

Differences in Differences

One Diff is good. Two is doubly good!

May 2, 2023

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Introduction

- DID is one of the most popular methods of applied researchers aiming to analyze Causal Effects.
 - The canonical DID (2x2) compares the changes in the outcome of treated units with changes observed among non-treated/control units.
 - Under the Parallel Trends Assumption (PTA), and SUTVA, differences in those changes (DiD) identify the Average Treatment Effects of the treated units (ATT).
- Empirical research typically deviates from the Canonical design because:
 - Researchers have access to many periods. ($T > 2$)
 - Treatment may occur at different points in time. ($G > 1$)
 - Groups may be different in terms of observed characteristics. ($X's$)

Introduction

- Simple Solution: Identify the ATT (θ) by
 - Adding fixed effects for individuals or cohorts.
 - Adding time fixed effects.
 - Adding controls

$$y = \alpha_i + \delta_t + \beta X + \theta^{twfe} * (Eff_Tr) + u$$

- Recent research (de Chaisemartin and D'Haultoeuille, 2020; Goodman-Bacon, 2021; Borusyak and Jaravel, 2017) has shown that this simple generalization (A.K.A. TWFE) may not be adequate to identify an ATT when effects are heterogeneous.
- While others (Abadie, 2005; Heckman et al 1997; Imbens and Wooldridge, 2009; Sant'Anna and Zhao, 2020) have proposed many alternatives to better account for differences in controls.

Introduction

With this framework, today I'll focus on the following topics:

- The identification of the ATT using canonical DID designs, the role of covariates (based on Sant'Anna and Zhao (2020) - SZ), and its implementation via [drdid](#).
- The problems related with the simple TWFE generalization of the DID estimators. (based on Goodman-Bacon (2021))
- The estimation of the DID effects with Multiple Periods (based on Callaway and Sant'Anna (2021)-CS), and its implementation via [csdid](#).

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Canonical 2x2 DID

Setup

- Assume that we have access to a panel data where all units are followed over two periods: $t = 0, 1$.
- All units fall within two groups: Treated or untreated/control, status which cannot be changed (D_i).

Under full heterogeneity, potential and observed outcomes for a unit i at time t can be written as:

$$y_{i,t}(W) = \mu_i + \gamma_i t + \theta_i W \times t$$

$$y_{i,t} = D_i y_{i,t}(1) + (1 - D_i) y_{i,t}(0)$$

$$y_{i,0} = y_{i,0}(1) = y_{i,0}(0)$$

Canonical 2x2 DID

In this framework, the treatment effect for unit i at $t = 1$ is the difference between both Potential Outcomes:

$$\theta_i = y_{i,1}(1) - y_{i,1}(0)$$

And the ATT is:

$$\begin{aligned} ATT &= E(\theta_i | D_i = 1) = E_1(\theta_i) \\ &= E_1(y_{i,1}) - E_1(y_{i,1}(0)) \\ &= E_1(y_{i,1}) - (E_1(y_{i,0}) + E_1(\gamma_i)) \\ &= E_1(y_{i,1} - y_{i,0}) - E_1(\gamma_i) \end{aligned}$$

If we can estimate $E_1(\gamma_i)$, (Change regardless of treatment) we can estimate the ATT.

Canonical 2x2 DID

Thus, we rely on the Parallel trends Assumption (PTA)

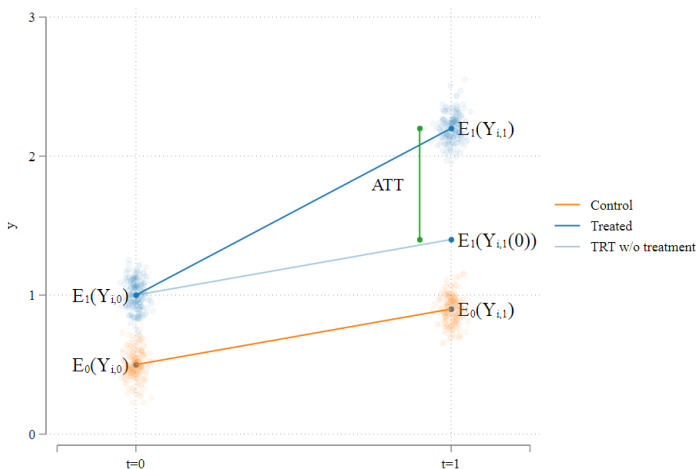
$$E_1(\gamma_i) = E_0(\gamma_i)$$

$$E_1(y_{i,1}(0) - y_{i,0}) = E_0(y_{i,1} - y_{i,0})$$

This assumes that the change experienced by the control group $E_0(\gamma_i)$ should be the same as the change of the treated group $E_1(\gamma_i)$ in absence of the treatment.

$$ATT = [E_1(y_{i,1} - y_{i,0})] - [E_0(y_{i,1} - y_{i,0})]$$

Canonical 2x2 DID



2x2 DID with Covariates

Simple 2x2 DID identifies the ATT under Unconditional PTA.

This may be appropriate if:

- The treated and control groups have similar characteristics; or if
- The change in outcome γ_i does not depend on characteristics.

How reasonable are these assumptions?

What to do if the assumptions do not hold?

2x2 DID with Covariates

SZ assumes that the PTA holds only when considering groups with the same characteristics (Conditional PTA):

$$E_1(\gamma_i|X) = E_0(\gamma_i|X)$$

$$E_1(y_{i,1}(0) - y_{i,0}|X) = E_0(y_{i,1} - y_{i,0}|X) = \gamma(x)$$

Thus, the ATT estimation should adjust for differences in characteristics.

$$\begin{aligned} ATT &= [E_1(y_{i,1} - y_{i,0})] - [E_1(E_0(y_{i,1} - y_{i,0}|X))] \\ &= [E_1(y_{i,1} - y_{i,0})] - E_1(\gamma(x)) \end{aligned}$$

2x2 DID with Covariates

What to kind of controls can be used?

Panel

- They should not be unique to treatment or control group (overlapping assumption)
- They should capture pre-treatment characteristics. (Avoid bias)
- Time varying variables are allowed only if the changes are strictly exogenous. (bad control risk)

Repeated Cross-section

- Time varying controls are possible but SZ assumes stationary in the covariates (Abadie, 2005).
- Changes should be strictly exogenous.
- Post-treatment units should represent their pre-treatment counterparts.

2x2 DID with Covariates: How?

How are ATT's Estimated?

SZ discusses the properties of three types of estimators, which accommodate to panel and repeated cross-sectional data.

- Outcome regression (Linear Regression model)
- Reweighting approach (IPW and IPT)
- Doubly Robust Estimators: Combining OR and RW

For simplicity, I will focus on panel estimators.

2x2 DID with Covariates

$$ATT = E(\Delta y_i | D_i = 1) - \hat{E}(\gamma_i | D_i = 1)$$

Outcome Regression

$$S1 : \gamma_i = \Delta y_i = \gamma(x) + v_i \quad \forall i | D_i = 0$$

$$S2 : E(\gamma_i | x) = \hat{\gamma}(x)$$

$$S3 : \widehat{ATT}_{OR} = E(\Delta y_i | D_i = 1) - E(\hat{\gamma}(x) | D_i = 1)$$

Depends strongly on the correct specification for the outcome change.

2x2 DID with Covariates

$$ATT = E(\Delta y_i | D_i = 1) - \hat{E}(\gamma_i | D_i = 1)$$

Re-weighted Approach

$$S1 : P(D_i = 1 | X) = F(X) \rightarrow \hat{\pi}(X)$$

$$S2 : \omega(x) = \frac{\hat{\pi}(X)}{1 - \hat{\pi}(X)}$$

$$S3 : \widehat{ATT}_{ipw}^1 = E(\Delta y_i | D_i = 1) - \frac{E(\omega(x) \Delta y_i | D_i = 0)}{E(\omega(x) | D_i = 0)}$$

$$S3 : \widehat{ATT}_{ipw}^2 = E(\Delta y_i | D_i = 1) - \frac{E(\omega(x) \Delta y_i | D_i = 0)}{E(D_i) / (1 - E(D_i))}$$

Depends strongly on the correct specification of the propensity score.

2x2 DID with Covariates

$$ATT = E(\Delta y_i | D_i = 1) - \hat{E}(\gamma_i | D_i = 1)$$

Doubly Robust OPT 1

$$S1 : P(D_i = 1 | X) = \hat{\pi}(X) \rightarrow \omega(x) = \frac{\hat{\pi}(X)}{1 - \hat{\pi}(X)}$$

$$S2 : \gamma_i = \Delta y_i = \gamma_\omega(x) + v_i \quad \forall i | D_i = 0 \quad \text{weighted by } \omega(x)$$

$$S3 : \widehat{ATT}_{DR}^1 = E(\Delta y_i | D_i = 1) - E(\hat{\gamma}_\omega(x) | D_i = 1)$$

Both Doubly Robust estimators are consistent if either the outcome model or the propensity score is correctly specified

2x2 DID with Covariates

$$ATT = E(\Delta y_i | D_i = 1) - \hat{E}(\gamma_i | D_i = 1)$$

Doubly Robust OPT 2

$$S1 : P(D_i = 1 | X) = \hat{\pi}(X) \rightarrow \omega(x) = \frac{\hat{\pi}(X)}{1 - \hat{\pi}(X)}$$

$$S2 : \gamma_i = \Delta y_i = \gamma(x) + v_i \quad \forall i | D_i = 0$$

$$S3 : \widehat{ATT}_{DR}^2 = E(\Delta y_i | D_i = 1) - E(\hat{\gamma}(x) | D_i = 1) - \frac{E(\omega(x)(\Delta y_i - \hat{\gamma}(x)) | D_i = 0)}{E(\omega(x) | D_i = 0)}$$

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drdid: Doubly Robust DID estimator

```

# Command is available from ssc
ssc install drdid, replace
# General Syntax
drdid y x1 x2 ... [if/in] [w=.] , [ivar(pid)]  time(tmt) treatment(trt) //
      [method] [SE CI options]
# ivar -> Panel, Otherwise RC. tmt and trt Should be Binary
# "Method" Options:
drimp [rc1]   : ATT_DR  OPT 1: p(trt=1|X)~IPT
dripw [rc1]   : ATT_DR  OPT 2: p(trt=1|X)~Logit
stipw         : ATT_IPW OPT 1
ipw           : ATT_IPW OPT 2
reg           : ATT_OR
all           : Estimates all options

```

drdid: Doubly Robust DID estimator

```

# "SE/CI" options: Default Asymptotic Standard Errors
cluster(cvar)      : Clustered Standard Errors (by ivar if panel)
wboot[(opt)]       : Wildbootstrap:
  reps()           : Repetitions, Default 999
  wdtype()         : Wdtype: mammen / rademacher
rseed()            : Seed for replication
gmm                : Estimation via gmm.
level()            : Level of Confidence. Default 95
# Other options
noisily            : Shows all intermediate steps

## Additional utilities
# Predicts IPWeights or Pcores
drdid_predict {newvar}, [weight pscore]
# Displays Intermediate Steps
drdid_display, bmatrix(name) vmatrix(name)

```

Example

```
use https://friosavila.github.io/playingwithstata/drdid/lalonde.dta, clear

. drdid re age educ black married nodegree hisp re74 if treated==0 | sample==2,
ivar(id) time(year) tr(experimental) dripw
```

Doubly robust difference-in-differences

Number of obs = 32,834

Outcome model : least squares

Treatment model: inverse probability

	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
ATET						
experimental						
(1 vs 0)	-871.3271	396.0211	-2.20	0.028	-1647.514	-95.14007

Example

```
drdid re age educ black married nodegree hisp re74 if
treated==0 | sample==2, cluster(id) time(year) tr(experimental) drimp
# output Omitted
drdid_predict wgt, weight
```

```
tabstat age educ black married nodegree hisp re74 if
treated==0 | sample==2 [w=wgt], by(experimental)
```

exper	age	educ	black	married	nodegree	hisp	re74
-----+							
0	24.44706	10.18824	.8	.1576471	.8141176	.1129412	3672.485
1	24.44706	10.18824	.8	.1576471	.8141176	.1129412	3672.485
-----+							
Total	24.44706	10.18824	.8	.1576471	.8141176	.1129412	3672.485

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GxT and the TWFE

As mentioned before, empirical research usually differs from the canonical approach: Many periods (T) and treatment at different times (G).

The common approach is to estimate this model using a TWFE:

$$y_{it} = \alpha_i + \gamma_t + \theta^{TWFE} * p_{it} + u_{it}$$

$$p_{it} = 1 \quad \text{if already treated}$$

This would capture the ATT only if the effect is homogeneous across units.

Limitations of TWFE

There are two ways of understanding the limitations of the simple TWFE estimator.

Negative Weights Assume a balanced panel and no controls:

$$\hat{\theta}^{TWFE} = \frac{\sum \tilde{P}_{it} y_{it}}{\sum \tilde{P}_{it}^2} \quad ; \quad \tilde{P}_{it} = P_{it} + \bar{P} - (\bar{P}_i + \bar{P}_t)$$

\tilde{P}_{it} : Also the residual from a LPM. (problems?)

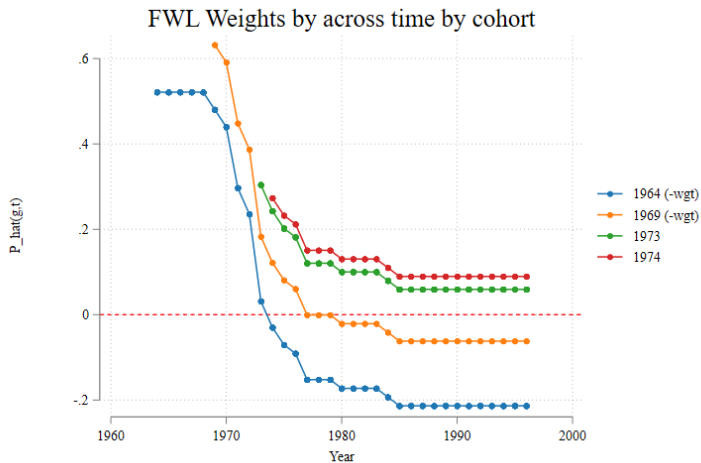
Treated units $P_{it} = 1$ should always receive a positive weight. however, \tilde{P}_{it} could be negative because:

- \bar{P}_t is larger at later periods
- \bar{P}_i is larger for units treated earlier

Thus, \tilde{P}_{it} could be negative for units treated earlier, but seen at later periods.

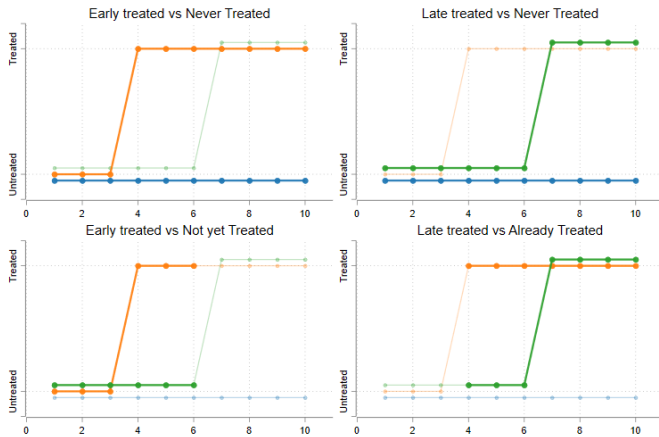
Negative Weights

Data: Bacon_example.dta



Good vs Bad Control groups

Goodman-Bacon (2021): TWFE estimator can be described as a weighted average of all 2x2 DID designs given the variation in the treatment status. But not all are good designs:



Solution: a more flexible estimator

The “problem” with TWFE is how LR computes coefficients.

The alternative is to use a more flexible specification, or/and avoiding “bad” control groups.

There are many options, but two are the easiest to understand:

Opt1: Sun and Abraham (2021) and Wooldridge (2021)

$$y_{it} = \alpha_i + \gamma_t + \sum_{g=g_0}^G \sum_{s=g}^T \theta(g, s) * 1(G = g, t = s) + e$$

Opt2: Callaway and Sant’Anna (2021)

Breakdown a single GxT DID to multiple 2x2 DID.

One can aggregate ATT's as needed

DID with Multiple Time Periods

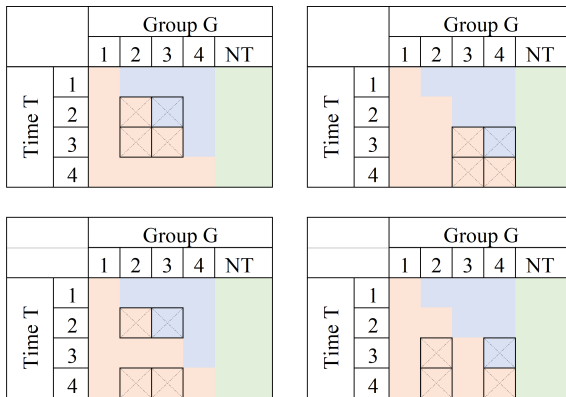
- CS breaks down the problem from one GxT DID to many 2x2 DID, using only good designs.
- Each design estimates a particular $ATT(G,T)$.
- `drdid` can be applied on each design independently.

		Group G				
		1	2	3	4	NT or ∞
Time T	1					
	2					
	3					
	4					

Treated
 Not-yet Treated
 Never Treated

DID with Multiple Time Periods

Figure: 2x2 to avoid



DID with Multiple Time Periods

Figure: 2x2 Using Never Treated

ATT(2,2)		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

ATT(2,3)		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

ATT(2,4)		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

ATT(3,3)		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

ATT(3,4)		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

ATT(4,4)		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

DID with Multiple Time Periods

2x2 Using Not-yet Treated

		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

2x2 Pre-treatment trends

		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

		Group G				
		1	2	3	4	NT
Time T	1					
	2					
	3					
	4					

DID with Multiple Time Periods: $ATT(g,t)$

In CS, the main Building block is the $ATT(g,t)$:

$ATT(g,t)$

The treatment effect for units treated at time g , measured at time t .

If $g \leq t$, it is useful to estimate treatment effects

$$ATT^{NT/NY}(g,t) = E(y_{i,t} - y_{i,g-1} | G_i = g) \\ - E(y_{i,t} - y_{i,g-1} | G_i = NT \text{ or } G_i > t)$$

If $g > t$, it is useful for pre-trend tests:

$$ATT^S(g,t) = E(y_{i,t} - y_{i,t-1} | G_i = g) \\ - E(y_{i,t} - y_{i,t-1} | G_i = NT) \\ ATT^L(g,t) = E(y_{i,g-1} - y_{i,t-1} | G_i = g) \\ - E(y_{i,g-1} - y_{i,t-1} | G_i = NT)$$

Aggregating $ATT(g,t)$'s

CS identifies all feasible $ATT(g,t)$'s, but also suggests a series of possible aggregations.

General Structure:

$$ATT_{TYP} = \frac{\sum_{TYP} w_{g,t} ATT(g,t)}{\sum_{TYP} w_{g,t}}$$

where $w_{g,t}$ are based on the number of treated observations used in a particular $ATT(g,t)$.

$$\textit{Simple} : t \geq g$$

$$\textit{Group} : t \geq g \& g = h$$

$$\textit{Calendar} : t \geq g \& t = s$$

$$\textit{Event} : t - g = e$$

$$\textit{CEvent} : c_1 \leq t - g \leq c_2$$

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csdid: DID with Multiple Time periods

```

# Command is available from ssc, requires drdid
ssc install csdid, replace
# General Syntax
csdid y x1 x2 ... [if/in] [w=.] , [ivar(pid)] time(T) gvar(G) //
    [method(@@@)] [long] [SE CI options]
# G=0 Never treated, and G subset of T (Not a 0-1 dummy)
# method(@@) options:
drimp [rc1] (default) ; dripw [rc1]
stdipw ; ipw ; reg
# Pretreatment ATT
long           : Long Gaps for Pretreatment ATT(g,t)
# SE option
pointwise      : If "wboot" were requested, one can call for pointwise CI
                  Default is uniform CI (valid for joint tests)
# One can save the RIF's into a file to save results.
saverif(file) [replace] : Useful for estimation of "wboot"
                        SE on other Aggregations

```

csdid: DID with Multiple Time periods

Pre-Estimation:

`gvar` (cohort) can be estimated using:

`egen gvar=csgvar(treat_post), ivar(00) tvar(00)`

Post-Estimation:

`after csdid : estat [agg pretrend], [option]`

`using rif_file: csdid_stats [agg], [option SE options]`

Possible aggregations

`attgt , [post estore(00) esave(00)]`

`simple , [post estore(00) esave(00)]`

`calendar, [post estore(00) esave(00)]`

`group , [post estore(00) esave(00)]`

`event , [window(%1 %2)] [post estore(00) esave(00)]`

`cevent , window(%1 %2) [post estore(00) esave(00)]`

Visualization (after csdid, estat or csdid_stat),

`csdid_plot, [options]: Plots previously estimated ATTGT's`

csdid: Example

use <https://friosavila.github.io/playingwithstata/drddid/mpdta.dta>, clear
tab year first_treat

year	first.treat				Total
	0	2004	2006	2007	
2003	309	20	40	131	500
2004	309	20	40	131	500
2005	309	20	40	131	500
2006	309	20	40	131	500
2007	309	20	40	131	500
Total	1,545	100	200	655	2,500

DID estimation, using Panel estimators, and DRIPW method.

Asymptotic Standard errors

```
csdid lemp lpop , ivar(countyreal) time(year) gvar(first_treat) method(dripw)
```

csdid: Example

use <https://friosavila.github.io/playingwithstata/drddid/mpdta.dta>, clear
 tab year first_treat if `runiform()`>0.05

year	first.treat				Total
	0	2004	2006	2007	
2003	296	20	37	118	471
2004	294	19	38	125	476
2005	299	18	35	122	474
2006	294	19	40	123	476
2007	292	20	39	116	467
Total	1,475	96	189	604	2,364


```
csdid lemp lpop , ivar(countyreal) time(year) gvar(first_treat) method(dripw)
saverif(rif)
```

File rif.dta will be used to save all RIFs

..... *# Each dot is a successful 2x2 estimation. X Otherwise*

file rif.dta saved

Difference-in-difference with Multiple Time Periods *# Type of Model*

Outcome model : least squares

Treatment model: inverse probability

	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
<hr/>						
g2004	# Indicates the Cohort					
t_2003_2004	-.0145297	.0221292	-0.66	0.511	-.057902	.0288427
t_2003_2005	-.0764219	.0286713	-2.67	0.008	-.1326166	-.0202271
t_2003_2006	-.1404483	.0353782	-3.97	0.000	-.2097882	-.0711084
t_2003_2007	-.1069039	.0328865	-3.25	0.001	-.1713602	-.0424476

t_#1_#2: Indicate which period was used as Pre (#1) and Post (#2) Periods

Ommited Output for g2006 & g2007

Control: Never Treated

See Callaway and Sant'Anna (2020) for details

```
estat cevent, window(0 2)
```

ATT for events between 0 2 # *Average of ATT from T+0 to T+2*

Event Study:Aggregate effects

	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
ATTC	-.0369435	.010938	-3.38	0.001	-.0583815	-.0155055

```
. estat event
```

ATT by Periods Before and After treatment

Event Study:Dynamic effects

	Coefficient	Std. err.	z	P> z	[95% conf. interval]	
Pre_avg	-.0000442	.0075204	-0.01	0.995	-.014784	.0146955
Post_avg	-.0803539	.0189576	-4.24	0.000	-.1175101	-.0431978
Tm3	.0267278	.0140657	1.90	0.057	-.0008404	.054296
Tm2	-.0036165	.0129283	-0.28	0.780	-.0289555	.0217226
Tm1	-.023244	.0144851	-1.60	0.109	-.0516343	.0051463
Tp0	-.0210604	.0114942	-1.83	0.067	-.0435886	.0014679
Tp1	-.0530032	.0163465	-3.24	0.001	-.0850417	-.0209647
Tp2	-.1404483	.0353782	-3.97	0.000	-.2097882	-.0711084
Tp3	-.1069039	.0328865	-3.25	0.001	-.1713602	-.0424476

csdid_plot

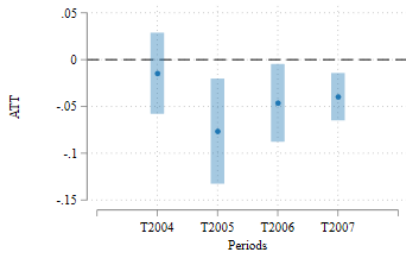
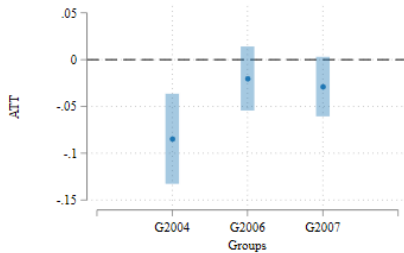
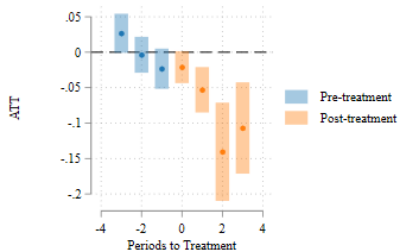
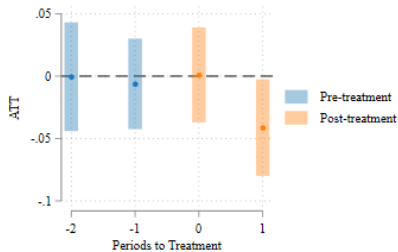


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Conclusions

- The use of DID estimators of ATT's using DID has changed drastically over the last couple of years.
- Today I showed commands to implement two of these estimators:
- `drdid` implements Sant'Anna and Zhao (2020) estimator, which emphasizes the benefits of doubly robust DID estimators.
- `csdid` implements Callaway and Sant'Anna (2021), which proposes a strategy to identify and aggregate the treatment effects for GxT DID.

For other examples, discussions, and explanations check <https://friosavila.github.io/playingwithstata/index.html>

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RC estimators

For next slides, I use the following notation:

$$E(y|D = d, T = t) = E_{d,t}(y)$$

where y is the observed outcome for an unit.

$D = 1$ if a unit is in the treated group.

$T = 1$ if we are considering the Post-period.

Thus, $E_{1,0}(y)$ is the average observed outcome for the treated group, pre-treatment ($T=0$).

and the ATT estimator will be:

RC Estimators: Regression Outcome

S1: Estimate 2 outcome models:

$$y = \theta_0(x) + e \text{ if } D = 0 \text{ and } T = 0$$

$$y = \theta_1(x) + e \text{ if } D = 0 \text{ and } T = 1$$

$$\hat{\gamma}(x) = \hat{\theta}_1(x) - \hat{\theta}_0(x)$$

S2: ATT:

$$ATT_{or} = E_{1,1}(y) - E_{1,0}(y) - E(\hat{\gamma}(x)|D = 1)$$

RC Estimators: IPW1

S1: Estimate Pscore

$$P(D = 1|X) = F(X) \rightarrow \hat{\pi}(x)$$

S2: Estimation of weights

$$\omega(x) = \frac{\hat{\pi}(x)}{1 - \hat{\pi}(x)}$$

S3: ATT

$$ATT_{IPW}^1 = E_{1,1}(y) - E_{1,0}(y) - \left(\frac{E_{0,1}(\omega(x)y)}{E_{0,1}(\omega(x))} - \frac{E_{0,0}(\omega(x)y)}{E_{0,0}(\omega(x))} \right)$$

RC Estimators: IPW2

S1: Estimate Pscore $\hat{\pi}(x)$ and Weights $\omega(x)$

S2: Define $\pi = E(D)$ and $\tau = E(t)$

S3: Expected growth absent of treatment

$$\hat{E}(\gamma(x)|D=1) = \frac{E_{0,1}(\omega(x)y)}{\pi/(1-\pi)} \frac{E(t|D=0)}{\tau} - \frac{E_{0,0}(\omega(x)y)}{\pi/(1-\pi)} \frac{1 - E(t|D=0)}{1-\tau}$$

S4: ATT

$$ATT_{IPW}^2 = E_{1,1}(y) \frac{E(Dt)}{\pi\tau} - E_{1,0}(y) \frac{E(D(1-t))}{\pi(1-\tau)} - E(\gamma(x)|D=1)$$

RC Estimators: DR1

S1: Estimate Pscore $\pi(x)$ and weights $\omega(x)$

S2: Estimation of Outcome Regressions using WLS with $\omega(x)$ for the control group ($D = 0$):

$$\theta_{0,1}^w(x) \text{ if } t = 1 \text{ and } \theta_{0,0}^w(x) \text{ if } t = 0$$

S3: Estimate ATT as:

$$ATT_{DR}^1 = E_{1,1}(y - \hat{\theta}_{0,1}^w(x)) - E_{1,0}(y - \hat{\theta}_{0,0}^w(x)) - \left(\frac{E_{0,1}(\omega(x)(y - \hat{\theta}_{0,1}^w(x)))}{E_{0,1}(\omega(x))} - \frac{E_{0,0}(\omega(x)(y - \hat{\theta}_{0,0}^w(x)))}{E_{0,0}(\omega(x))} \right)$$

RC Estimators: DR2

S1: Estimate Pscore $\pi(x)$ and weights $\omega(x)$

S2: Estimation of Outcome Regressions using WLS with $\omega(x)$ for the control group ($D = 0$). And OR using OLS for the treated group ($D = 1$):

$$\theta_{0,1}^w(x); \theta_{0,0}^w(x)$$

$$\theta_{1,1}(x); \theta_{1,0}(x)$$

S3: Estimate ATT as

$$ATT_{DR}^2 = E(\hat{\theta}_{1,1}(x) - \hat{\theta}_{1,0}(x) - (\hat{\theta}_{0,1}^w(x) - \hat{\theta}_{0,0}^w(x)) | D = 1) \\ - \left(\frac{E_{0,1}(\omega(x)(y - \hat{\theta}_{0,1}^w(x)))}{E_{0,1}(\omega(x))} - \frac{E_{0,0}(\omega(x)(y - \hat{\theta}_{0,0}^w(x)))}{E_{0,0}(\omega(x))} \right)$$