

Estimating the Effect of a Mis-measured, Endogenous, Binary Treatment

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What is the causal effect of T^* ?

$$y_i = h(T_i^*, \mathbf{x}_i) + \varepsilon_i$$

- ▶ y – Outcome of interest
- ▶ h – Unknown function that *does not depend on* i
- ▶ T^* – Unobserved, endogenous binary treatment
- ▶ T – Observed, mis-measured surrogate for T^*
- ▶ \mathbf{x} – Exogenous covariates
- ▶ ε – Mean-zero error term
- ▶ z – Discrete instrumental variable

Example 1: Smoking and Birthweight

RCT with 612 pregnant smokers in Glasgow, Scotland: 306 are offered financial incentives to attend smoking cessation program.

- ▶ y – Birthweight
- ▶ T^* – True smoking behavior
- ▶ T – Self-reported smoking behavior
- ▶ \mathbf{x} – Mother characteristics
- ▶ z – Offer of financial incentive

Example 2: Schooling and Test Scores

RCT in Afghanistan: a school is built in 6 out of 11 villages.

- ▶ y – Score on math and language test
- ▶ T^* – True school attendance
- ▶ T – Self-reported school attendance
- ▶ \mathbf{x} – Household characteristics
- ▶ z – School built in village

Non-classical Measurement Error: Binary T^*

- ▶ Many applications of linear model have *binary* treatment
- ▶ Binary $T^* \implies \mathbb{E}[T^* w] \leq 0$
- ▶ Misclassification Probabilities:

$$\alpha_0 = \mathbb{P}(T = 1 | T^* = 0)$$

$$\alpha_1 = \mathbb{P}(T = 0 | T^* = 1)$$

- ▶ Non-Differential Measurement Error: $T \perp (z, u) | T^*$
- ▶ $\sigma_{T^*}^2 \not\leq \sigma_T^2$ so work with α_0, α_1 rather than κ
- ▶ *Four-dimensional* Problem. . .

Results for a Mis-classified Binary Regressor

Aigner (1973), Bollinger (1996)...

- ▶ Even if $\rho_{T^*u} = 0$, OLS is biased and inconsistent: typically attenuated towards zero *but could flip signs!*

Kane et al. (1999), Black et al. (2000), Frazis et al. (2003)...

- ▶ $\rho_{zu} = 0 \implies$ IV solves endogenous regressor problem if there is no mis-classification
- ▶ $\rho_{T^*u} = 0$ and $\rho_{zu} = 0 \implies$ non-linear GMM estimator can solve the mis-classification problem

OLS and IV Probability Limits: Binary T^*

$$\text{plim} \left(\hat{\beta}_{OLS} \right) = \frac{\sigma_{T^*}^2}{\sigma_T^2} \left[\beta (1 - \alpha_0 - \alpha_1) + \frac{\sigma_{T^*u}}{\sigma_{T^*}^2} \right]$$

$$\text{plim} \left(\hat{\beta}_{IV} \right) = \frac{\beta}{1 - \alpha_0 - \alpha_1} + \frac{\sigma_{zu}}{\sigma_{zT}}$$

$$\sigma_{T^*}^2 = \frac{(p - \alpha_0)(1 - p - \alpha_1)}{(1 - \alpha_0 - \alpha_1)^2}$$

Where $p = \mathbb{P}(T = 1)$

What About Endogenous, Mis-measured T^* , Valid z ?

$$y = \beta T^* + u$$

$$u = c + \varepsilon$$

- ▶ No results in the literature for this case
- ▶ Important setting in applied work: e.g. RCTs
- ▶ Discrete Instrument: $z \in \{z_1, \dots, z_K\}$
- ▶ Non-parametric First Stage: $p_k^* = \mathbb{P}(T^* = 1 | z = z_k)$
- ▶ What does $E[\varepsilon | z] = 0$ buy us in this case?

Observable Moments: $y = \beta T^* + u$

	$z = 1$	$z = 1$	\dots	$z = K$
$T = 0$	\bar{y}_{01} p_{01}	\bar{y}_{02} p_{02}	\dots	\bar{y}_{0K} p_{0K}
$T = 1$	\bar{y}_{11} p_{11}	\bar{y}_{12} p_{12}	\dots	\bar{y}_{1K} p_{1K}

$$\bar{y}_{tk} = \mathbb{E}[y | T = t, z = z_k], \quad p_{tk} = q_k p_k$$

$$q_k = \mathbb{P}(z = z_k), \quad p_k = \mathbb{P}(T = 1 | z = z_k)$$

Unobservable Moments: $y = \beta T^* + u$

	$z = 1$	$z = 1$	\dots	$z = K$
$T^* = 0$	m_{01}^* p_{01}^*	m_{02}^* p_{02}^*	\dots	m_{0K}^* p_{0K}^*
$T^* = 1$	m_{11}^* p_{11}^*	m_{12}^* p_{12}^*	\dots	m_{1K}^* p_{1K}^*

$$m_{tk}^* = \mathbb{E}[u | T^* = t, z = z_k], \quad p_{tk}^* = q_k p_k^*$$

$$p_k^* = \mathbb{P}(T^* = 1 | z = z_k) = \frac{p_k - \alpha_0}{1 - \alpha_0 - \alpha_1}$$

Possible Assumptions On m_{tk}^*

Joint Exogeneity: $\mathbb{E}[\varepsilon | T^*, z] = 0$

$$\implies m_{tk}^* = c \quad \text{for all } t, k$$

Exogenous Treatment: $\mathbb{E}[\varepsilon | T^*] = 0$

$$\implies \frac{1}{\mathbb{P}(T^* = t)} \sum_k p_{tk}^* m_{tk}^* = c \quad \text{for all } t$$

Exogenous Instrument: $\mathbb{E}[\varepsilon | z] = 0$

$$\implies (1 - p_k^*) m_{0k}^* + p_k^* m_{1k}^* = c \quad \text{for all } k$$

Moment Conditions Imposing $\mathbb{E}[\varepsilon|z] = 0$

One pair of equations for each $k = 1, \dots, K$

$$\hat{y}_{0k} = \alpha_1(p_k - \alpha_0) \left(\frac{\beta}{1 - \alpha_0 - \alpha_1} \right) + (1 - \alpha_0)c - (p_k - \alpha_0)m_{1k}^*$$

$$\hat{y}_{1k} = (1 - \alpha_1)(p_k - \alpha_0) \left(\frac{\beta}{1 - \alpha_0 - \alpha_1} \right) + \alpha_0 c + (p_k - \alpha_0)m_{1k}^*$$

where $\hat{y}_{0k} = (1 - p_k)\bar{y}_{0k}$ and $\hat{y}_{1k} = p_k\bar{y}_{1k}$

2K Equations in $K + 4$ Unknowns

Mahajan

Proposition: β is Unidentified Regardless of K

Proof Sketch

- (1) Show that $\mathcal{W} = \beta/(1 - \alpha_0 - \alpha_1)$ is identified.
- (2) Show that $\mathcal{Q} = c + \beta(1 - \alpha_0)/(1 - \alpha_0 - \alpha_1)$ is identified.
- (3) (1) + (2) $\implies (\mathcal{Q}, \mathcal{W})$ are *fixed*
- (4) Use (3) to rewrite equations in terms of $(\mathcal{Q}, \mathcal{W})$.
- (5) Discover that there is only *one* equation per k ! Rearranging:

$$m_{1k}^* = \frac{\mathcal{W}(\hat{y}_{0k} - \alpha_1 \mathcal{Q}) - \beta(\mathcal{Q} - \beta - \mathcal{W}\alpha_1) + \mathcal{W}^2(1 - p_k)\alpha_1}{\mathcal{W}(1 - p_k - \alpha_1) - \beta}$$

Special Case of Prev Proof: $\alpha_0 = 0$

$$\hat{y}_{0k} = c + p_k \beta \left(\frac{\alpha_1}{1 - \alpha_1} \right) - p_k m_{1k}^*$$

$$\hat{y}_{1k} = p_k \beta + p_k m_{1k}^*$$

Identification by Conditional Variances?

New Assumption

Homoskedastic errors w.r.t. the *instrument*: $E[\varepsilon^2|z] = E[\varepsilon^2]$

Not Crazy!

Holds in an RCT or a *true* natural experiment.

New Moment Conditions

For each pair (k, ℓ)

$$\begin{aligned}s_k^2 - s_\ell^2 &= \mathcal{W}^2 [p_k(1 - p_k) - p_\ell(1 - p_\ell) + (\alpha_0 - \alpha_1)(p_k - p_\ell)] \\ &\quad + 2\mathcal{W} [(p_k - \alpha_0)(m_{1k}^* - c) - (p_\ell - \alpha_0)(m_{1\ell}^* - c)]\end{aligned}$$

Where $s_k^2 = \text{Var}(y|z = z_k)$, and \mathcal{W} is the Wald IV estimator.

Proposition: $(\alpha_0 - \alpha_1)$ is Identified

Define

$$\widetilde{\mathcal{W}}_{k\ell} = \frac{\mathbb{E}[yT|z_k] - \mathbb{E}[yT|z_\ell]}{p_k - p_\ell}$$

Show that:

$$\begin{aligned} (p_k - \alpha_0)(m_{1k}^* - c) - (p_\ell - \alpha_0)(m_{1\ell}^* - c) = \\ (p_k - p_\ell) \left[\widetilde{\mathcal{W}}_{k\ell} - \mathbb{E}[y] - \mathcal{W} \{ (1 - p) + (\alpha_0 - \alpha_1) \} \right] \end{aligned}$$

Substituting and rearranging:

$$\alpha_0 - \alpha_1 = (2p - 1 - p_k - p_\ell) + \frac{2(\widetilde{\mathcal{W}}_{k\ell} - \mathbb{E}[y])}{\mathcal{W}} - \frac{s_k^2 - s_\ell^2}{(p_k - p_\ell)\mathcal{W}^2}$$

What Good is $(\alpha_0 - \alpha_1)$?

- ▶ Test a necessary condition for *no mis-classification*: $\alpha_0 = \alpha_1$
- ▶ Simple, tighter partial identification bounds for β
- ▶ In some settings, one of the mis-classification probabilities is known to be zero $\implies \beta$ point identified

Identification from Third Moments

Simulation Study

$$y = \beta T^* + \varepsilon$$

$$T^* = \mathbf{1}\{\gamma_0 + \gamma_1 z + \eta > 0\}$$

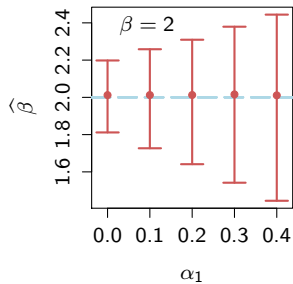
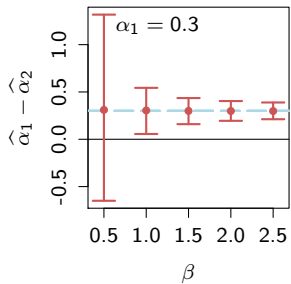
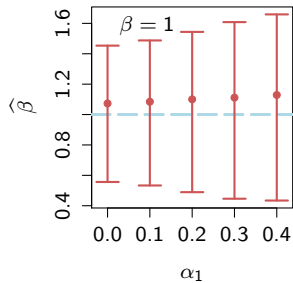
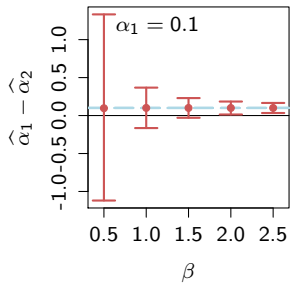
$$\gamma_0 = \Phi^{-1}(\delta), \gamma_1 = \Phi^{-1}(1 - \delta) - \Phi(\delta) \text{ so that } \delta$$

E.g. if $\delta = 0.1$ then 10% of those *not* offered treatment get it anyway, and 10% of those offered treatment don't take it up.

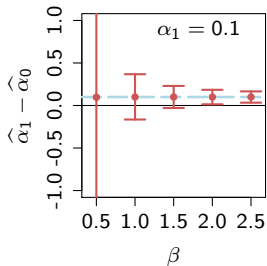
If $T^* = 0$ then $T = 0$ (E.g. Birthweight and smoking)

$$T|T^* = 1 \sim \text{Bernoulli}(?)$$

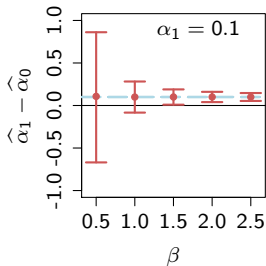
$$\begin{bmatrix} \varepsilon \\ \eta \end{bmatrix} \sim N\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & 0.3 \\ 0.3 & 1 \end{bmatrix}\right)$$



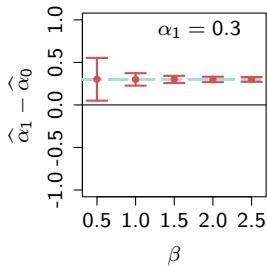
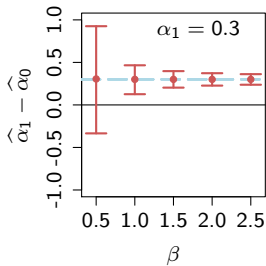
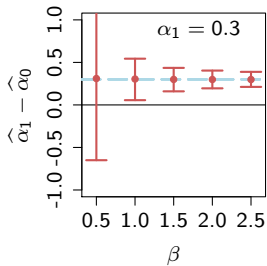
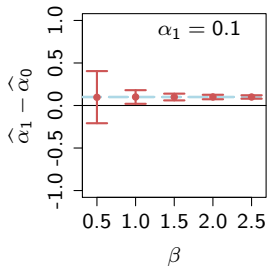
(a) $N = 500, \delta = 0.1$



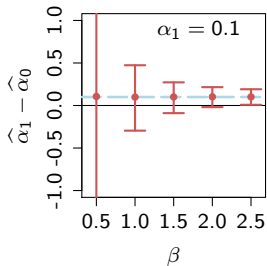
(b) $N = 1000, \delta = 0.1$



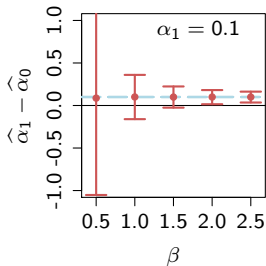
(c) $N = 5000, \delta = 0.1$



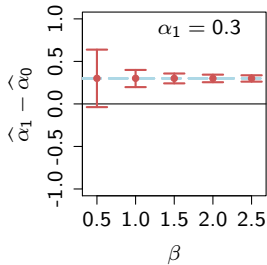
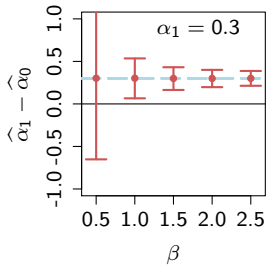
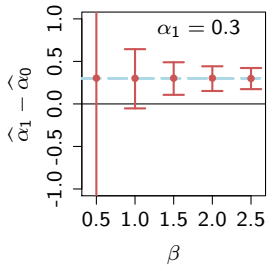
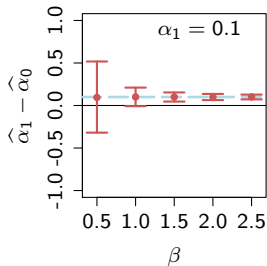
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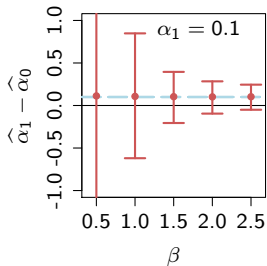
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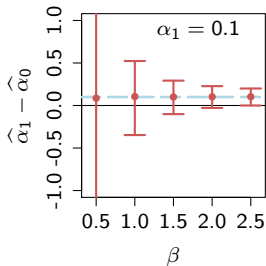
(c) $N = 5000, \delta = 0.2$



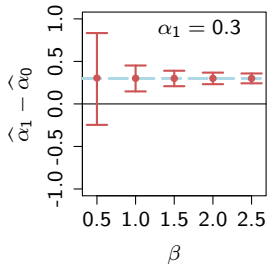
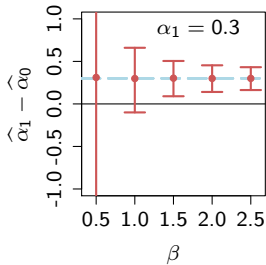
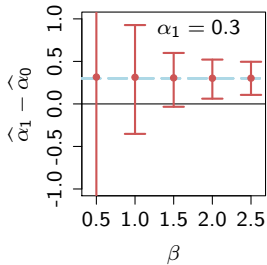
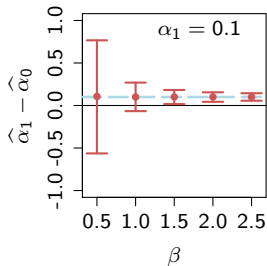
(a) $N = 500, \delta = 0.3$



(b) $N = 1000, \delta = 0.3$



(c) $N = 5000, \delta = 0.3$



Empirical Illustration: Schooling and Test Scores