Lecture 4:
Difference in Difference, 2 of 2

February 4, 2026

Course Administration

1. Returned comments on proposals
2. Will send update with summary grading
3. Lab after class this week
4. PS 2 due in two weeks
5. Any problem set 2 issues?
6. If you haven't identified a replication paper, I'm nervous
7. Any other issues?

Today

Relaxing diff-in-diff: event study

1. Simplest possible event study
2. Diff-in-diff event study
3. Estimating trends
4. Testing for trends
5. Estimation concerns with diff-in-diff

Today

Relaxing diff-in-diff: event study

1. Simplest possible event study
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5. Estimation concerns with diff-in-diff

Janssen and Zhang

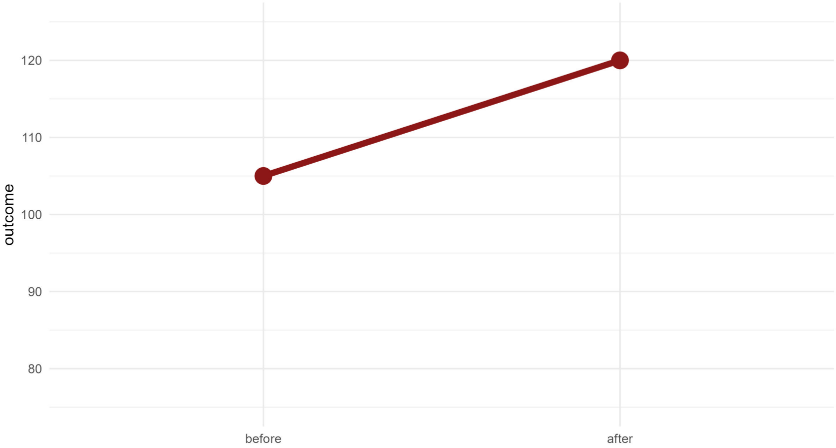
1. Diff-in-diff specification
2. Event study specification

1. Simplest Event Study

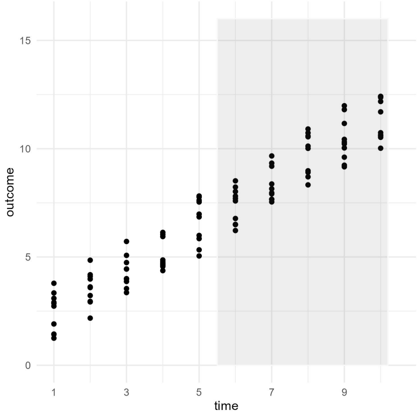
Basic Set-Up

- We want to know the impact of X on Y
- Over time, the impact of treatment X changes – increases, decreases, appears, disappears
- Compare outcomes Y before and after change in X
- Examples, please!

Last Week: Only Before and After



More Dots: Observe Each i in each time t



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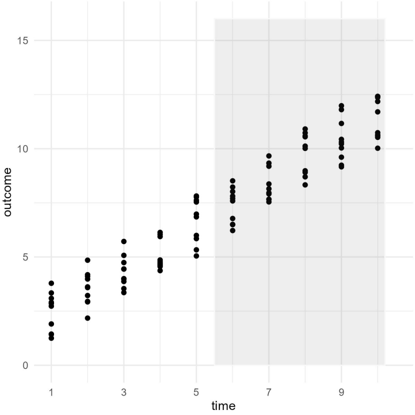

- All i are treated
- At all times $t > T_0$

Equation to estimate average Y after?

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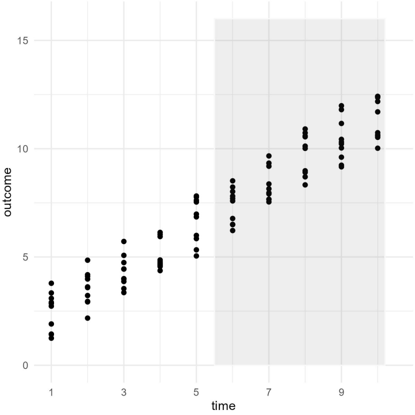

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where after_t is 1 for years $t > T_0$.

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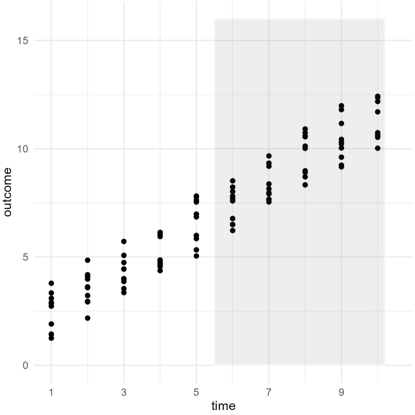

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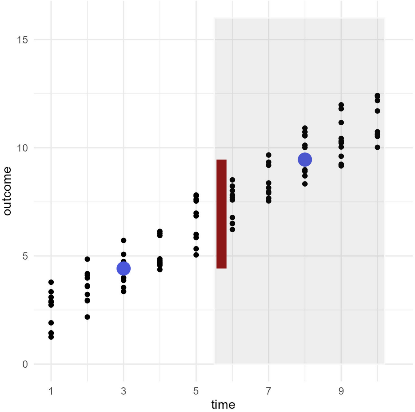
What does β_1 report?

What β_1 Reports



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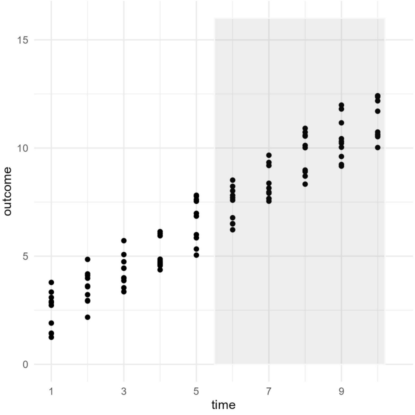
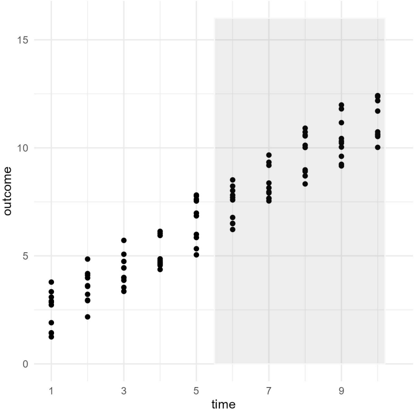
Estimating the Impact of Time Granularly



How do we estimate the impact of treatment in each period individually?

Estimating the Impact of Time Granularly



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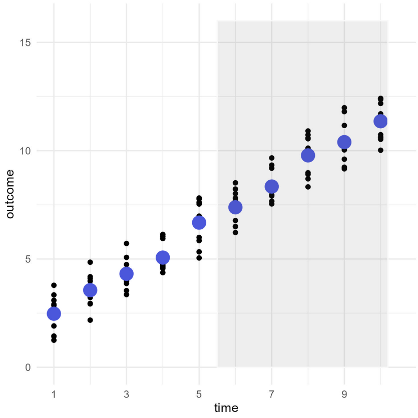
Raw Data: Event Study Diagram



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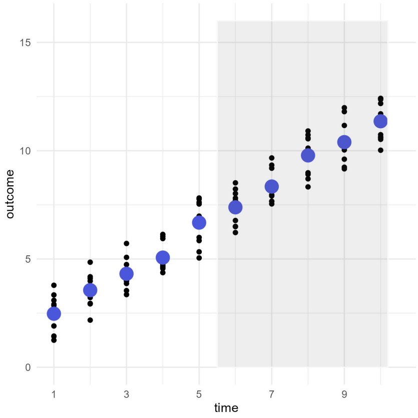
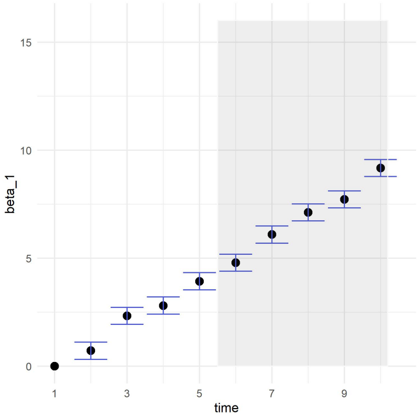


$$Y_{i,t} = \beta_0 + \beta_{1,t} 1\{\text{time} = t\}_t + \epsilon_{i,t}$$

- Regression coefficients should measure these means in the raw data
- What do you think a plot of $\beta_{1,t}$ should look like?

Regression Coefficients: Event Study Diagram



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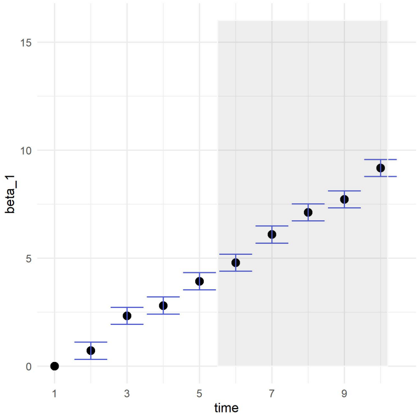

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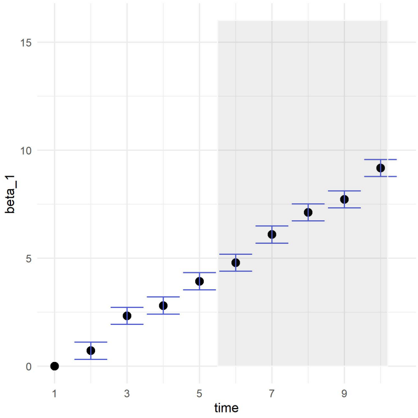

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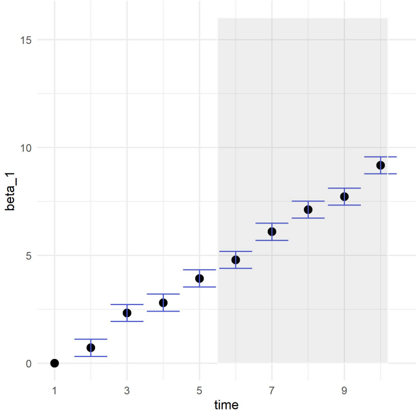


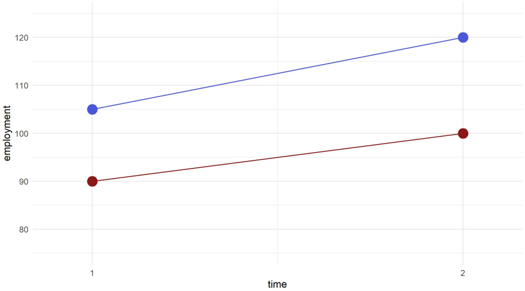
- Everything is relative to mean in year 1
- Why might comparing pre- and post blue dots not give the causal impact of X on Y?
- How do we fix with the strategy from last lecture?

2. Diff-in-diff Event Study

Basic Set-Up

- We want to know the impact of X on Y
- Over time, the impact of treatment X changes – increases, decreases, appears, disappears
- **Some units experience a change in X – are treated – and others are not**
- Compare outcomes Y before and after change in X
- Examples, please!

Review: How We Do This with Just Before and After



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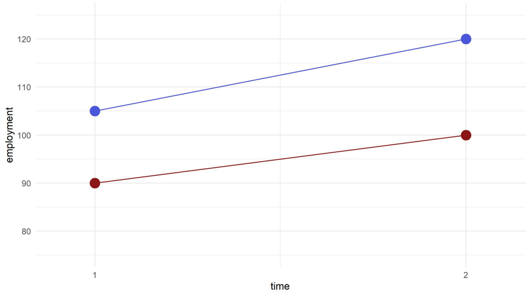

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- For treated i assign $\text{treated}_i = 1$
- Treatment at all times $t > T_0$

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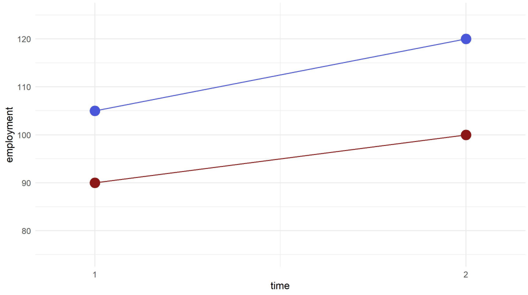

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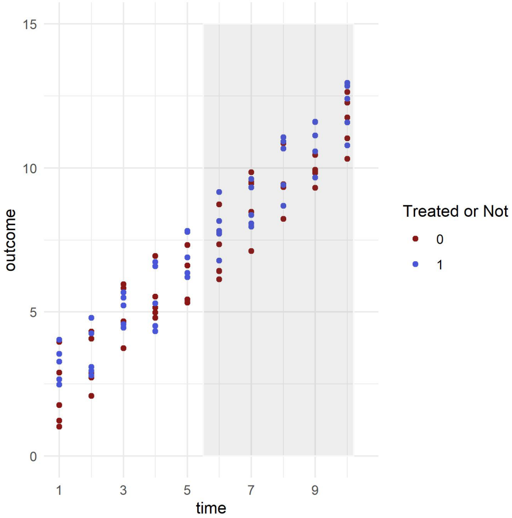
Treated and Untreated in an Event Study Framework



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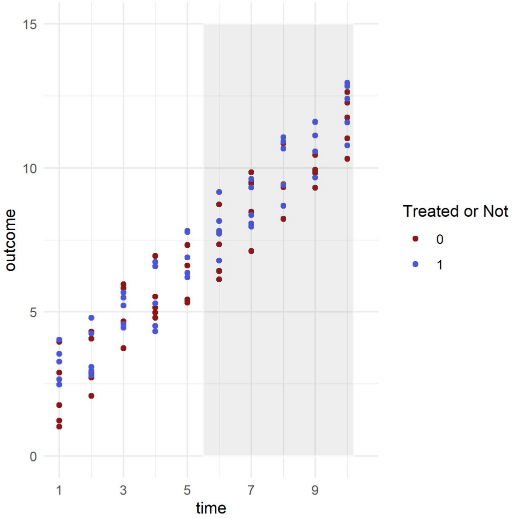

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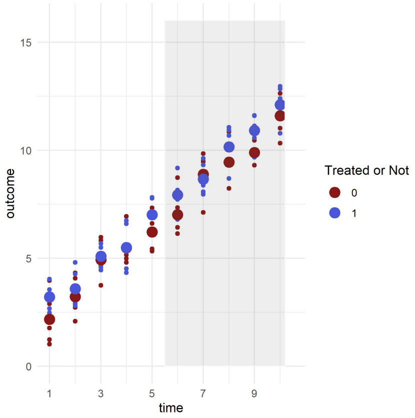
what does it compare? Comparison is **still** all before vs all after, but relative to untreated

Estimating the Impact of Time Granularly: Event Study



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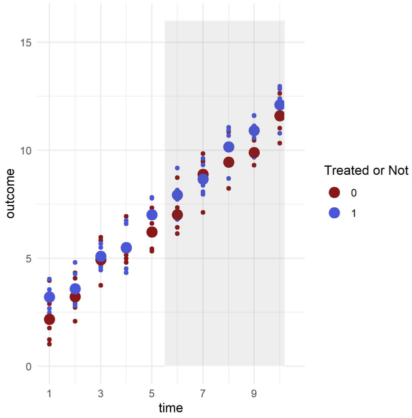

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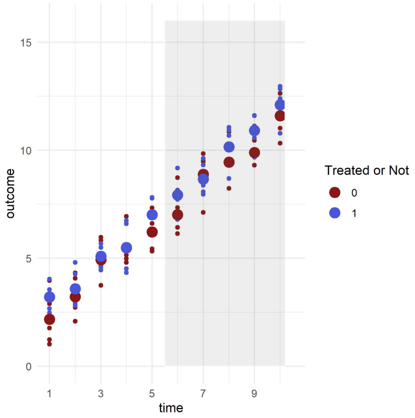

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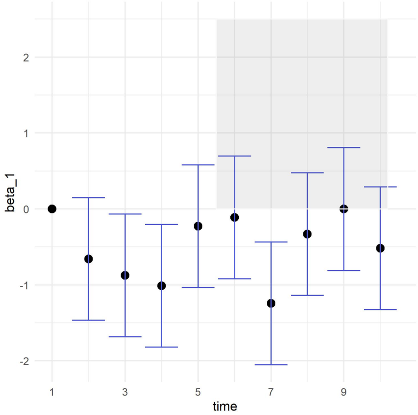
What do you expect $\beta_{1,t}$ to be given this figure?

Estimating the Impact of Time Granularly: Regression Coefficients



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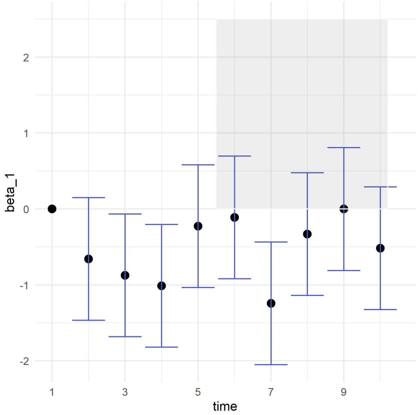

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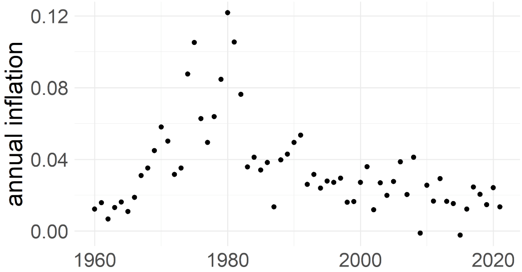
But ...

- you may care about the change in trends
- you may want to estimate the effect net of trends

3. Estimating Trends

On Trends



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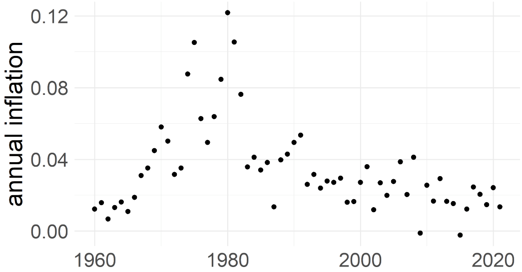

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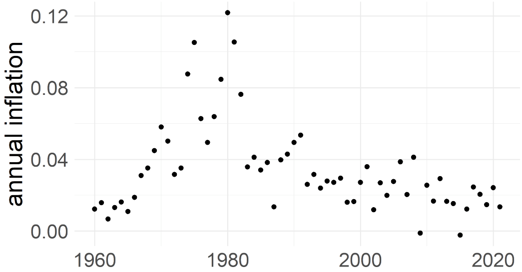

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Graph $\alpha_0 + \alpha_1 * \text{year}_t$ where year_t is $\{1, 2, 3, ...\}$

Just To Be Clear on Data

year	inflation	year2
1980	0.12	1
1981	0.10	2
1982	0.07	3
1983	0.03	4

$$\text{inflation}_t = \alpha_0 + \alpha_1 \text{year}_t + \epsilon_t$$

and

$$\text{inflation}_t = \gamma_0 + \gamma_1 \text{year2}_t + \epsilon_t$$

yield $\alpha_1 = \gamma_1$

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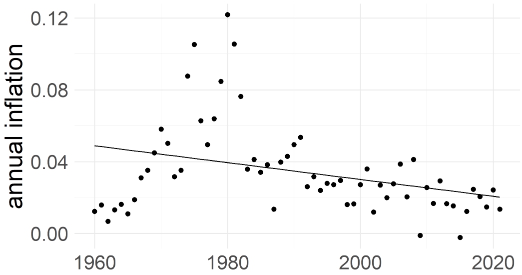
yield $\alpha_1 = \gamma_1$, but not $\alpha_0 = \gamma_0$

Adding Trends



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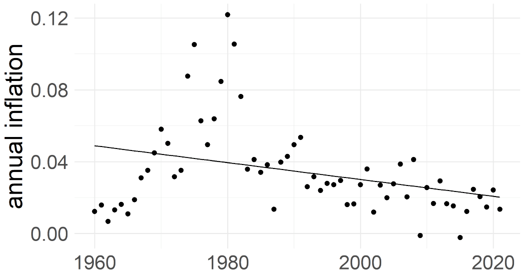
Adding Trends



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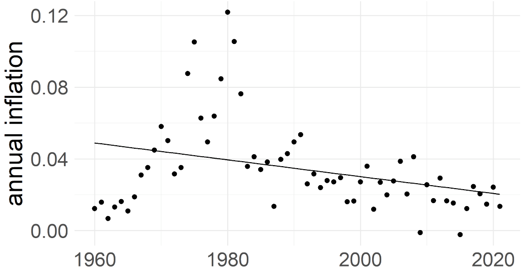

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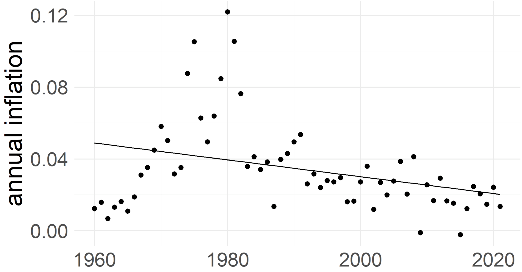

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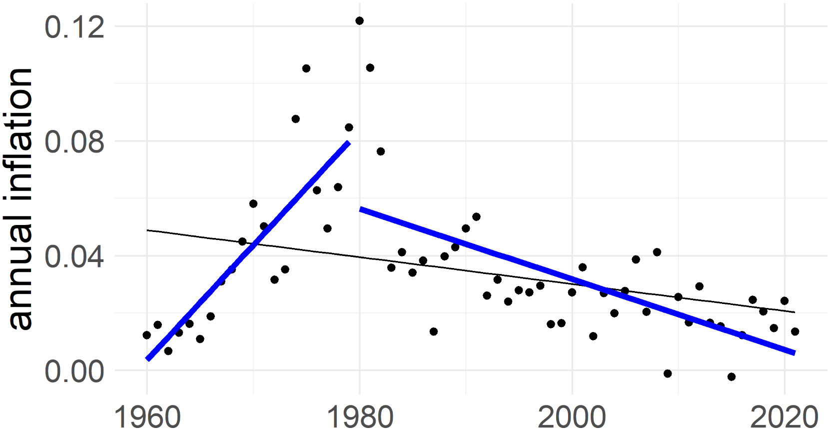
What might you want T_0 to be?

Separate Trends



Adding Linear Trends

What is a linear trend?

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- the calendar year is a trend variable
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ID	year	t1	t2
A	1990	1	5
A	1991	2	10
A	1992	3	15
B	2000	11	55
B	2001	12	60
B	2002	13	65

4. Validity Tests

Validity Tests

- Parallel trends in the absence of treatment is unobservable
- But you can assess parallel trends pre-treatment
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- Parallel trends in the absence of treatment is unobservable
- But you can assess parallel trends pre-treatment
- This is precisely estimable
- Pre-treatment parallel trends neither necessary nor sufficient
- See Angrist for discussion about concerns

Adding a Pre-Treatment Trend

Suppose you start with

$$Y_{i,t} = \beta_0 + \beta_1 \text{treated}_i * \text{after}_t + \beta_2 \text{treated}_i + \beta_3 \text{after}_t + \epsilon_{i,t}$$

and you want to test for pre-treatment trends. What do you do?

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- Use only data from before treatment
- Estimate

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- What do we expect if there is no pre-treatment trend? $\alpha_3 = 0$

Additional Validity Tests

- Add unit-specific time trends. If these kill the effect, what does this tell us?
  - for example, you have state by year data
  - looking for the impact of a policy that hits some states and not others

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- Add unit-specific time trends. If these kill the effect, what does this tell us?
  - for example, you have state by year data
  - looking for the impact of a policy that hits some states and not others
- Triple difference – not always possible

5. Recent Diff-in-diff Concerns

Time Is Limited, So We Skip Important Things

A non-exhaustive list includes

1. Standard errors too small
   - Serial correlation in treatment can inflate estimated standard errors. See Bertrand, et al., 2004
   - Largely solved with clustered standard errors

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A non-exhaustive list includes

1. Standard errors too small
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   - Largely solved with clustered standard errors
2. Bias in estimate
   - Staggered treatment timing
   - Heterogeneous treatment effects

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Give a real world example!

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Toy example

	State 1			State 2		
Period	1	2	3	1	2	3
treatment	0	1	1	0	0	1
$Y_st(0)$	0	0	0	0	0	0
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  - but useful for pointing out role of changing treatment
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  $(1-0) - (0-0) = 1$

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Suppose the Impact of Treatment Varies Over Time

Give a real world example!

Toy example

	State 1			State 2		
Period	1	2	3	1	2	3
treatment	0	1	1	0	0	1
$Y_s t(0)$	0	0	0	0	0	0
$Y_s t(1)$	-	1	4	-	-	1

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- Average across two periods? -0.5
- Plain TWFE fails

Suppose the Impact of Treatment Varies Across Units

Give a real world example!

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Give a real world example!

Toy example

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Suppose the Impact of Treatment Varies Across Units

Give a real world example!

Toy example

	State 1			State 2		
Period	1	2	3	1	2	3
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$Y_st(0)$	0	0	0	0	0	0
$Y_st(1)$	-	1	1	-	-	4

- Problem occurs when we implicitly compare later treated units with earlier treated units

Solutions?

- Does the problem apply to you?
  - Varying treatment time?
  - Potentially heterogeneous impacts?

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* have Stata and R packages

Opioids and Event Studies

Order of Events

1. Paper background
2. Diff-in-diff strategies
    1. independent vs chain, geographic fixed effects
    2. exploit independents that change to chain
    3. independent vs chain, before and after reformulation

Paper Basics

- What are the two key pharmacy types?

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- by pharmacy
- by month

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- What is the causal research question?
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Data

- morphine equivalent doses (MEDs)
- by pharmacy
- by month

- What is the unit of observation?
- And the unit of analysis?

E1: Independents vs Everyone Else

$$Y_{it} = \beta \text{Indep}_i + \mu_t + \gamma_{FE} + \epsilon_{it}$$

- $Y_{i,t}$ MED at pharmacy i at time t
- Indep_i: 1 if independent
- μ_t: year-month FE
- γ_{FE}: place FE

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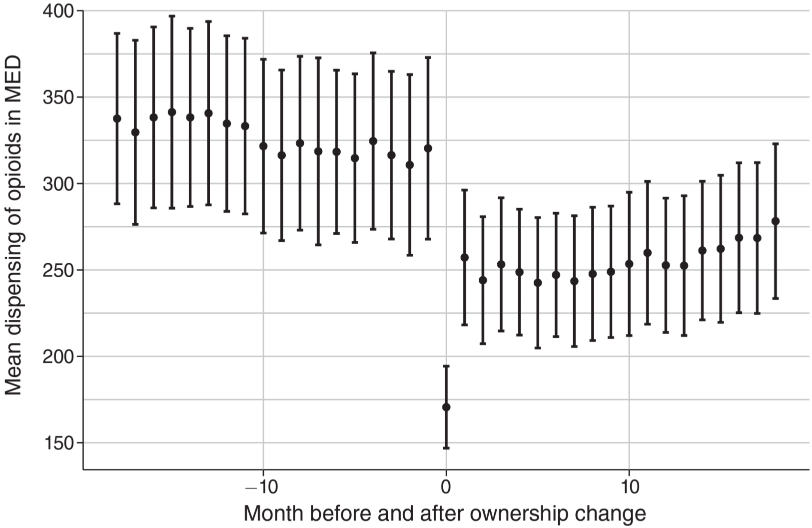
What sign do we expect for β?

	(1)	(2)	(3)	(4)
Independent	50.131	51.362	107.826	128.016
	(4.908)	(4.912)	(5.551)	(5.875)
Constant	306.488			
	(2.109)			
Year-month fixed effects	No	Yes	Yes	Yes
County fixed effects	No	No	Yes	No
Zip code fixed effects	No	No	No	Yes
Mean outcome	327.19	327.19	327.19	327.19
Mean effect in percent	15.32	15.7	32.96	39.13
Observations	5,055,761	5,055,761	5,055,761	5,055,761
R^2	0.002	0.010	0.089	0.225

Putting Independent Finding in Context

	All	Chain	Independent
Panel D. Opioid dispensing			
Monthly MED dispensing, all opioids	327.19	306.49	356.62
	(541.11)	(342.89)	(735.15)

E2: Change in Ownership, Raw Data



E2: Change in Ownership, Regression Form

Estimate either

$$Y_{i,t} = \beta_0 D_{it}^{\mathrm{PRE}} + \beta_1 D_{it}^{\mathrm{POST}} + \beta_C \mathrm{CHAIN}_i + \mu_t + \epsilon_{i,t}$$

or

$$Y_{i,t} = \beta_1 D_{it}^{\mathrm{POST}} + \alpha_i + \mu_t + \epsilon_{i,t}$$

- D_{it}^{PRE}: 1 for indep's that change to chain, before change
- D_{it}^{POST}: 1 for indep's that change to chain, after change
- CHAIN_i: 1 for always chains
- α_i: pharmacy FE

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- how do we interpret β_0?

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- how do we interpret β_0?
- and β_1?

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- CHAIN_i: 1 for always chains
- α_i: pharmacy FE

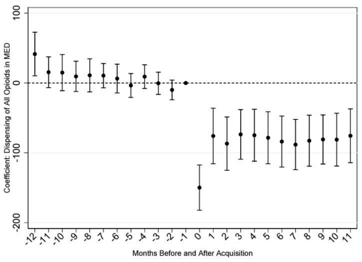
- how do we interpret β_0?
- and β_1?
- why no D_{it}^{PRE} in second equation?

E2: Change in Ownership, Results

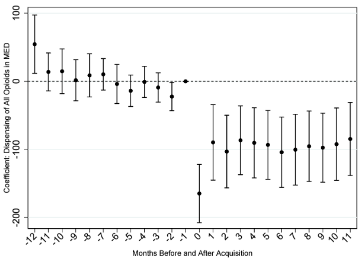
	All			
	OLS	OLS	OLS	OLS
	(1)	(2)	(3)	(4)
D^{PRE}	1.516	32.777	−1.226	
	(33.915)	(33.655)	(32.747)	
D^{POST}	−102.89	−130.867	−153.215	−110.507
	(19.755)	(19.61)	(20.439)	(16.65)
CHAIN	−49.933	−50.89	−127.879	
	(4.931)	(4.934)	(5.912)	
Constant	356.624			
	(4.883)			
Year-month fixed effects	No	Yes	Yes	Yes
Zip code fixed effects	No	No	Yes	No
Facility fixed effects	No	No	No	Yes
Mean outcome	327.19	327.19	327.19	327.19
Mean effect in percent	−31.45	−40	−46.83	−33.77
Observations	5,055,761	5,055,761	5,055,761	5,055,761
R^2	0.002	0.01	0.225	0.809

E2: Change in Ownership, Event Study Estimates

From Online Appendix, Figure E.1



(a) Dispensing of all opioids in MED, facility and year-month fixed effects



(b) Dispensing of all opioids in MED, facility and ZIP code × year-month fixed effects

E3: Reformulation

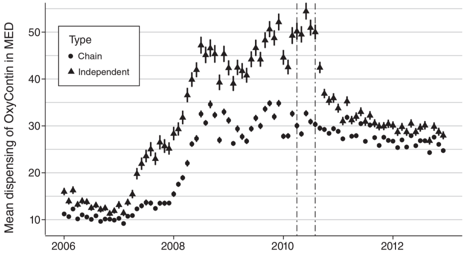


Figure 2

E3: Reformulation

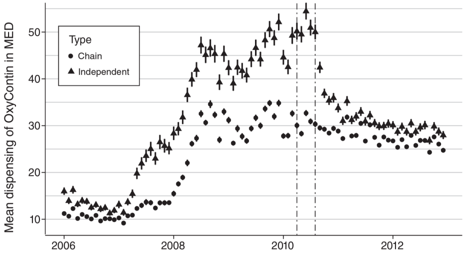


Figure 2

- why should reformulation matter?
- what should we be comparing in this figure to see the double diff?
- what should we be comparing to look for validity?

E3: Specification

What regression should we use to test impact of reformulation at independent pharmacies vs chains?

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E3: Specification

What regression should we use to test impact of reformulation at independent pharmacies vs chains?

$$Y_{it} = \beta \text{Indep}_i * \text{Post}_t + \alpha_i + \mu_t + \epsilon_{it}$$

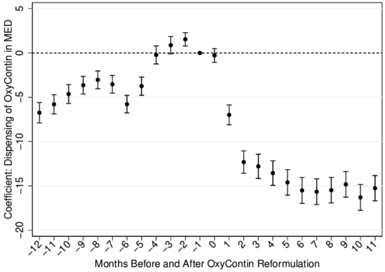
- Why no chain indicator?
- How do we interpret β?

E3: Reformulation, Results

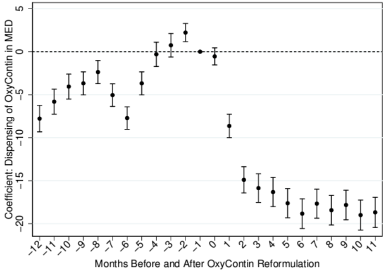
	Full sample: 2006–2012			
	(1)	(2)	(3)	(4)
Independent × Post	−6.097	−6.436	−6.996	−5.339
	(0.529)	(0.529)	(0.565)	(0.484)
Independent	10.569	10.912	18.886	
	(0.681)	(0.683)	(0.832)	
Post	6.095			
	(0.154)			
Constant	21.495			
	(0.281)			
Year-month fixed effects	No	Yes	Yes	Yes
Zip code fixed effects	No	No	Yes	No
Pharmacy fixed effects	No	No	No	Yes
Mean outcome	27.14	27.14	27.14	27.14
Mean effect in percent	−22.47	−23.72	−25.78	−19.67
Observations	5,055,761	5,055,761	5,055,761	5,054,885
R^2	0.004	0.019	0.159	0.650

E3: Reformulation Event Study Results

Online Appendix Figure E.5



(a) Dispensing of OxyContin in MED, pharmacy and year-month fixed effects



(b) Dispensing of OxyContin in MED, pharmacy and ZIP code × year-month fixed effects

Next Lecture

- Read
  - *Mastering Metrics* Chapter 3
  - an oldie but goodie: Angrist and Kreuger, 1991
  - Skim 2c
- Turn in PS 2 in two weeks
- Summary due next week if you're on the list