \varepsilon_i$, $D_i = \Pi Z_i + \eta_i$: $\Pi = 0.1$ (Weaker)

Weak Instruments: Visualized

Monte Carlo: $Y_i = \varepsilon_i$, $D_i = \Pi Z_i + \eta_i$: $\Pi = 0.01$ (Very Weak)

Many IVs

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As we'll see, this bias is especially relevant in judge IV designs

- Potentially many judge assignment indicators as the instrument

- Leave-out corrections (e.g. Angrist et al. 1999) have been adapted to this setting in recent years (e.g. Kolesár 2013)
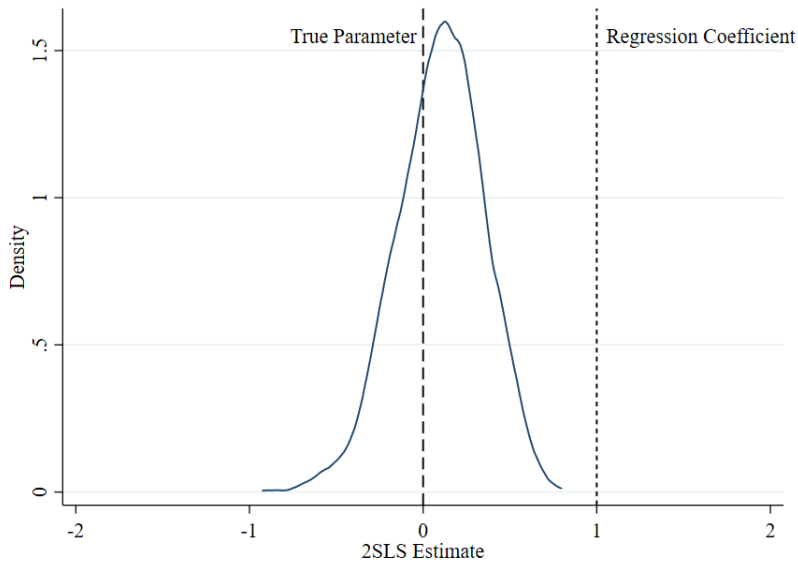
Many Instruments: Visualized

Monte Carlo: $Y_i = \varepsilon_i$, $D_i = \Pi Z_{i1} + \eta_i$: IV with one Z_{i1}
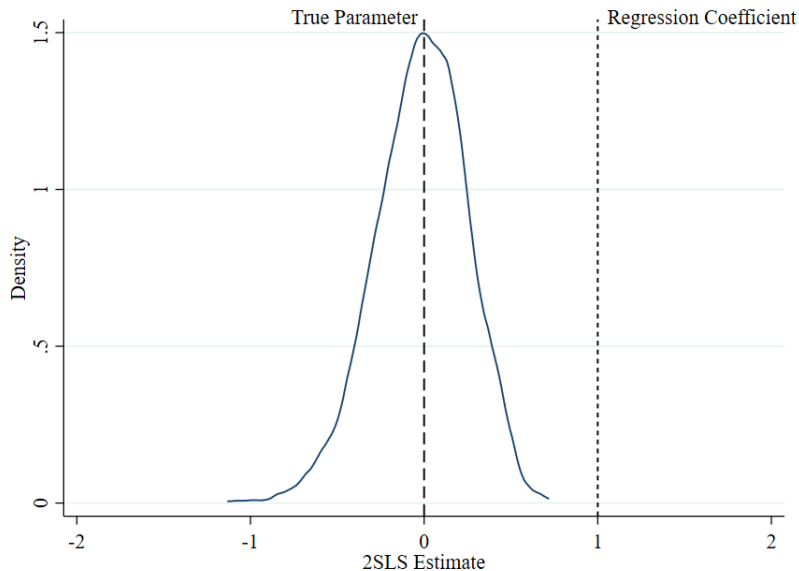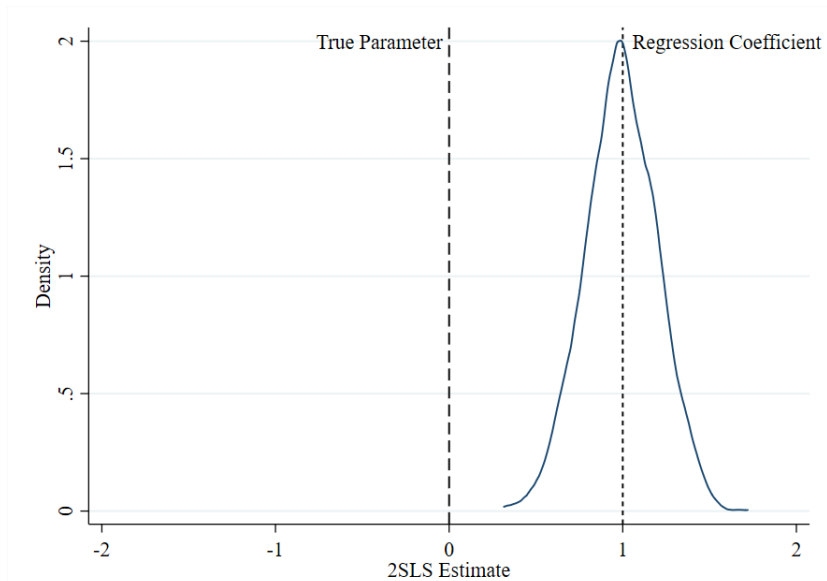
Many Instruments: Visualized

Monte Carlo: $Y_i = \varepsilon_i$, $D_i = \Pi Z_{i1} + \eta_i$: IV with ten Z_{ij}

Many Instruments: Visualized

Monte Carlo: $Y_i = \varepsilon_i$, $D_i = \Pi Z_{i1} + \eta_i$: IV with 100 Z_{ij}

What to Do?

Check your F's after every IV regression

- State of the art: Montiel Olea and Pflueger '15; `weakivtest` in Stata

- Staiger-Stock rule-of-thumb ($F > 10$) still seems widely held

- See Lee et al. (2020) for a recent alternative approach

If your F is small, some things to consider:

- Is there a different instrument that's stronger?

- Is there a better functional form for the instrument you have?

- Do interactions with covariates help? (note: beware many-weak!)

- Does changing the covariate set help? (note: beware invalidity!)