

Estimating the Intensive Margin Effect in Panel Data Settings

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Motivation

- Many policies have an effect through two distinct channels: the **intensive margin** and the **extensive margin**.

Examples:

- ▶ Job training policies affect wages, but also labor market participation.
- ▶ Education policies affect performance, but also enrollment.
- ▶ Carbon taxes affect emissions, but also firms' entry and exit.
- ▶ Childcare provision affects parents' labor market outcomes, but also fertility decisions.
- ▶ Education affects earnings, but also occupational choices.

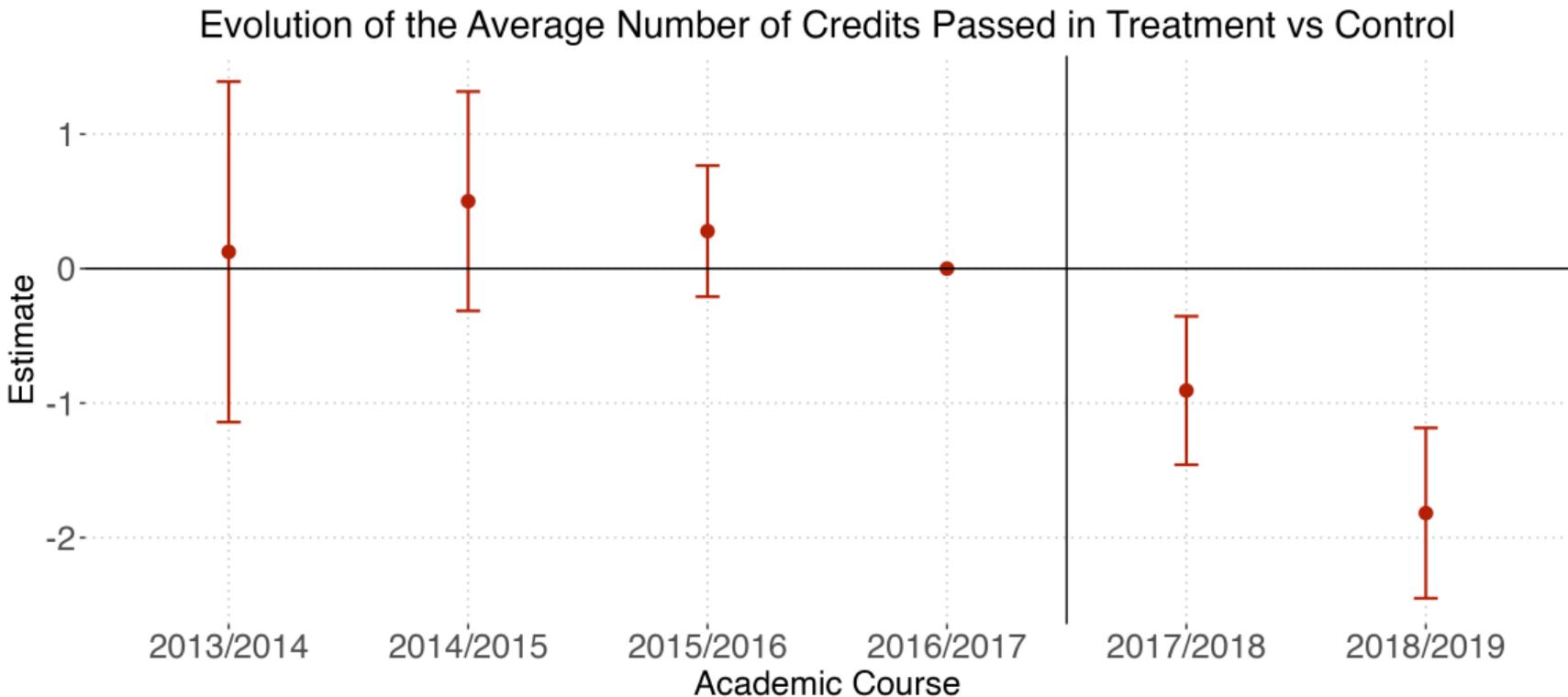
In these examples, the intensive margin must be estimated in a selected sample.

- **This paper** studies how to disentangle these two effects and correctly estimate the **intensive margin** effect in **panel data** settings (DiD).

A running (real-world) example

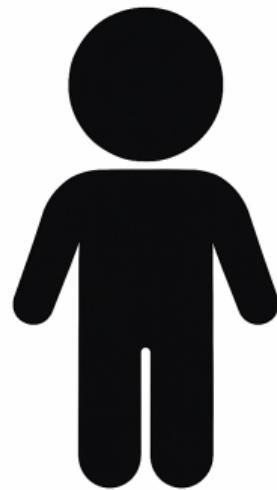
- In 2017, the Andalusian government (Spain) introduced tuition fee waivers based on previous academic performance.
- The policy affected all students in Andalusian public universities ($\sim 20\%$ of the total in Spain).
- The main goal of the waiver was to increase academic performance.
- **Research Question:**
How did this policy affect the academic performance of treated students?
- Available data:
 - ▶ Individual performance (i.e., # Credits Passed) before and after the policy.
 - ▶ Two groups of universities: Andalusian (treated) and the rest of Spain (control).

A descriptive event study



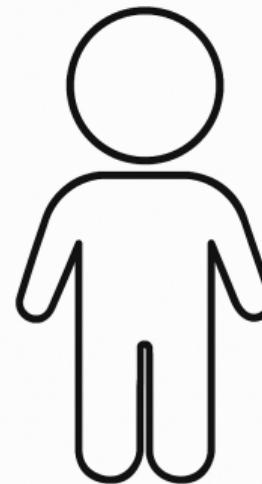
The extensive margin effect

Observed (e.g. Enrolled)



$$S = 1$$

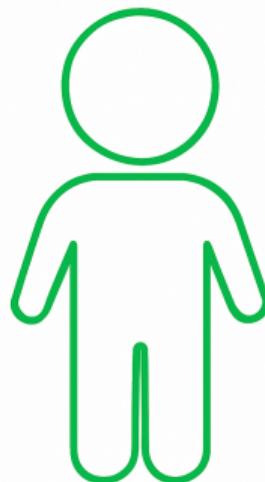
Not observed (e.g. drop out)



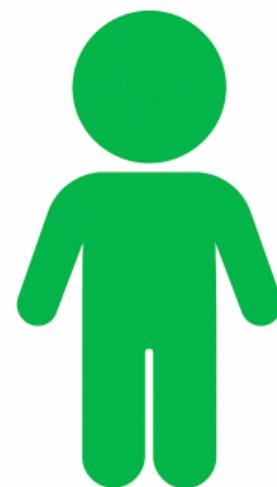
$$S = 0$$

Enrollment as a post-treatment variable

Control



Treatment



$$S_i(0) = 0$$

$$S_i(1) = 1$$

This student would be **observed** in the sample **only if treated**.

Principal Strata (Frangakis & Rubin, 2002)

Always Observed		Observed-if-Treated	
Control	Treatment	Control	Treatment
			
$S_i(0) = 1$	$S_i(1) = 1$	$S_i(0) = 0$	$S_i(1) = 1$
Observed-if-Control		Never Observed	
Control	Treatment	Control	Treatment
			
$S_i(0) = 1$	$S_i(1) = 0$	$S_i(0) = 0$	$S_i(1) = 0$

Drawbacks of the complete case analysis

Suppose you discard observations with missing outcomes and perform your preferred analysis using only the units without missing outcomes.

- ① **Conditioning on a post-treatment variable** (e.g., being enrolled), your estimand loses its causal interpretation.
Known as ‘bad control’ (Angrist & Pischke, 2009; Rosenbaum, 1984).
- ② Your estimand will have limited interpretation.
It does not allow you to **distinguish between the extensive and intensive margin**.

This paper:

Estimate causal effects for the Always-Observed principal stratum ($S(0) = S(1) = 1$).
The proposed estimands can be interpreted as the effect at the intensive margin.

Literature

- One particular, well-studied form of this problem is sample selection (Heckman, 1979; Manski, 1989).
- Seminal paper by Zhang and Rubin (2003) formally introduced the use of Principal Stratification in sample selection settings. (Imai, 2008; Zhang et al., 2009)
- Lee (2009) popularized the ‘Lee bounds’: a trimming approach to partially identify the ATE on the Always-Observed stratum.
- This literature has been extended in multiple directions: including covariates (Ding et al., 2011; Grilli & Mealli, 2008; Long & Hudgens, 2013; Samii et al., 2025; Semenova, 2025), instruments (Mattei et al., 2014), post-censoring outcomes (Yang & Small, 2016), structural model for selection (Honoré & Hu, 2020), longitudinal data (Comment et al., 2025; Grossi et al., 2023), noncompliance (Blanco et al., 2020; Chen & Flores, 2015).
- However, **all these papers require the treatment to be unconfounded .**

This paper as an extension of the Horowitz-Manski-Lee bounds

The **original Horowitz-Manski-Lee bounds** rely on the assumptions of:

- ① Treatment unconfoundedness.
- ② Monotonicity of selection.

This paper :

- ① Allows treatment to be confounded with unobservable unit-level characteristics.
- ② Relaxes monotonicity when multiple sources of selection are available.

Some notation

Consider the 2 periods ($t \in \{1, 2\}$), 2 groups case,

- Y_{it} : outcome of interest (e.g., # Credits Passed).
- G_i : treatment group indicator (1 treatment, 0 control).
- S_{it} : binary selection indicator (1 if unit i 's outcome is observed at period t , 0 otherwise).
- V_i : Principal Stratum of unit i :

$S_{i2}(0)$	$S_{i2}(1)$	Description	V_i
1	1	Always Observed	AO
0	0	Never Observed	NO
1	0	Observed only in Control	OC
0	1	Observed only in Treatment	OT

Principal Causal Effects

- ① Average Treatment Effect on the Treated **Always-Observed** units,

$$\text{ATT}_{\text{AO}} = \mathbb{E}[Y_{i2}(1) - Y_{i2}(0) \mid G_i = 1, V_i = AO].$$

- ② Quantile Treatment Effect on the Treated **Always-Observed** units,

$$\begin{aligned} \text{QTT}_{\text{AO}}(q) &= Q_{Y_2(1)|G=1, V=AO}(q) - Q_{Y_2(0)|G=1, V=AO}(q), \\ q &\in [0, 1]. \end{aligned}$$

where

- ▶ $F_Y(y)$ is the c.d.f. of Y
- ▶ $Q_Y(q)$ is the quantile function of Y , $Q_Y(q) = \inf\{y : F_Y(y) \geq q\}$.

Principal Stratification vs Bias-correction

- This paper:

$$\text{ATT}_{\text{AO}} = \mathbb{E}[Y_{i2}(1) - Y_{i2}(0) \mid G_i = 1, V_i = AO]$$

What's the effect for the units with observed outcomes under both treatment arms?
(Intensive margin effect)

- Bias-correction literature:

$$ATT = \mathbb{E}[Y_{i2}(1) - Y_{i2}(0) \mid G_i = 1]$$

What would be the effect if the outcome for all the units were observed?
(Blend of intensive and extensive margin effect)

This literature implicitly assumes...

- ▶ outcomes are always well defined, even when not directly observed.
- ▶ selection is manipulable, as they rely on ‘a priori counterfactuals’ potential outcomes.
- ▶ restrictions on how potential outcomes are distributed across principal strata (exclusion restrictions, structural models).

Some useful readings: Angrist et al. (1996) with discussions and rejoinder, Imbens (2010) and Mealli and Mattei (2012).

Identification of latent distributions

- Observed distributions are a mixture of principal strata:

- ▶ Control group: Always-Observed and Observed-if-Control

$$F_{Y_2|G=0,S_2=1}(y) = \pi_0 F_{Y_2|G=0,V=AO}(y) + (1 - \pi_0) F_{Y_2|G=0,V=OC}(y).$$

- ▶ Treatment group: Always-Observed and Observed-if-Treated

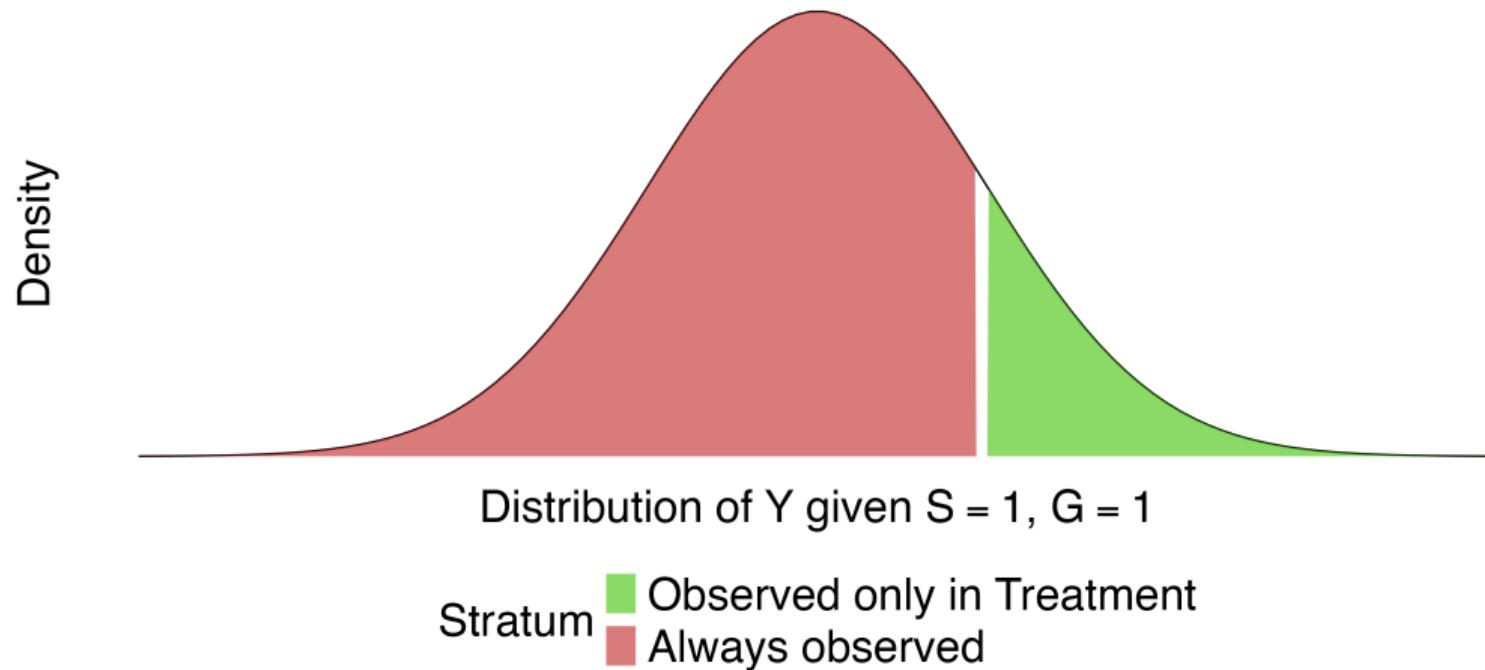
$$F_{Y_2|G=1,S_2=1}(y) = \pi_1 F_{Y_2|G=1,V=AO}(y) + (1 - \pi_1) F_{Y_2|G=1,V=OT}(y).$$

where $\pi_g = Pr(V_i = AO \mid G_i = g, S_2 = 1)$.

- Given the mixture proportions, I follow Horowitz and Manski (1995) to partially identify the distributions of the observed outcome for the AO units.

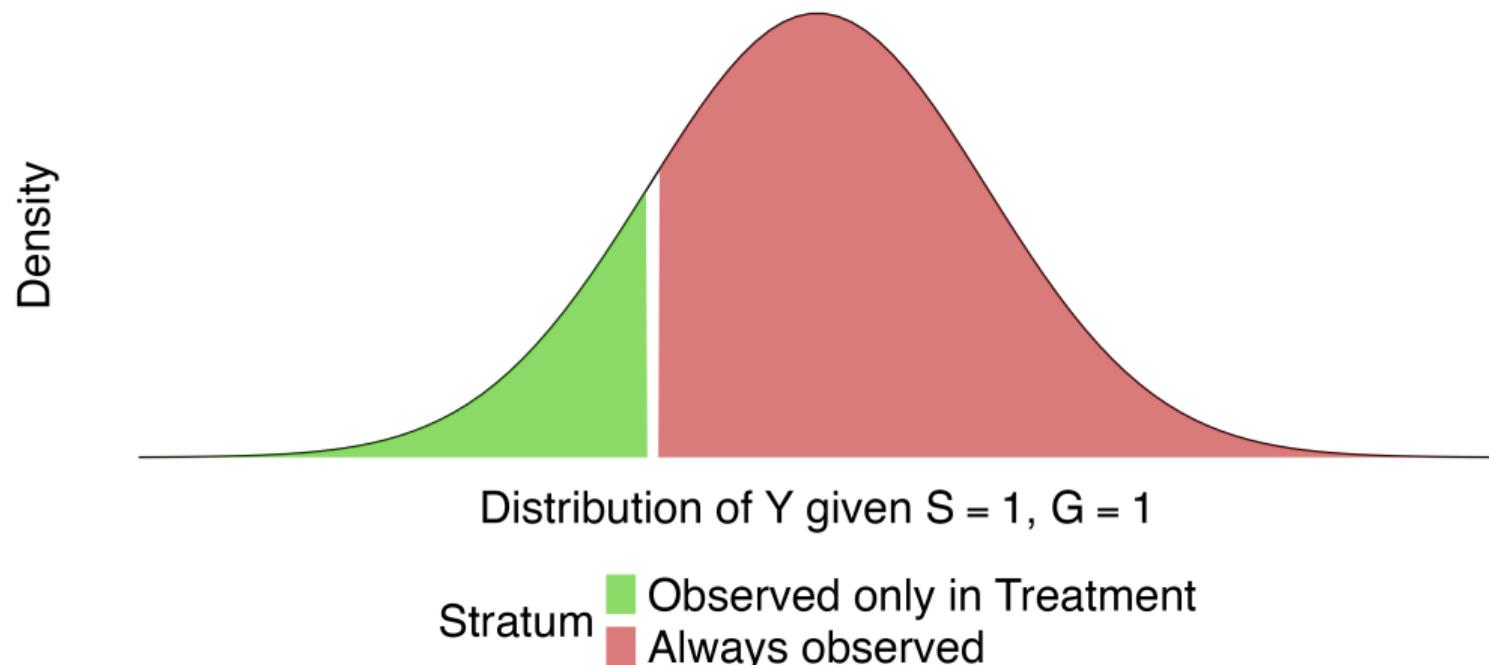
Lower bound

Figure: Intuition behind Horowitz and Manski (1995)



Upper bound

Figure: Intuition behind Horowitz and Manski (1995)



Using the trimmed distributions



Distribution of Y given $S = 1, G = 1$

Stratum Observed only in Treatment
 Always observed



Distribution of Y given $S = 1, G = 0$

Stratum Observed only in Control
 Always observed

Identification assumption: Changes-in-Changes (Athey & Imbens, 2006)

Assumption: Changes-in-changes for the **Always-Observed** Outcome:

$$(Y_{it}(0) \mid V_i = AO) = m(\mathcal{U}_{it}, t),$$

where

- $m(\cdot)$ is strictly increasing in \mathcal{U} ,
- the distribution of $\mathcal{U}_{it} \mid G_i, V_i = AO$ is stable over time,
- and $\mathbb{Y}_1 \subseteq \mathbb{Y}_0$.

Example: $Y_{it}(0) = m(\mathcal{U}_{it}, t) = \lambda_t + \underbrace{\alpha_i + \varepsilon_{it}}_{\mathcal{U}_{it}}$

Intuition behind Changes-in-Changes I

Suppose unit i (treated) and j (control) have the same value of Y in the pre-treatment period:

$$Y_{i1} = Y_{j1}.$$

Then, $Y_{it}(0) = m(\mathcal{U}_{it}, t)$, with $m(\cdot)$ is strictly increasing in \mathcal{U} implies

$$\mathcal{U}_{i1} = \mathcal{U}_{i2}.$$

If \mathcal{U} were constant over time, the missing potential outcome for unit i would be given by unit j 's outcome:

$$Y_{i2}(0) = m(\mathcal{U}_{i2}, 2) = m(\mathcal{U}_{j2}, 2) = Y_{j2}$$

The assumption is not constant \mathcal{U} but constant distribution within groups.

Intuition behind Changes-in-Changes II

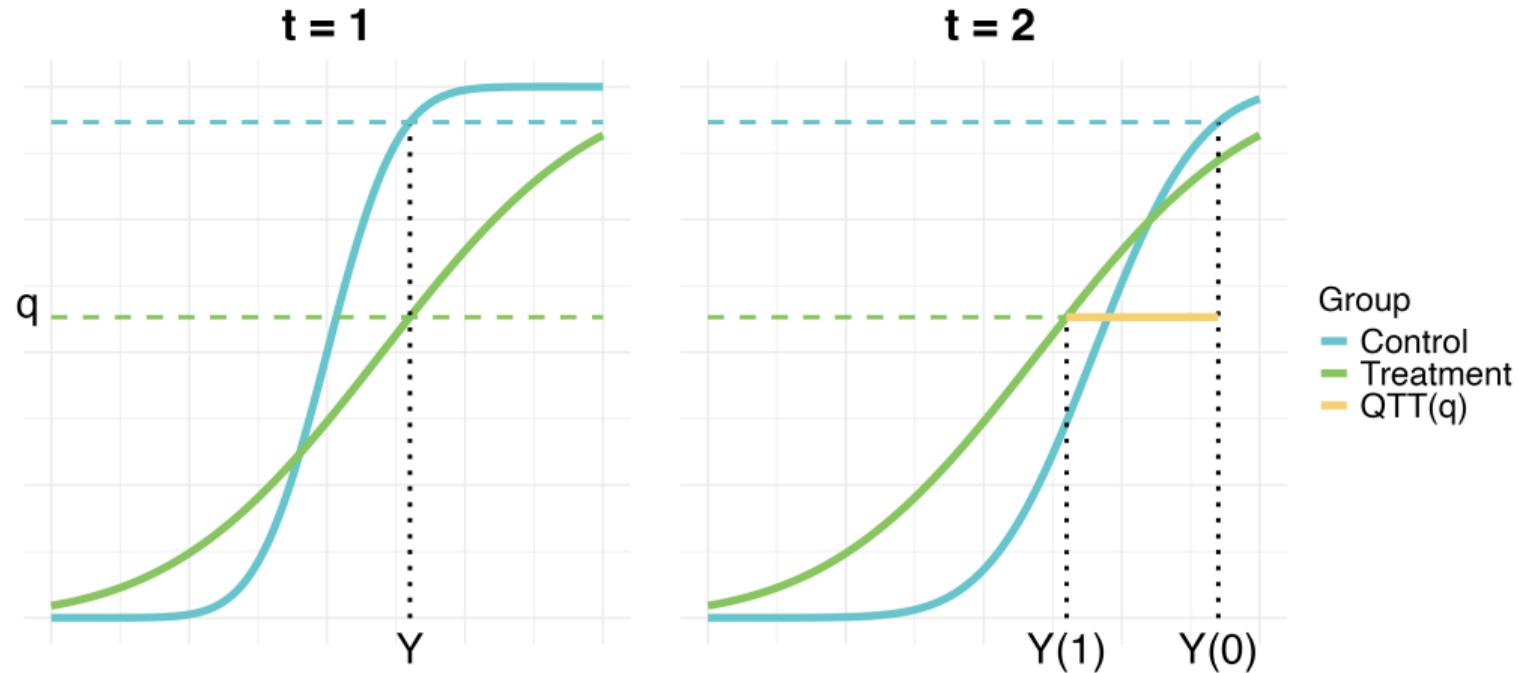
We want to impute the quantile q of the distribution of the missing potential outcome $Y_2(0)$ for treated units: $Q_{Y_2(0)|G=1}(q)$.

$$\text{If } Y_{i1} = Y_{j1} \text{ and } \begin{cases} F_{Y_1|G=1}(Y_{i1}) = q \\ F_{Y_1|G=0}(Y_{j1}) = \tilde{q} \end{cases} \implies Q_{Y_1|G=1}(q) = Q_{Y_1|G=0}(\tilde{q})$$

Under the CiC assumptions, we can reconstruct the missing distribution of $Y_{i2}(0)$ for treated units as follows:

$$Q_{Y_2(0)|G=1}(q) = Q_{Y_2|G=0, S_2=1} \left(\underbrace{F_{Y_1|G=0, S_2=1} \left(\underbrace{Q_{Y_1|G=1, S=1}(q)}_{Y_{i1}=Y_{j2}} \right)}_{\tilde{q}} \right)$$

Intuition behind Changes-in-Changes III



Identification result: CiC

Identification result: $\Lambda^{LB}(q)$ and $\Lambda^{UB}(q)$ are sharp lower and upper bounds for the Quantile Treatment Effect on the Treated Always-Observed units ($QTT_{AO}(q)$), where:

$$\begin{aligned}\Lambda^{LB}(q) &= Q_{Y_2|G=1,S_2=1}(q\pi_1) \\ &\quad - Q_{Y_2|G=0,S_2=1}\left(F_{Y_1|G=0,S_2=1}\left(Q_{Y_1|G=1,S_2=1}(q\pi_1 + 1 - \pi_1)\right) + 1 - \pi_0\right),\end{aligned}$$

$$\begin{aligned}\Lambda^{UB}(q) &= Q_{Y_2|G=1,S_2=1}(q\pi_1 + 1 - \pi_1) \\ &\quad - Q_{Y_2|G=0,S_2=1}\left(F_{Y_1|G=0,S_2=1}\left(Q_{Y_1|G=1,S_2=1}(q\pi_1)\right) - (1 - \pi_0)\right),\end{aligned}$$

$$\pi_1 = Pr(V_i = AO \mid G_i = 1, S_{i2}(1) = 1),$$

$$\pi_0 = Pr(V_i = AO \mid G_i = 0, S_{i2}(0) = 1),$$

$$F_Y(y) := Pr(Y \leq y)$$

$$Q_Y(q) := \inf\{y : F_Y(y) \geq q\}$$

$$\int_0^1 \Lambda^{LB}(q)dq \leq ATT_{AO} \leq \int_0^1 \Lambda^{UB}(q)dq$$

Identification result: DiD

Assumption: **Principal** Parallel Trends

$$\mathbb{E}[Y_{i2}(0) - Y_{i1}(0) \mid G_i = 1, V_i = AO] = \mathbb{E}[Y_{i2}(0) - Y_{i1}(0) \mid G_i = 0, V_i = AO]$$

Identification result: Δ^{LB} and Δ^{UB} are sharp lower and upper bounds for the Average Treatment Effect on the Treated Always-Observed units (ATT_{AO}), where

$$\Delta^{LB} = \mathbb{E}[\ddot{Y}_i \mid G_i = 1, S_{i2} = 1, \ddot{Y}_i \leq \ddot{y}_{\pi_1}^1] - \mathbb{E}[\ddot{Y}_i \mid G_i = 0, S_{i2} = 1, \ddot{Y}_i \geq \ddot{y}_{1-\pi_0}^0]$$

$$\Delta^{UB} = \mathbb{E}[\ddot{Y}_i \mid G_i = 1, S_{i2} = 1, \ddot{Y}_i \geq \ddot{y}_{1-\pi_1}^1] - \mathbb{E}[\ddot{Y}_i \mid G_i = 0, S_{i2} = 1, \ddot{Y}_i \leq \ddot{y}_{\pi_0}^0]$$

$$\ddot{Y}_i = Y_{i2} - Y_{i1}$$

$$\ddot{y}_q^g = \inf\{\ddot{y} : F(\ddot{y}) \geq q\}, \text{ with } F \text{ the c.d.f. of } \ddot{Y}$$

conditional on $S_{i2} = 1$ and $G = g$

$$\pi_1 = Pr(V_i = AO \mid G_i = 1, S_{i2}(1) = 1)$$

$$\pi_0 = Pr(V_i = AO \mid G_i = 0, S_{i2}(0) = 1).$$

Identification of the principal strata proportions

Two assumptions needed:

- ① Monotonicity:

$$S_{i2}(1) \geq S_{i2}(0) \quad \forall i.$$

- ② Changes-in-Changes (Athey & Imbens, 2006) for **Selection**

$$S_{it}(0) = h^0(U_{it}, t),$$

where

- ▶ $h^0(\cdot)$ is non-decreasing in U ,
- ▶ the distribution of $U_{it} \mid G_i$ is constant over time,
- ▶ and $\mathbb{U}_1 \subseteq \mathbb{U}_0$.

▶ Expression

Identification of the principal strata proportions

Or conversely:

- ① Monotonicity:

$$S_{i2}(1) \leq S_{i2}(0) \quad \forall i.$$

- ② Changes-in-Changes (Athey & Imbens, 2006) for **Selection**

$$S_{it}(1) = h^1(U_{it}, t),$$

- ▶ $h^1(\cdot)$ is non-decreasing in U ,
- ▶ the distribution of $U_{it} \mid G_i$ is constant over time,
- ▶ and $\mathbb{U}_0 \subseteq \mathbb{U}_1$.

▶ Expression

Full Identification Result

Identification result: $\Lambda^{LB}(q)$ and $\Lambda^{UB}(q)$ are lower and upper bounds for the Quantile Treatment Effect on the Treated Always-Observed units ($QTT_{AO}(q)$), where:

$$\begin{aligned}\Lambda^{LB}(q) &= Q_{Y_2|G=1,S_2=1}(q\pi_1) \\ &\quad - Q_{Y_2|G=0,S_2=1}\left(F_{Y_1|G=0,S_2=1}\left(Q_{Y_1|G=1,S_2=1}(q\pi_1 + 1 - \pi_1)\right) + 1 - \pi_0\right),\end{aligned}$$

$$\begin{aligned}\Lambda^{UB}(q) &= Q_{Y_2|G=1,S_2=1}(q\pi_1 + 1 - \pi_1) \\ &\quad - Q_{Y_2|G=0,S_2=1}\left(F_{Y_1|G=0,S_2=1}\left(Q_{Y_1|G=1,S_2=1}(q\pi_1)\right) - (1 - \pi_0)\right),\end{aligned}$$

$$\pi_1 = 1$$

$$\pi_0 = \frac{\mathbb{E}[S_{i2}(1) | G_i = 0]}{\mathbb{E}[S_{i2} | G_i = 0]} = \frac{\mathbb{E}[S_{i1} | G_i = 0]}{\mathbb{E}[S_{i2} | G_i = 0]} \frac{\mathbb{E}[S_{i2} | G_i = 1]}{\mathbb{E}[S_{i1} | G_i = 1]} \in [0, 1]$$

$$F_Y(y) := Pr(Y \leq y)$$

$$Q_Y(q) := \inf\{y : F_Y(y) \geq q\}$$

$$\int_0^1 \Lambda^{LB}(q) dq \leq ATT_{AO} \leq \int_0^1 \Lambda^{UB}(q) dq$$

Relaxing the Monotonicity Assumption

If different unobservables affect selection in different directions, and they translate into different sources of selection, we can leverage them to relax monotonicity.

Example:

- tuition waivers may help financially constrained students \implies decrease in dropout,

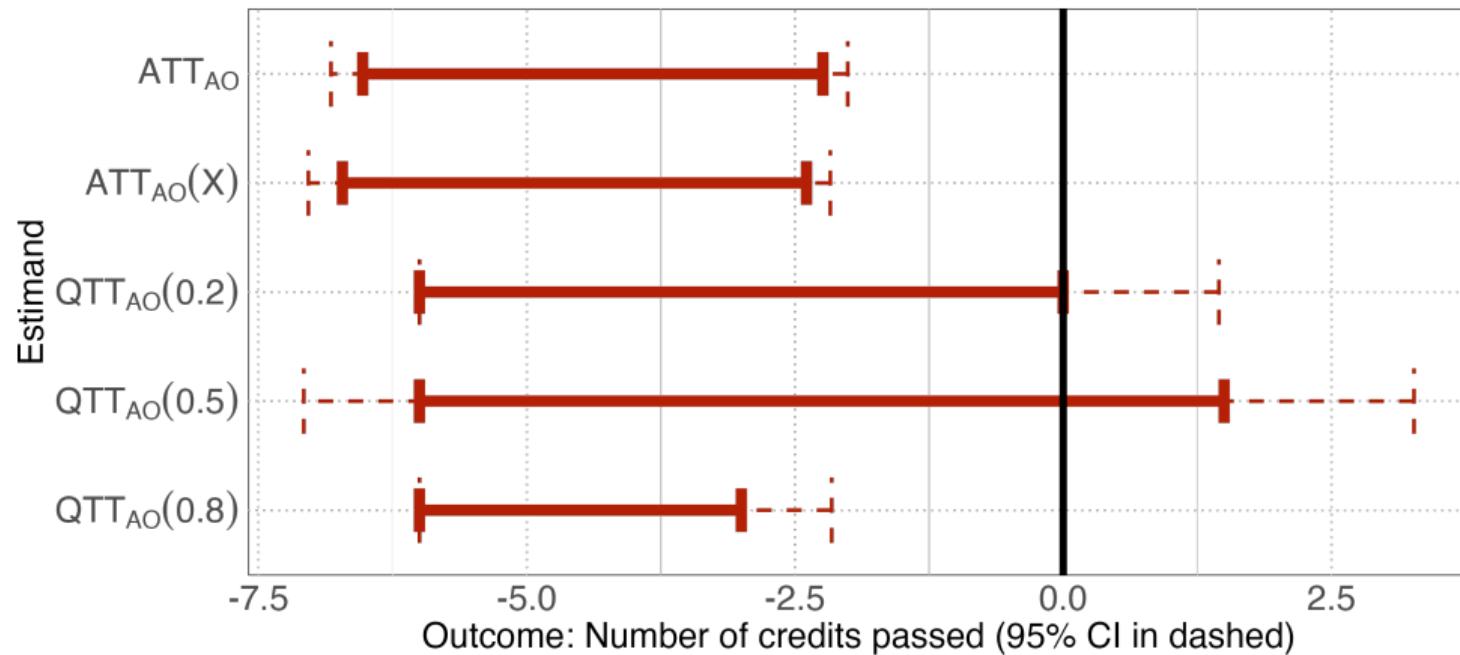
$$s^{drop}(1) \geq s^{drop}(0).$$

- tuition waivers may increase performance \implies increase in graduation,

$$s^{grad}(1) \leq s^{grad}(0).$$

▶ Expression

Back to the real-world example



$\text{ATT}_{\text{AO}}(X)$ refers to the ATT_{AO} including the following covariates in the estimation: parental education and highschool grades.

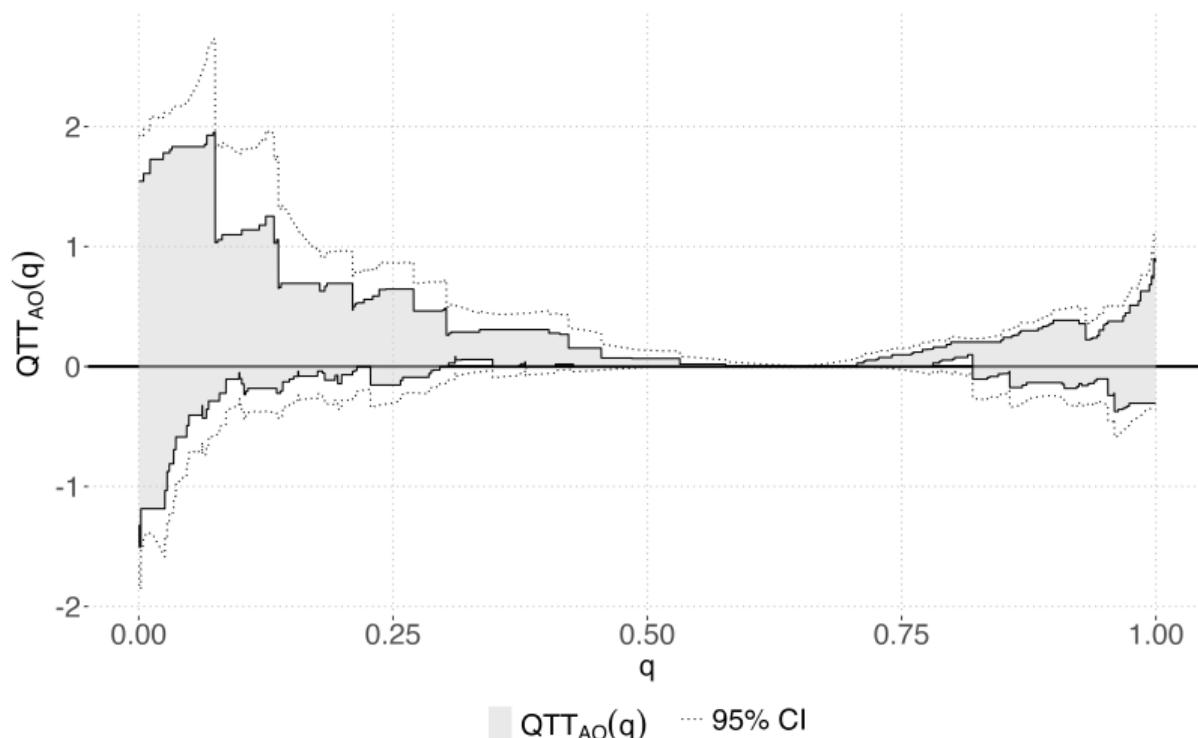
Revisiting Attanasio et al. (2011)

- Attanasio et al. (2011) estimate the effect of a job training program on wages.

Outcome	Log of salaried earnings			
	ATT _{AO}		Complete Case	
Estimand				
Estimate	[-0.11 , 0.429]	[-0.095 , 0.319]	0.129	0.123
95% CI	(-0.169 , 0.527)	(-0.158 , 0.416)	(0.037 , 0.22)	(0.031 , 0.215)
Covariates	No	Yes	No	Yes
N	888	888	888	888

Table: Estimates of the bounds for the ATT_{AO} and naive approach (using complete case analysis).

Distributional effects in Attanasio et al. (2011)



In the paper you will find...

- Asymptotically Normal estimators.
 - Valid inference (Imbens & Manski, 2004).
 - Some extensions
 - ▶ Sample selection in the pre-treatment period.
 - ▶ Relax monotonicity assumption.
 - ▶ Discrete Outcomes.
 - ▶ Covariates.
 - ▶ Repeated Cross Sections.
 - An application (Attanasio et al., 2011).
- + R package (coming soon!)

Working Paper:



arxiv.org/abs/2502.08614

Thanks!
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Full identification result CiC I

Identification result: $\Lambda^{LB}(q)$ and $\Lambda^{UB}(q)$ are sharp lower and upper bounds for the Quantile Treatment Effect on the Treated Always-Observed units ($QTT_{AO}(q)$), where:

$$\begin{aligned}\Lambda^{LB}(q) &= Q_{Y_2|G=1,S_2=1}(q\pi_1) \\ &\quad - Q_{Y_2|G=0,S_2=1} \left(F_{Y_1|G=0,S_2=1} \left(Q_{Y_1|G=1,S_2=1}(q\pi_1 + 1 - \pi_1) \right) + 1 - \pi_0 \right),\end{aligned}$$

$$\begin{aligned}\Lambda^{UB}(q) &= Q_{Y_2|G=1,S_2=1}(q\pi_1 + 1 - \pi_1) \\ &\quad - Q_{Y_2|G=0,S_2=1} \left(F_{Y_1|G=0,S_2=1} \left(Q_{Y_1|G=1,S_2=1}(q\pi_1) \right) - (1 - \pi_0) \right),\end{aligned}$$

$$\pi_1 = Pr(V_i = AO \mid G_i = 1, S_{i2}(1) = 1),$$

$$\pi_0 = Pr(V_i = AO \mid G_i = 0, S_{i2}(0) = 1),$$

$$F_Y(y) := Pr(Y \leq y)$$

$$Q_Y(q) := \inf \{y : F_Y(y) \geq q\}$$

provided that

$$\begin{aligned}F_{Y_1|G=0,S_2=1} \left(Q_{Y_1|G=1,S_2=1}(q\pi_1 + 1 - \pi_1) \right) &\leq \pi_0 \\ F_{Y_1|G=0,S_2=1} \left(Q_{Y_1|G=1,S_2=0}(q\pi_1) \right) &\geq 1 - \pi_0.\end{aligned}$$

Full identification result CiC II

If $F_{Y_1|G=0,S_2=1}(Q_{Y_1|G=1,S_2=1}(q\pi_1 + 1 - \pi_1)) > \pi_0$, then

$$\Lambda^{LB}(q) = Q_{Y_2|G=1,S_2=1}(q\pi_1) - Q_{Y_2|G=0,S_2=1}(1).$$

If $F_{Y_1|G=0,S_2=1}(Q_{Y_1|G=1,S_2=0}(q\pi_1)) < 1 - \pi_0$, then

$$\Lambda^{UB}(q) = Q_{Y_2|G=1,S_2=1}(q\pi_1 + 1 - \pi_1) - Q_{Y_2|G=0,S_2=1}(0).$$

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Identification PS proportions

Under Positive Monotonicity,

$$S_{i2}(1) \geq S_{i2}(0) \quad \forall i :$$

$$\pi_0 = 1$$

$$\pi_1 = \frac{\mathbb{E}[S_{i2}(0) \mid G_i = 1]}{\mathbb{E}[S_{i2} \mid G_i = 1]} = \frac{\mathbb{E}[S_{i1} \mid G_i = 1]}{\mathbb{E}[S_{i2} \mid G_i = 1]} \frac{\mathbb{E}[S_{i2} \mid G_i = 0]}{\mathbb{E}[S_{i1} \mid G_i = 0]} \in [0, 1]$$

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Identification PS proportions

Under Negative Monotonicity,

$$S_{i2}(1) \leq S_{i2}(0) \quad \forall i :$$

$$\pi_0 = \frac{\mathbb{E}[S_{i2}(1) | G_i = 0]}{\mathbb{E}[S_{i2} | G_i = 0]} = \frac{\mathbb{E}[S_{i1} | G_i = 0]}{\mathbb{E}[S_{i2} | G_i = 0]} \frac{\mathbb{E}[S_{i2} | G_i = 1]}{\mathbb{E}[S_{i1} | G_i = 1]} \in [0, 1]$$
$$\pi_1 = 1$$

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Identification PS proportions with multiple sources

$$\pi_0 = \frac{1}{\mathbb{E}[S_{i2} | G_i = 0]} \left(1 - \sum_{j \in J^+} \left(1 - \mathbb{E}[s_{i2}^j | G_i = 0] \right) - \sum_{j \in J^-} \left(1 - \mathbb{E}[s_{i1}^j | G_i = 0] \frac{\mathbb{E}[s_{i2}^j | G_i = 1]}{\mathbb{E}[s_{i1}^j | G_i = 1]} \right) \right)$$

$$\pi_1 = \frac{1}{\mathbb{E}[S_{i2} | G_i = 1]} \left(1 - \sum_{j \in J^+} \left(1 - \mathbb{E}[s_{i1}^j | G_i = 1] \frac{\mathbb{E}[s_{i2}^j | G_i = 0]}{\mathbb{E}[s_{i1}^j | G_i = 0]} \right) - \sum_{j \in J^-} \left(1 - \mathbb{E}[s_{i2}^j | G_i = 1] \right) \right)$$

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Asymptotically Normal Estimators

$$\hat{\pi}_0 = \frac{1}{\sum_i S_{i2}(1-G_i)} \left(1 - \left(1 - \frac{\sum_i s_{i2}^1(1-G_i)}{N_0} \right) - \left(1 - \frac{\sum_i s_{i1}^2(1-G_i)}{N_0} \frac{\sum_i s_{i2}^2 G_i}{\sum_i s_{i1}^2 G_i} \right) \right) \quad (1)$$

$$\hat{\pi}_1 = \frac{1}{\sum_i S_{i2} G_i} \left(1 - \left(1 - \frac{\sum_i s_{i1}^1 G_i}{N_1} \frac{\sum_i s_{i2}^1(1-G_i)}{\sum_i s_{i1}^1(1-G_i)} \right) - \left(1 - \frac{\sum_i s_{i2}^2 G_i}{N_1} \right) \right) \quad (2)$$

$$\widehat{\Lambda^{LB}}(q) = \widehat{Q}_{Y_2|G=1,S_2=1}(q\hat{\pi}_1) - \widehat{Q}_{Y_2|G=0,S_2=1}(\hat{q}_{LB}^*) , \quad (3)$$

$$\hat{q}_{LB}^* = \min \left\{ \widehat{F}_{Y_1|G=0,S_2=1} \left(\widehat{Q}_{Y_1|G=1,S_2=1}(q\hat{\pi}_1 + 1 - \hat{\pi}_1) \right) + 1 - \hat{\pi}_0, 1 \right\} , \quad (4)$$

$$\widehat{\Lambda^{UB}}(q) = \widehat{Q}_{Y_2|G=1,S_2=1}(q\hat{\pi}_1 + 1 - \hat{\pi}_1) - \widehat{Q}_{Y_2|G=0,S_2=1}(\hat{q}_{UB}^*) , \quad (5)$$

$$\hat{q}_{UB}^* = \max \left\{ \widehat{F}_{Y_1|G=0,S_2=1} \left(\widehat{Q}_{Y_1|G=1,S_2=1}(q\hat{\pi}_1) \right) - (1 - \hat{\pi}_0), 0 \right\} , \quad (6)$$

where \widehat{F}_Y denotes the empirical distribution of Y .

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Empirical Distributions

For instance,

$$\widehat{F}_{Y_1|G=0,S_2=1}(y) = \frac{\sum_i S_{i2}(1 - G_i)\mathbb{1}(Y_{i1} \leq y)}{\sum_i S_{i2}(1 - G_i)}$$
$$\widehat{Q}_{Y_2|G=0,S_2=1}(q) = \inf \left\{ y : \widehat{F}_{Y_2|G=0,S_2=1}(y) \geq q \right\}.$$

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Discrete Outcomes: CiC

$$\Lambda^{LB}(q) = Q_{Y_2|G=1,S_2=1}(q\pi_1) - Q_{Y_2|G=0,S_2=1} \left(F_{Y_1|G=0,S_2=1} \left(Q_{Y_1|G=1,S_2=1}(q\pi_1 + 1 - \pi_1) \right) + 1 - \pi_0 \right),$$

$$\Lambda^{UB}(q) = Q_{Y_2|G=1,S_2=1}(q\pi_1 + 1 - \pi_1) - \tilde{Q}_{Y_2|G=0,S_2=1} \left(F_{Y_1|G=0,S_2=1} \left(\tilde{Q}_{Y_1|G=1,S_2=1}(q\pi_1) \right) - (1 - \pi_0) \right),$$

$$\begin{aligned}\pi_1 &= Pr(S_{i2}(0) = 1 \mid G_i = 1, S_{i2}(1) = 1), \\ \pi_0 &= Pr(S_{i2}(1) = 1 \mid G_i = 0, S_{i2}(0) = 1),\end{aligned}$$

$$F_Y(y) := Pr(Y \leq y),$$

$$Q_Y(q) := \inf\{y : F_Y(y) \geq q\},$$

$$\tilde{Q}_Y(q) := \sup\{y \cup \{-\infty\} : F_Y(y) \leq q\}.$$

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Discrete Outcomes: DiD (reweighting)

$$\underline{\mathcal{P}}_Y^\pi(y) = \begin{cases} \frac{Pr(Y=y)}{\pi} & \text{if } y < Q_Y(\pi) \\ \frac{\pi - Pr(y < Q_Y(\pi))}{\pi} & \text{if } y = Q_Y(\pi) \\ 0 & \text{if } y > Q_Y(\pi) \end{cases} \quad (7)$$

$$\overline{\mathcal{P}}_Y^\pi(y) = \begin{cases} 0 & \text{if } y < Q_Y(1-\pi) \\ \frac{\pi - Pr(Y > Q_Y(1-\pi))}{\pi} & \text{if } y = Q_Y(1-\pi) \\ \frac{Pr(Y=y)}{\pi} & \text{if } y > Q_Y(1-\pi) \end{cases} \quad (8)$$

$$\Delta^{LB} = \sum_{i:G_i=1,S_{i2}=1} \ddot{Y}_i \underline{\mathcal{P}}_{\ddot{Y}_i|G_i=1,S_{i2}=1}^{\pi_1}(y) - \sum_{i:G_i=0,S_{i2}=1} \ddot{Y}_i \overline{\mathcal{P}}_{\ddot{Y}_i|G_i=0,S_{i2}=1}^{\pi_0}(y)$$

$$\Delta^{UB} = \sum_{i:G_i=1,S_{i2}=1} \ddot{Y}_i \overline{\mathcal{P}}_{\ddot{Y}_i|G_i=1,S_{i2}=1}^{\pi_1}(y) - \sum_{i:G_i=0,S_{i2}=1} \ddot{Y}_i \underline{\mathcal{P}}_{\ddot{Y}_i|G_i=0,S_{i2}=1}^{\pi_0}(y)$$

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Covariates I

- ① Target Conditional Estimands: e.g., Conditional Average Treatment Effect on the Treated

$$CATT_{AO}(x) = \mathbb{E}[Y_{i2}(1) - Y_{i2}(0) \mid G_i = 1, V_i = AO, X_i = x]$$

- ② Make Conditional Assumptions: e.g., Conditional Positive Monotonicity

$$S_{i2}(1) \geq S_{i2}(0) \quad \forall i : X_i = x$$

- ③ Identification and estimation in each cell of the covariates:

$$\Delta^{LB}(x) = \mathbb{E}[\ddot{Y}_i \mid G_i = 1, S_{i2} = 1, \ddot{Y}_i \leq \ddot{y}_{\pi_1}^1, X_i = x] - \mathbb{E}[\ddot{Y}_i \mid G_i = 0, S_{i2} = 1, \ddot{Y}_i \geq \ddot{y}_{1-\pi_0}^0, X_i = x]$$

$$\Delta^{UB}(x) = \mathbb{E}[\ddot{Y}_i \mid G_i = 1, S_{i2} = 1, \ddot{Y}_i \geq \ddot{y}_{1-\pi_1}^1, X_i = x] - \mathbb{E}[\ddot{Y}_i \mid G_i = 0, S_{i2} = 1, \ddot{Y}_i \leq \ddot{y}_{\pi_0}^0, X_i = x]$$

$$\pi_0 = 1$$

$$\pi_1 = \frac{\mathbb{E}[S_{i1} \mid G_i = 1, X_i = x]}{\mathbb{E}[S_{i2} \mid G_i = 1, X_i = x]} \frac{\mathbb{E}[S_{i2} \mid G_i = 0, X_i = x]}{\mathbb{E}[S_{i1} \mid G_i = 0, X_i = x]}$$

Covariates II

① Aggregate:

$$\overline{\text{ATT}_{\text{AO}}} \in \left[\overline{\Delta^{LB}}, \overline{\Delta^{UB}} \right],$$

where

$$\overline{\Delta^{LB}} = \sum_{x \in X} \Delta^{LB}(x)p(x) \quad ; \quad \overline{\Delta^{UB}} = \sum_{x \in X} \Delta^{UB}(x)p(x),$$
$$p(x) = \Pr(X_i = x \mid G_i = 1, V_i = AO)$$

which are estimated as:

$$\widehat{\Delta^{LB}} = \sum_{x \in X} \omega_x \widehat{\Delta^{LB}}(x) \quad ; \quad \widehat{\Delta^{UB}} = \sum_{x \in X} \omega_x \widehat{\Delta^{UB}}(x)$$
$$\omega_x = \frac{\widehat{\pi}_1^x}{\Pi_1} \frac{\sum_i \mathbb{1}(G_i = 1, S_{i2} = 1, X_i = x)}{N_1} \quad ; \quad \Pi_1 = \sum_{x \in X} \widehat{\pi}_1^x$$

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Repeated Cross-Sections

The proportions of AO units in the pre-treatment period are given by:

$$\varpi_1 = \pi_1 \frac{\mathbb{E}[S_{i2} | G_i = 1]}{\mathbb{E}[S_{i1} | G_i = 1]} \quad ; \quad \varpi_0 = \pi_0 \frac{\mathbb{E}[S_{i2} | G_i = 0]}{\mathbb{E}[S_{i1} | G_i = 0]}$$

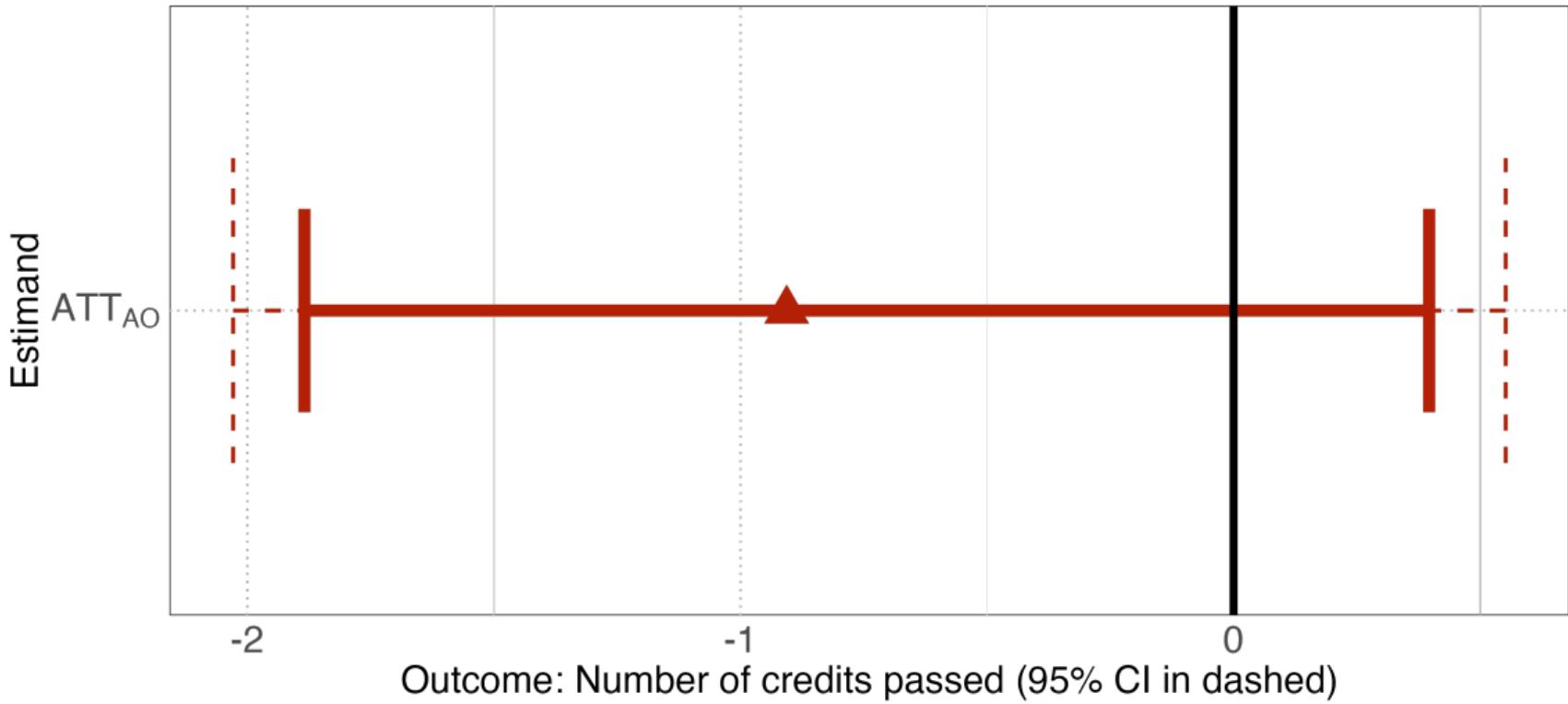
or, if missigness is not an absorbing state, they are bounded by

$$\max \left\{ 0, \frac{\pi_1 \mathbb{E}[S_{i2} | G_i = 1] - (1 - \mathbb{E}[S_{i1} | G_i = 1])}{\mathbb{E}[S_{i1} | G_i = 1]} \right\} \leq \varpi_1 \leq \min \left\{ 1, \pi_1 \frac{\mathbb{E}[S_{i2} | G_i = 1]}{\mathbb{E}[S_{i1} | G_i = 1]} \right\}$$

$$\max \left\{ 0, \frac{\pi_0 \mathbb{E}[S_{i2} | G_i = 0] - (1 - \mathbb{E}[S_{i1} | G_i = 0])}{\mathbb{E}[S_{i1} | G_i = 0]} \right\} \leq \varpi_0 \leq \min \left\{ 1, \pi_0 \frac{\mathbb{E}[S_{i2} | G_i = 0]}{\mathbb{E}[S_{i1} | G_i = 0]} \right\}$$

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Bounds with DiD



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