

PLSC 504 – Fall 2022

Endogenous Selection and Potential Outcomes

September 19, 2022

Sample Selection In Theory

- Challenge: Inference to a Population from a Non-Random Sample
- Widespread Problem...
 - Heckman's wage equations...
 - Self-selection (e.g., into groups)
 - Surveys: "Screening" questions (sometimes...)
- Parallels in Missing Data, Causal/Counterfactual Inference

Consider latent Y^* s:

$$Y_{1i}^* = \mathbf{X}_i\beta + u_{1i}$$

$$Y_{2i}^* = \mathbf{Z}_i\gamma + u_{2i}$$

Observe:

$$Y_{1i} = \begin{cases} Y_{1i}^* & \text{if } Y_{2i}^* > 0 \\ \text{missing} & \text{if } Y_{2i}^* \leq 0 \end{cases}$$

- Y_{2i}^* unobserved (except for sign);
- \mathbf{X}_i observed iff Y_{1i} is observed;
- \mathbf{Z}_i observed in every case.

Sample Selection Basics

When do we observe Y_1 ?

$$\begin{aligned}\Pr(Y_{2i}^* \leq 0 | \mathbf{X}, \mathbf{Z}) &= \Pr(u_{2i} \leq -\mathbf{Z}_i\gamma) \\ &= 1 - \Pr(u_{2i} \geq -\mathbf{Z}_i\gamma) \\ &= 1 - \Pr(-u_{2i} \leq \mathbf{Z}_i\gamma) \\ &= 1 - \int_{-\infty}^{\mathbf{Z}_i\gamma} f(u_2) du_2 \\ &= 1 - F_{u_2}(\mathbf{Z}_i\gamma)\end{aligned}$$

Define:

$$D_i = \begin{cases} 1 & \text{if } Y_{1i} \text{ is observed.} \\ 0 & \text{otherwise.} \end{cases}$$

Then

$$\Pr(D_i = 1) = F_{u_2}(\mathbf{Z}_i\gamma).$$

Assume:

$$\{u_1, u_2\} \sim \mathcal{BVN}(0, 0, \sigma_1^2, 1, \sigma_{12})$$

Means

$$\Pr(D_i = 1 | \mathbf{Z}_i, \mathbf{X}_i) = \Phi(\mathbf{Z}_i \gamma).$$

Define:

$$\rho = \text{corr}(u_1, u_2).$$

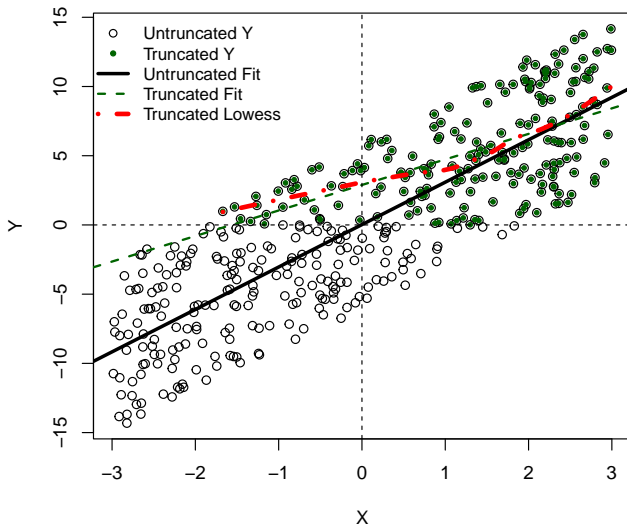
What we get:

$$E(Y_{1i}|\mathbf{X}_i, \mathbf{Z}_i, D_i = 1) = \mathbf{X}_i\boldsymbol{\beta} + \rho\sigma_1 \left[\frac{\phi(\mathbf{Z}_i\boldsymbol{\gamma})}{\Phi(\mathbf{Z}_i\boldsymbol{\gamma})} \right]$$

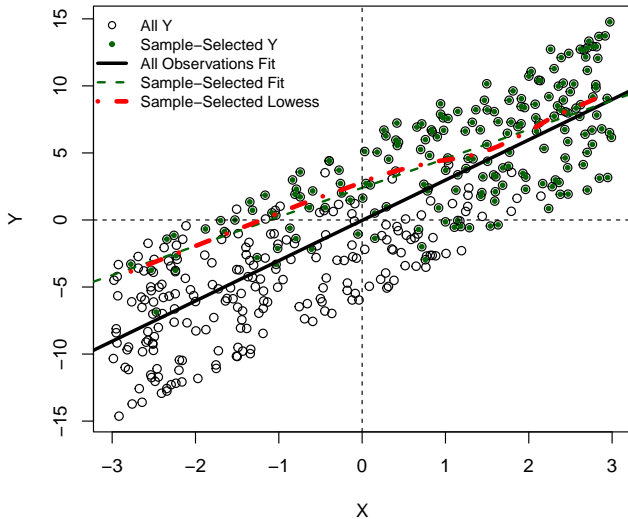
Without conditioning on \mathbf{Z} :

$$E(Y_{1i}|\mathbf{X}_i, D_i = 1) = \mathbf{X}_i\boldsymbol{\beta} + E \left\{ \rho\sigma_1 \left[\frac{\phi(\mathbf{Z}_i\boldsymbol{\gamma})}{\Phi(\mathbf{Z}_i\boldsymbol{\gamma})} \right] \middle| \mathbf{X}_i \right\}$$

Truncation Bias



Sample Selection Bias



Selection Bias: Substantive Effects

- Specification Error (unless $\rho = 0$)

- Indeterminate bias in $\hat{\beta}$

- Including \mathbf{Z}_i will not generally* remove the bias:

“With quasi-experimental data derived from nonrandomized assignments, controlling for additional variables in a regression may worsen the estimate of the treatment effect, even when the additional variables improve the specification.” – Achen (1986, p. 27)

- Bias remains even if inference is limited to the “selected” group. [This point is made nicely in Berk (1983)...]

* Unless sample selection is completely deterministic (i.e., determined *perfectly* by \mathbf{X} , \mathbf{Z}) (Heckman & Robb 1985).

Conditional Density:

$$h(Y|\mathbf{X}, \mathbf{Z}, \beta, \gamma, \sigma_1, \rho) = \frac{\phi\left(\frac{Y_{1i} - \mathbf{X}_i\beta}{\sigma_1}\right)}{\sigma_1 \Phi(\mathbf{Z}_i\gamma)} \cdot \Phi\left[\frac{\frac{\rho(Y_{1i} - \mathbf{X}_i\beta)}{\sigma_1} + \mathbf{Z}_i\gamma}{\sqrt{1 - \rho^2}}\right]$$

Note: $\rho = 0$ yields

$$\begin{aligned} h(Y|\mathbf{X}, \mathbf{Z}, \beta, \gamma, \sigma_1, \rho = 0) &= \frac{\phi\left(\frac{Y_{1i} - \mathbf{X}_i\beta}{\sigma_1}\right)}{\sigma_1 \Phi(\mathbf{Z}_i\gamma)} \cdot \Phi\left[\frac{0 + \mathbf{Z}_i\gamma}{1}\right] \\ &= \frac{\phi\left(\frac{Y_{1i} - \mathbf{X}_i\beta}{\sigma_1}\right)}{\sigma_1}. \end{aligned}$$

Under sample selection, the full likelihood is:

$$\begin{aligned}\ln L(\beta, \gamma, \sigma_1, \rho | Y_1) &= \sum_{i=1}^N (1 - D_i) \ln[1 - \Phi(\mathbf{Z}_i \gamma)] \\ &\quad + \sum_{i=1}^N D_i \ln[\Phi(\mathbf{Z}_i \gamma)] \\ &\quad + \sum_{i=1}^N D_i \ln \left\{ \frac{\phi\left(\frac{Y_{1i} - \mathbf{x}_i \beta}{\sigma_1}\right)}{\sigma_1 \Phi(\mathbf{Z}_i \gamma)} \cdot \Phi \left[\frac{\frac{\rho(Y_{1i} - \mathbf{x}_i \beta)}{\sigma_1} + \mathbf{Z}_i \gamma}{\sqrt{1 - \rho^2}} \right] \right\}\end{aligned}$$

Estimation can be via:

- MLE (above)
- Or, reconsider:

$$E(Y_{1i} | \mathbf{X}_i, \mathbf{Z}_i, D_i = 1) = \mathbf{X}_i \boldsymbol{\beta} + \rho \sigma_1 \left[\frac{\phi(\mathbf{Z}_i \boldsymbol{\gamma})}{\Phi(\mathbf{Z}_i \boldsymbol{\gamma})} \right]$$

- Note that $\Phi(\mathbf{Z}_i \boldsymbol{\gamma}) = \Pr(D_i = 1)$
- Suggests a two-step approach...

Heckman's Two-Step Estimator

1. Estimate $\hat{\gamma}$ from

$$\Pr(D_i = 1) = \Phi(\mathbf{Z}_i\gamma)$$

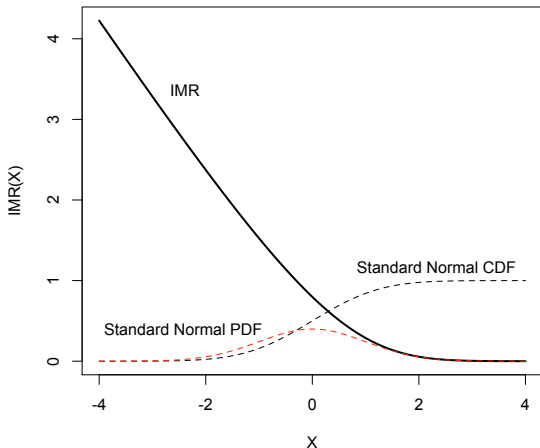
and calculate the estimated inverse Mills' ratio:

$$\hat{\lambda}_i = \frac{\phi(\mathbf{Z}_i\hat{\gamma})}{\Phi(-\mathbf{Z}_i\hat{\gamma})}$$

2. Estimate $\beta, \theta(\equiv \rho\sigma_1)$ as:

$$Y_{1i} = \mathbf{X}_i\beta + \theta\hat{\lambda}_i + u_{1i}$$

What exactly *is* an “inverse Mills’ ratio,” anyway?



In the two-step approach:

- Since $\sigma_1 > 0$, $\hat{\theta} = 0 \implies \rho = 0$
- Two-step approach:
 - Is “LIML” ...
 - Consistent for $\hat{\beta}$, but
 - Inconsistent estimating $\widehat{\mathbf{V}}(\hat{\beta})$; so
 - Standard errors require correction (e.g., bootstrap)
 - *Can* yield $\hat{\rho} \notin [-1, 1]$ (because $\hat{\rho} = \hat{\theta}/\hat{\sigma}_1$)
 - Sensitive to prediction of D_i (better prediction = better precision)

For any estimation approach:

- If $\mathbf{X} = \mathbf{Z}$, then β, γ, ρ (formally) identified by nonlinearity of $\Phi(\cdot)$
- (Much) better: \geq one covariate in \mathbf{Z} not in \mathbf{X}
- But...
 - Factors causing Y_1 also (often) cause D
 - $\implies \mathbf{X}, \mathbf{Z}$ highly correlated
 - ...just makes things worse (Stolzenberg and Relles 1997)

Some Practical Things

- In practice, few people use two-step anymore,
- Model is *always* sensitive to joint normality of $\{u_i, u_2\}$,
- It is also very sensitive to model specification...
- Key issue: endogeneity of selection...

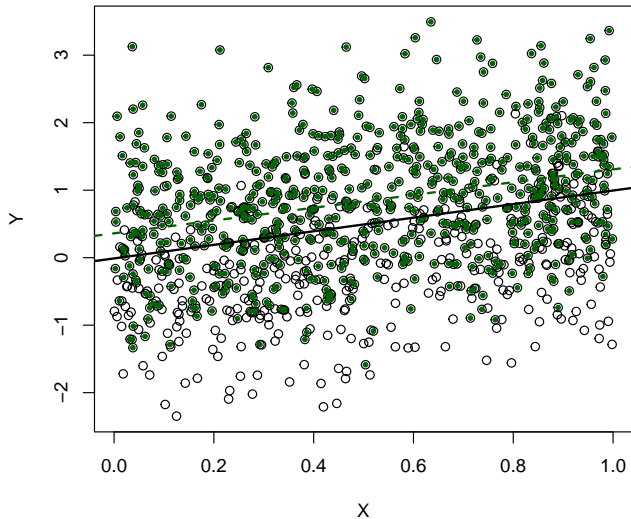
Simulated Example I: $\text{Cov}(X, Z) = 0$

```
> set.seed(7222009)
> N <- 1000          # N of observations

> # Bivariate normal us, correlated at r=0.7
> us <- rmvnorm(N,c(0,0),matrix(c(1,0.7,0.7,1),2,2))

> Z <- runif(N)      # Sel. variable
> Sel<- Z + us[,1]>0  # Selection eq.
> X <- runif(N)      # X
> Y <- X + us[,2]     # B0=0, B1=1
> Yob<- ifelse(Sel==TRUE,Y,NA)    # Selected Y
>
> # OLSs:
>
> NoSel<-lm(Y~X)      # all data
> WithSel<-lm(Yob~X)  # sample-selected data
```

Simulation I (continued)



Simulation I (continued)

```
> # Two-Step:
>
> probit<-glm(Sel~Z,family=binomial(link="probit"))
> IMR<-((1/sqrt(2*pi))*exp(-((probit$linear.predictors)^2/2))) /
+   pnorm(probit$linear.predictors)
>
> OLS2step<-lm(Yob~X+IMR)
>
>
> # FIML:
>
> FIML<-selection(Sel~Z,Y~X,method="ml")
```

Simulation I (continued)

	OLS-All	OLS-Selected	Two-Stage	FIML
X (true OLS = 1)	1.000*** (0.106)	0.947*** (0.114)	0.948*** (0.114)	0.939*** (0.112)
IMR			0.428* (0.223)	
Constant (true = 0)	-0.011 (0.062)	0.360*** (0.068)	0.152 (0.128)	-0.007 (0.092)
Observations	1,000	691	691	1,000
R ²	0.083	0.091	0.096	
Adjusted R ²	0.082	0.089	0.093	
Log Likelihood				-1,479.000
ρ				0.742*** (0.088)

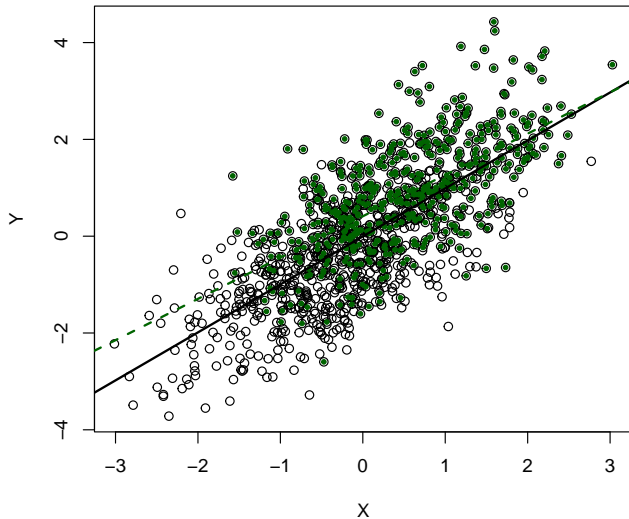
Note:

* p<0.1; ** p<0.05; *** p<0.01

Simulated Example II: $\text{Cov}(X, Z) > 0$

```
> set.seed(9021970)
> N <- 1000          # N of observations
>
> # Bivariate normal us & Xs, correlated at r=0.7 / 0.8
> us <- rmvnorm(N,c(0,0),matrix(c(1,0.7,0.7,1),2,2))
> Xs <- rmvnorm(N,c(0,0),matrix(c(1,0.8,0.8,1),2,2))
> Z <- Xs[,1]
> X <- Xs[,2]
> Sel<- Z + us[,1]>0      # Selection eq.
> Y <- X + us[,2]         # B0=0, B1=1
> Yob<- ifelse(Sel==TRUE,Y,NA) # Selected Y
>
> # OLSs:
>
> NoSel2<-lm(Y~X)         # all data
> WithSel2<-lm(Yob~X)    # sample-selected data
```

Simulation II (continued)



Simulation II (continued)

	OLS-All	OLS-Selected	Two-Stage	FIML
X (true OLS = 1)	0.991*** (0.029)	0.853*** (0.046)	1.020*** (0.061)	1.010*** (0.056)
IMR			0.533*** (0.133)	
Constant (true = 0)	-0.005 (0.030)	0.412*** (0.046)	0.041 (0.103)	0.045 (0.088)
Observations	1,000	511	511	1,000
R ²	0.533	0.403	0.421	
Adjusted R ²	0.532	0.401	0.419	
Log Likelihood				-1,146.000
ρ				0.560*** (0.097)

Note:

* p<0.1; ** p<0.05; *** p<0.01

Extensions: “Probit-Probit”

- Selection + binary second stage ($Y_i \in \{0, 1\}$) (a/k/a “Heckit”).
- Assume errors are bivariate standard Normal [so, $\{u_1, u_2 \sim \mathcal{BVN}(0, 0, 1, 1, \rho) \equiv \Phi_2(\cdot)\}$]
- Log-Likelihood:

$$\begin{aligned}\ln L(\beta, \gamma, \sigma_1, \rho | Y_1) &= \sum_{Y_{1i}=1, D_i=1} \ln[\Phi_2(\mathbf{X}_i\beta, \mathbf{Z}_i\gamma, \rho)] \\ &+ \sum_{Y_{1i}=0, D_i=1} \ln[\Phi_2(-\mathbf{X}_i\beta, \mathbf{Z}_i\gamma, -\rho)] \\ &+ \sum_{D_i=0} \ln \Phi(-\mathbf{Z}_i\gamma)\end{aligned}$$

- Different outcome stages:
 - Poisson (Greene 1995; Cameron & Trivedi 2013, Ch. 10)
 - Durations (Boehmke et al. 2006)
 - Count/binary/ordinal (Mirand and Rabe-Hesketh 2005)
- Selection stage is ordered (Chiburis & Lokshin 2007)
- Multiple-stage models (not much... work in finance + Signorino and others)
- Semi- and non-parametric variants (e.g., Liu and Yu (2019) on monotone control functions)

- R (selection and heckit in `sampleSelection`; robust estimation via `ssmrob`)
 - Binary selection
 - Continuous/binary outcomes
 - Also tobit, etc. models
- Stata
 - `heckman` (binary-continuous model)
 - `heckprob` (binary-binary model)
 - `heckprobit` (ordinal Y)
 - `heckpoisson` (Poisson)
 - `dursel` (binary-duration model)
 - `xtheckman` (selection models for panel data)
 - Also Bayesian versions, using the `bayes:` prefix

Further Readings: References

Articles by Heckman (1974, 1976, 1979).

Breen, Richard. 1996. Regression Models for Censored, Sample Selected, or Truncated Data. Thousand Oaks, CA: Sage.

Stolzenberg, Ross M. and Daniel A. Relles. 1997. "Tools for Intuition about Sample Selection Bias and Its Correction." American Sociological Review 62:494-507.

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Further Readings: Applications

- Berinsky, Adam J. 1999. "The Two Faces of Public Opinion." *American Journal of Political Science* 43:1209-1230.
- Blanton, Shannon Lindsey. 2000. "Promoting Human Rights and Democracy in the Developing World: U.S. Rhetoric versus U.S. Arms Exports." *American Journal of Political Science* 44:123-131.
- Hart, David M. 2001. "Why Do Some Firms Give? Why Do Some Give a Lot?: High-Tech PACs, 1977-1996." *The Journal of Politics* 63:1230-1249.
- Jensen, Nathan M. 2003. "Democratic Governance and Multinational Corporations: Political Regimes and Inflows of Foreign Direct Investment." *International Organization* 57:587-616.
- Jo, Hyeran. 2008. "[Taming the Selection Bias: An Application to Compliance with International Agreements.](#)" 2008 *Visions in Methodology* conference, Columbus, OH.
- Nooruddin, Irfan. 2002. "Modeling Selection Bias in Studies of Sanctions Efficacy." *International Interactions* 28: 57-74.
- Timpone, Richard J. 1998. "Structure, Behavior and Voter Turnout in the United States." *American Political Science Review* 92: 145-158.
- Vance, Colin, and Nolan Ritter. 2014. "Is Peace a Missing Value or a Zero? On Selection Models in Political Science." *Journal of Peace Research* 51:528-540.
- Von Stein, Jana. 2005. "Do Treaties Constrain or Screen? Selection Bias and Treaty Compliance." *American Political Science Review* 99:611-622.

Potential Outcomes and Counterfactual Inference

The goal: **Making causal inferences from observational data.**

- Establish and measure the *causal* relationship between variables in a non-experimental setting.

- The *fundamental problem of causal inference*:

It is impossible to observe the causal effect of a treatment / predictor on a single unit.

- Specific challenges:
 - *Confounding*
 - *Selection bias*
 - *Heterogenous treatment effects*

Causation and Counterfactuals

Causal statements imply counterfactual reasoning.

- “If the cause(s) had been different, the outcome(s) would be different, too.”
- Conditioning, probabilistic and causal:

Probabilistic conditioning	Causal conditioning
$\Pr(Y X = x)$	$\Pr[Y do(X = x)]$
Factual	Counterfactual
Select a sub-population	Generate a new population
Predicts passive observation	Predicts active manipulation
Calculate from full DAG*	Calculate from surgically-altered DAG*
Always identifiable when X and Y are observable	Not always identifiable even when X and Y are observable

*See below. Source: Swiped from Shalizi, “Advanced Data Analysis from an Elementary Point of View”, Table 23.1.

- Causality (typically) implies / requires:
 - *Temporal ordering*
 - *Mechanism*
 - *Correlation*

The Counterfactual Paradigm

Notation

- N observations indexed by i , $i \in \{1, 2, \dots, N\}$
- Outcome variable Y
- Interest: the effect on Y of a treatment variable W :
 - $W_i = 1 \leftrightarrow$ observation i is “treated”
 - $W_i = 0 \leftrightarrow$ observation i is “control”

Potential Outcomes

- Y_{0i} = the value of Y_i if $W_i = 0$
- Y_{1i} = the value of Y_i if $W_i = 1$
- $\delta_i = (Y_{1i} - Y_{0i})$ = the treatment effect of W

The average treatment effect (ATE) is just:

$$\begin{aligned} \text{ATE} \equiv \bar{\delta} &= E(Y_{1i} - Y_{0i}) \\ &= \frac{1}{N} \sum_{i=1}^N Y_{1i} - Y_{0i}. \end{aligned}$$

BUT we observe only Y_i :

$$Y_i = \begin{cases} Y_{0i} & \text{if } W_i = 0, \\ Y_{1i} & \text{if } W_i = 1. \end{cases}$$

or (equivalently)

$$Y_i = W_i Y_{1i} + (1 - W_i) Y_{0i}.$$

Estimating Treatment Effects

Key to estimating treatment effects: **Assignment mechanism for W .**

Neyman/Rubin/Holland: Treat inability to observe Y_{0i} / Y_{1i} as a missing data problem.

[press “pause”]

Notation:

$$\mathbf{X}_i \cup \{\mathbf{W}_i, \mathbf{Z}_i\}$$

$N \times k$

\mathbf{W}_i have some missing values,
 \mathbf{Z}_i are “complete”

$$R_{ik} = \begin{cases} 1 & \text{if } W_{ik} \text{ is missing,} \\ 0 & \text{otherwise.} \end{cases}$$

$$\pi_{ik} = \Pr(R_{ik} = 1)$$

Missing Data (continued)

Rubin's flavors of missingness:

- Missing completely at random (“MCAR”) (= “ignorable”):

$$\mathbf{R} \perp \{\mathbf{Z}, \mathbf{W}\}$$

- Missing at random (“MAR”) (conditionally “ignorable”):

$$\mathbf{R} \perp \mathbf{W} | \mathbf{Z}$$

- Anything else is “informatively” (or “non-ignorably”) missing.

Estimating Treatment Effects

Key to estimating treatment effects: **Assignment mechanism for W** .

Neyman/Rubin/Holland: Treat inability to observe Y_{0i} / Y_{1i} as a missing data problem.

- If the “missingness” due to the value of W_i is orthogonal to the values of Y , then it is ignorable. Formally:

$$\Pr(W_i | \mathbf{X}_i, Y_{0i}, Y_{1i}) = \Pr(W_i | \mathbf{X}_i)$$

- If that “missingness” is non-orthogonal, then it is not ignorable, and can lead to bias in estimation
- Non-ignorable assignment of W requires understanding the mechanism by which that assignment occurs

One more thing: the stable unit-treatment value assumption (“SUTVA”)

- Requires that there be two and only two possible values of Y for each observation i ...
- “the observation (of Y_i) on one unit should be unaffected by the particular assignment of treatments to the other units.”
- \equiv the “assumption of no interference between units,” meaning:
 - Values of Y for any two i, j ($i \neq j$) observations do not depend on each other
 - Treatment effects are homogenous within categories defined by W

Treatment Effects Under Randomization of W

If W_i is assigned randomly, then:

$$\Pr(W_i) \perp Y_{0i}, Y_{1i}$$

and so:

$$\Pr(W_i | Y_{0i}, Y_{1i}) = \Pr(W_i) \forall Y_{0i}, Y_{1i}.$$

This means that the “missing” data on Y_0/Y_1 are ignorable (here, in the special case where the \mathbf{X}_i on which W_i depends is null). This in turn means that:

$$f(Y_{0i} | W_i = 0) = f(Y_{0i} | W_i = 1) = f(Y_i | W_i = 0) = f(Y_i | W_i = 1)$$

and

$$f(Y_{1i} | W_i = 0) = f(Y_{1i} | W_i = 1) = f(Y_i | W_i = 0) = f(Y_i | W_i = 1)$$

Randomized W (continued)

Implication: Y_{0i} and Y_{1i} are (not identical but) *exchangeable*...

This in turn means that:

$$E(Y_{0i}|W_i) = E(Y_{1i}|W_i)$$

and so

$$\begin{aligned}\widehat{ATE} &= E(Y_i|W_i = 1) - E(Y_i|W_i = 0) \\ &= \bar{Y}_{W=1} - \bar{Y}_{W=0}.\end{aligned}$$

will be an unbiased estimate of the ATE.

Observational Data: W Depends on \mathbf{X}

Formally,

$$Y_{0i}, Y_{1i} \perp W_i | \mathbf{X}_i.$$

Here,

- \mathbf{X} are *known confounders* that (stochastically) determine the value of W_i ,
- Conditioning on \mathbf{X} is necessary to achieve exchangeability.

So long as W is entirely due to \mathbf{X} , we can condition:

$$f(Y_{1i} | \mathbf{X}_i, W_i = 1) = f(Y_{1i} | \mathbf{X}_i, W_i = 0) = f(Y_i | \mathbf{X}_i, W_i)$$

and similarly for Y_{0i} .

W Depends on \mathbf{X} (continued)

Estimands:

- the *average treatment effect for the treated* (ATT):

$$ATT = E(Y_{1i}|W_i = 1) - E(Y_{0i}|W_i = 1).$$

- the *average treatment effect for the controls* (ATC):

$$ATC = E(Y_{1i}|W_i = 0) - E(Y_{0i}|W_i = 0).$$

Corresponding estimates:

$$\widehat{ATT} = E\{[E(Y_i|\mathbf{X}_i, W_i = 1) - E(Y_i|\mathbf{X}_i, W_i = 0)]|W_i = 1\}.$$

and

$$\widehat{ATC} = E\{[E(Y_i|\mathbf{X}_i, W_i = 1) - E(Y_i|\mathbf{X}_i, W_i = 0)]|W_i = 0\}.$$

Note that in both cases **the expectation of the whole term is conditioned on W_i .**

Confounding occurs when one or more observed or unobserved factors \mathbf{X} affect the causal relationship between W and Y .

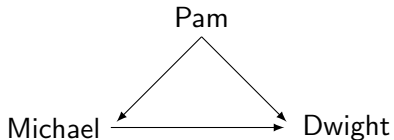
Formally, confounding requires that:

- $\text{Cov}(\mathbf{X}, W) \neq 0$ (the confounder is associated with the “treatment”)
- $\text{Cov}(\mathbf{X}, Y) \neq 0$ (the confounder is associated with the outcome)
- \mathbf{X} does not “lie on the path” between W and Z (that is, \mathbf{X} is not affected by either W or Y).

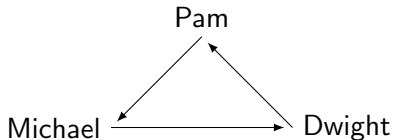
Directed acyclic graphs (DAGs) are a tool for visualizing and interpreting structural/causal phenomena.

- DAGs comprise:
 - Nodes (typically, variables / phenomena) and
 - Edges (or lines; typically, relationships/causal paths).
- Directed means each edge is *unidirectional*.
- Acyclical means exactly what it suggests: If a graph has a “feedback loop,” it is not a DAG.
- Read more at the [Wikipedia page](#), or at this useful [page](#).

Know your DAG

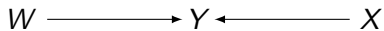


A DAG

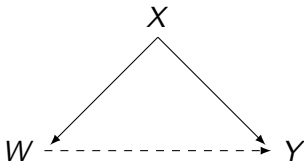


Not a DAG

DAGs and Confounding



No Confounding



Confounding

Confounding Bias: Some Toy Examples

Example One: $\text{Cov}(W, Y) = 0$ (ATE=2)

i	W_i	Y_{0i}	Y_{1i}	$Y_{1i} - Y_{0i}$	Y_i	$(\bar{Y} W=1) - (\bar{Y} W=0)$
1	0	8	(10)	(2)	8	-
2	0	10	(12)	(2)	10	-
3	0	12	(14)	(2)	12	-
4	1	(8)	10	(2)	10	-
5	1	(10)	12	(2)	12	-
6	1	(12)	14	(2)	14	-
Mean _{obs}	-	10	12	-	11	2
Mean _{all}	-	(10)	(12)	(2)	-	-

$$t = -1.22, p = 0.14$$

Confounding Bias: Some Toy Examples

Example Two: $\text{Cov}(W, Y) > 0$ (ATE=2)

i	W_i	Y_{0i}	Y_{1i}	$Y_{1i} - Y_{0i}$	Y_i	$(\bar{Y} W=1) - (\bar{Y} W=0)$
1	0	8	(10)	(2)	8	-
2	0	8	(10)	(2)	8	-
3	0	10	(12)	(2)	10	-
4	1	(10)	12	(2)	12	-
5	1	(12)	14	(2)	14	-
6	1	(12)	14	(2)	14	-
Mean _{obs}	-	8.67	13.33	-	11	4.67
Mean _{all}	-	(10)	(12)	(2)	-	-

$$t = -4.95, p < 0.001$$

Confounding Bias: Some Toy Examples

Example Three: $\text{Cov}(W, Y) < 0$ (ATE=2)

i	W_i	Y_{0i}	Y_{1i}	$Y_{1i} - Y_{0i}$	Y_i	$(Y W=1) - (Y W=0)$
1	0	12	(14)	(2)	12	-
2	0	12	(14)	(2)	12	-
3	0	10	(12)	(2)	10	-
4	1	(10)	12	(2)	12	-
5	1	(8)	10	(2)	10	-
6	1	(8)	10	(2)	10	-
Mean _{obs}	-	11.33	10.67	-	11	-0.67
Mean _{all}	-	(10)	(12)	(2)	-	-

$$t = 0.71, p = 0.74$$

Next time: How to make causal(-ish) inferences from observational data...