

# The Fundamental Problem of Econometrics

EC 320: Introduction to Econometrics

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# Prologue

# Statistics Inform Policy

**Policy:** In 2017, the University of Oregon started requiring first-year students to live on campus.

**Rationale:** First-year students who live on campus fare better than those who live off campus.

- *80 percent more likely* to graduate in four years.
- Second-year retention rate *5 percentage points higher*.
- GPAs *0.13 points higher*, on average.

Do these comparisons suggest that the policy will improve student outcomes?

Do they describe the effect of living on campus?

Do they describe *something else*?

# Other Things Equal

The UO's interpretation of those comparisons warrants skepticism.

- The decision to live on campus is probably related to family wealth and interest in school.
- Family wealth and interest in school are also related to academic achievement.

**Why?** The difference in outcomes between those on and off campus is not an *other things equal*\* comparison.

**Upshot:** We can't attribute the difference in outcomes solely to living on campus.

\* *Other things equal* = *ceteris paribus*, all else held constant, etc.

# Other Things Equal

## A high bar

When all other factors are held constant, statistical comparisons detect causal relationships.

(Micro)economics has developed a comparative advantage in understanding where *other things equal* comparisons can and cannot be made.

- Anyone can retort "*correlation doesn't necessarily imply causation.*"
- Understanding *why* is difficult, but useful for learning from data.

# The Fundamental Problem of Econometrics

# Causal Identification

## Goal

Identify the effect of a treatment on an outcome.

## Ideal data

Ideally, we could calculate the treatment effect *for each individual* as

$$\tau_i = Y_{1,i} - Y_{0,i}$$

- $Y_{1,i}$  is the outcome for person  $i$  when she receives the treatment.
- $Y_{0,i}$  is the outcome for person  $i$  when she does not receive the treatment.
- Known as potential outcomes.

# Causal Identification

## Ideal data

The *ideal* data for 10 people

##	i	trt	y1i	y0i	effect_i
## 1	1	1	5.01	2.56	2.45
## 2	2	1	8.85	2.53	6.32
## 3	3	1	6.31	2.67	3.64
## 4	4	1	5.97	2.79	3.18
## 5	5	1	7.61	4.34	3.27
## 6	6	0	7.63	4.15	3.48
## 7	7	0	4.75	0.56	4.19
## 8	8	0	5.77	3.52	2.25
## 9	9	0	7.47	4.49	2.98
## 10	10	0	7.79	1.40	6.39

Calculate the causal effect of treatment.

$$\tau_i = y_{1,i} - y_{0,i}$$

for each individual  $i$ .

The mean of  $\tau_i$  is the average treatment effect (ATE).

Thus,  $\bar{\tau} = 3.82$



# Fundamental Problem of Econometrics

## Ideal comparison

$$\tau_i = y_{1,i} - y_{0,i}$$

Highlights the fundamental problem of econometrics.

## The problem

- If we observe  $y_{1,i}$ , then we cannot observe  $y_{0,i}$ .
- If we observe  $y_{0,i}$ , then we cannot observe  $y_{1,i}$ .
- Can only observe what actually happened; cannot observe the **counterfactual**.

# Fundamental Problem of Econometrics

A dataset that we can observe for 10 people looks something like

##	i	trt	y1i	y0i
## 1	1	1	5.01	NA
## 2	2	1	8.85	NA
## 3	3	1	6.31	NA
## 4	4	1	5.97	NA
## 5	5	1	7.61	NA
## 6	6	0	NA	4.15
## 7	7	0	NA	0.56
## 8	8	0	NA	3.52
## 9	9	0	NA	4.49
## 10	10	0	NA	1.40

We can't observe  $y_{1,i}$  and  $y_{0,i}$ .

But, we do observe

- $y_{1,i}$  for  $i$  in 1, 2, 3, 4, 5
- $y_{0,j}$  for  $j$  in 6, 7, 8, 9, 10

**Q:** How do we "fill in" the NAs and estimate  $\bar{\tau}$ ?

# Estimating Causal Effects

**Notation:**  $D_i$  is a binary indicator variable such that

- $D_i = 1$  if individual  $i$  is treated.
- $D_i = 0$  if individual  $i$  is not treated (*control* group).

Then, rephrasing the previous slide,

- We only observe  $y_{1,i}$  when  $D_i = 1$ .
- We only observe  $y_{0,i}$  when  $D_i = 0$ .

**Q:** How can we estimate  $\bar{\tau}$  using only  $(y_{1,i}|D_i = 1)$  and  $(y_{0,i}|D_i = 0)$ ?

# Estimating Causal Effects

**Q:** How can we estimate  $\bar{\tau}$  using only  $(y_{1,i} | D_i = 1)$  and  $(y_{0,i} | D_i = 0)$ ?

**Idea:** What if we compare the groups' means? *I.e.*,

$$Avg(y_i | D_i = 1) - Avg(y_i | D_i = 0)$$

**Q:** When does a simple difference-in-means provide information on the causal effect of the treatment?

**Q2.0:** Is  $Avg(y_i | D_i = 1) - Avg(y_i | D_i = 0)$  a *good* estimator for  $\bar{\tau}$ ?

# Estimating Causal Effects

**Assumption:** Let  $\tau_i = \tau$  for all  $i$ .

- The treatment effect is equal (constant) across all individuals  $i$ .

**Note:** We defined

$$\tau_i = \tau = y_{1,i} - y_{0,i}$$

which implies

$$y_{1,i} = y_{0,i} + \tau$$

**Q:** Is  $Avg(y_i \mid D_i = 1) - Avg(y_i \mid D_i = 0)$  a *good* estimator for  $\tau$ ?

Difference-in-means

$$= Avg(y_i \mid D_i = 1) - Avg(y_i \mid D_i = 0)$$

$$= Avg(y_{1,i} \mid D_i = 1) - Avg(y_{0,i} \mid D_i = 0)$$

$$= Avg(\tau + y_{0,i} \mid D_i = 1) - Avg(y_{0,i} \mid D_i = 0)$$

$$= \tau + Avg(y_{0,i} \mid D_i = 1) - Avg(y_{0,i} \mid D_i = 0)$$

$$= \text{Average causal effect} + \text{Selection bias}$$

Our proposed difference-in-means estimator gives us the sum of

1.  $\tau$ , the causal, average treatment effect that we want.
2. Selection bias: How much treatment and control groups differ, on average.

# Randomized Control Trials

# Selection Bias

**Problem:** Existence of selection bias precludes *all else equal* comparisons.

- To make valid comparisons that yield causal effects, we need to shut down the bias term.

**Potential solution:** Conduct an experiment.

- How? Random assignment of treatment.
- Hence the name, *randomized* control trial (RCT).



# Randomized Control Trials

## Example: Effect of de-worming on attendance

**Motivation:** Intestinal worms are common among children in less-developed countries. The symptoms of these parasites can keep school-aged children at home, disrupting human capital accumulation.

**Policy Question:** Do school-based de-worming interventions provide a cost-effective way to increase school attendance?

# Randomized Control Trials

## Example: Effect of de-worming on attendance

**Research Question:** How much do de-worming interventions increase school attendance?

**Q:** Could we simply compare average attendance among children with and without access to de-worming medication?

**A:** If we're after the causal effect, probably not.

**Q:** Why not?

**A:** Selection bias: Families with access to de-worming medication probably have healthier children for other reasons, too (wealth, access to clean drinking water, *etc.*).

Can't make an *all else equal* comparison. Biased and/or spurious results.

# Randomized Control Trials

## Example: Effect of de-worming on attendance

**Solution:** Run an experiment.

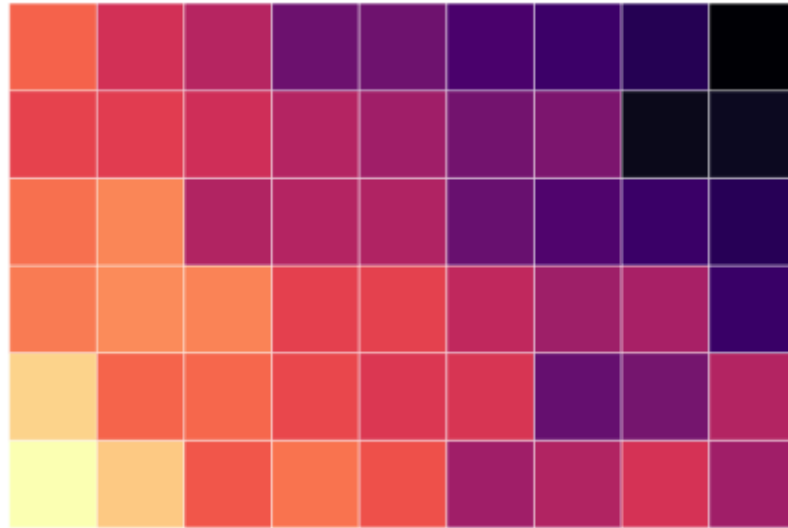
Imagine an RCT where we have two groups:

- Treatment: Villages that where children get de-worming medication in school.
- Control: Villages that where children don't get de-worming medication in school (status quo).

By randomizing villages into treatment or control, we will, on average, include all kinds of villages (poor vs. less poor, access to clean water vs. contaminated water, hospital vs. no hospital, etc.) in both groups.

*All else equal!*

54 villages of varying levels of development plus randomly assigned treatment



# Randomized Control Trials

## Example: Effect of de-worming on attendance

We can estimate the causal effect of de-worming on school attendance by comparing the average attendance rates in the treatment group (💊) with those in the control group (no 💊).

$$\overline{\text{Attendance}}_{\text{Treatment}} - \overline{\text{Attendance}}_{\text{Control}}$$

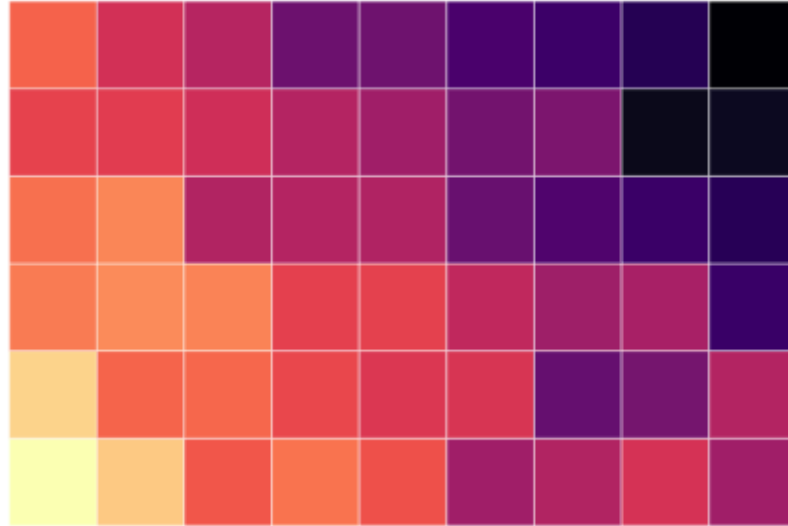
Alternatively, we can use the regression

$$\text{Attendance}_i = \beta_0 + \beta_1 \text{Treatment}_i + u_i \quad (1)$$

where  $\text{Treatment}_i$  is a binary variable (=1 if village  $i$  received the de-worming treatment). **Q:** Should trust the results of (1)? Why?

**A:** On average, randomly assigning treatment should balance treatment and control across the other dimensions that affect school attendance.

# Randomization can go wrong!



# Causality

## Example: Returns to education

The optimal investment in education by students, parents, and legislators depends in part on the monetary *return to education*.

Thought experiment:

- Randomly select an individual.
- Give her an additional year of education.
- How much do her earnings increase?

The change in her earnings describes the causal effect of education on earnings.

# Causality

## Example: Returns to education

**Q:** Could we simply compare the earnings those with more education to those with less?

**A:** If we want to measure the causal effect, probably not.

1. People *choose* education based on their ability and other factors.
2. High-ability people tend to earn more *and* stay in school longer.
3. Education likely reduces experience (time out of the workforce).

Point (3) also illustrates the difficulty in learning about the effect of education while *holding all else constant*.

Many important variables have the same challenge: gender, race, income.



# Causality

## Example: Returns to education

**Q:** How can we estimate the returns to education?

Option 1: Run an experiment.

- Randomly assign education (might be difficult).
- Randomly encourage education (might work).
- Randomly assign programs that affect education (*e.g.*, mentoring).

Option 2: Look for a *natural experiment* (a policy or accident in society that arbitrarily increased education for one subset of people).

- Admissions cutoffs
- Lottery enrollment and/or capacity constraints