

# What is Your Estimand?

Defining the Target Quantity  
Connects Statistical Evidence  
to Theory



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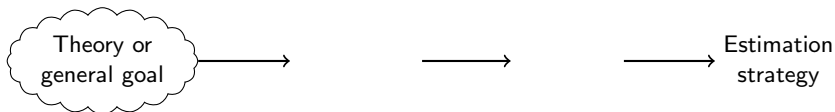
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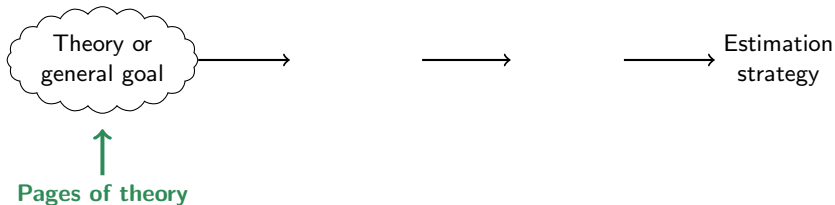
**NOTE:** These slides are for a pedagogical workshop.  
The main slides for this paper are [here](#).

6 October 2021. University of Wisconsin CDE Training Workshop.  
Paper in *American Sociological Review*. Preprint on [SocArxiv](#). Replication code on [Dataverse](#). Research reported in this publication was supported by The Eunice Kennedy Shriver National Institute of Child Health & Human Development of the National Institutes of Health under Award Number P2CHD047879.

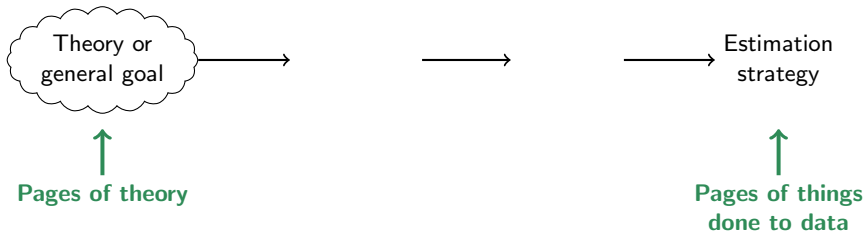
# Research framework: Estimands connect theory to evidence



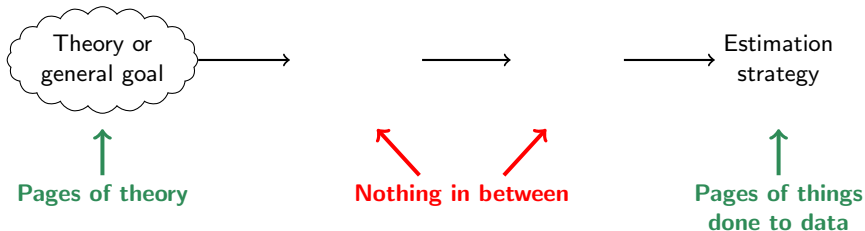
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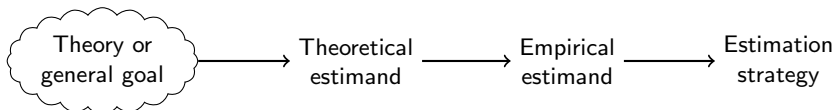
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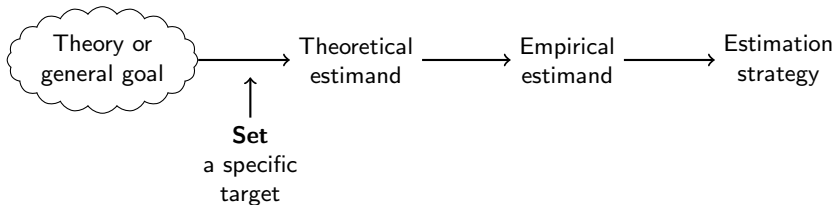
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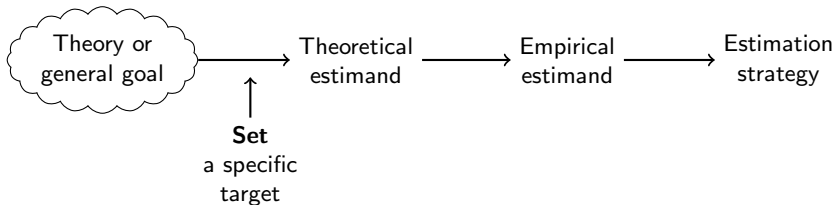
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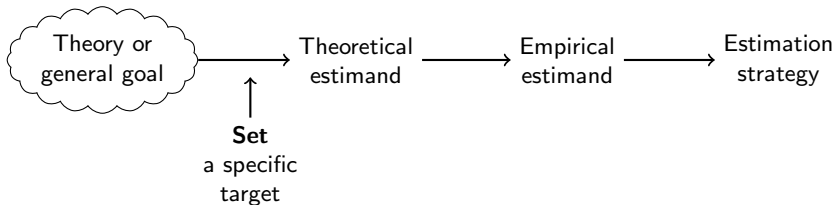
## Definition

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A **unit-specific quantity**  
aggregated over a  
**target population**



# Research framework: Estimands connect theory to evidence



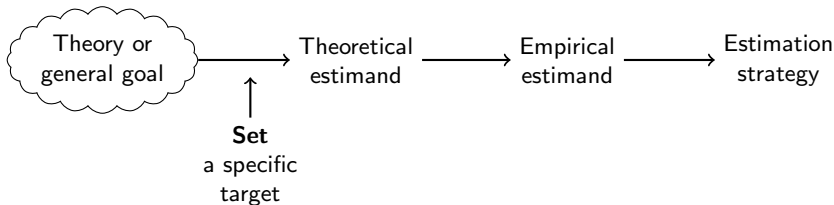
## Definition

A **unit-specific quantity**  
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## Example

$$\frac{1}{\text{Size of U.S. adult population}} \sum_{i \text{ in U.S. adult population}} \left( \text{Employed}_i \right)$$

# Research framework: Estimands connect theory to evidence



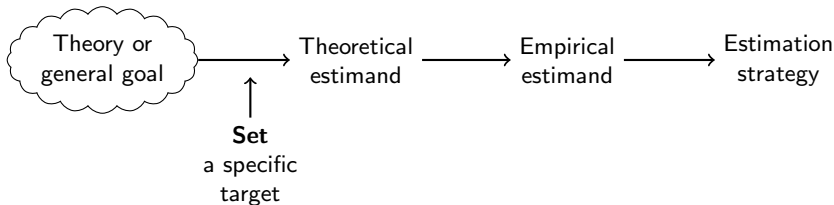
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## Example

$$\frac{1}{\text{Size of U.S. adult population}} \sum_{i \text{ in U.S. adult population}} \left( \underbrace{\text{Employed}_i(\text{Job training})}_{\text{Employment if received job training}} - \underbrace{\text{Employed}_i(\text{No job training})}_{\text{Employment if did not receive job training}} \right)$$

# Research framework: Estimands connect theory to evidence



## Definition

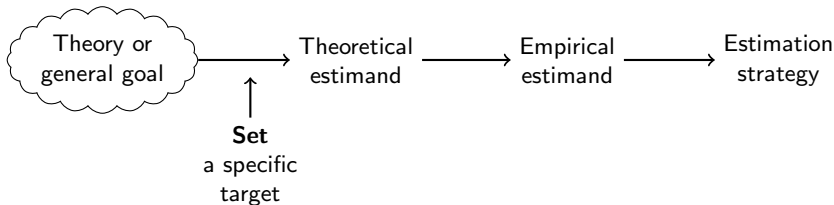
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Liebersen 1987, Abbott 1988, Freedman 1991, Xie 2013, Hernán 2018

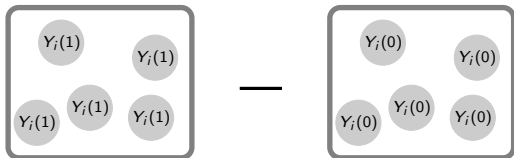
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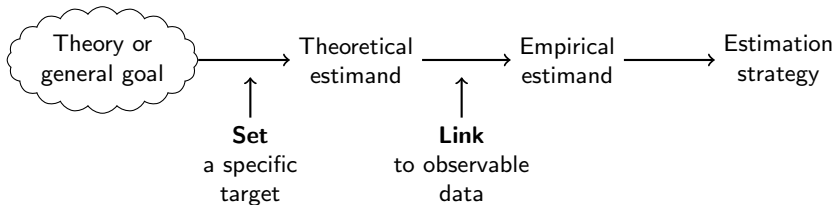
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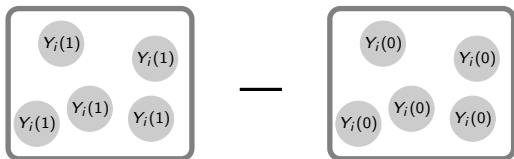
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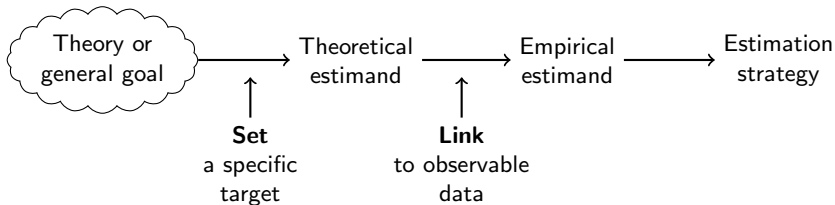
## Definition

A quantity involving  
**observable data**

## Example



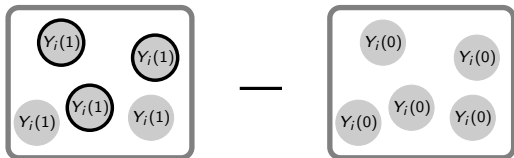
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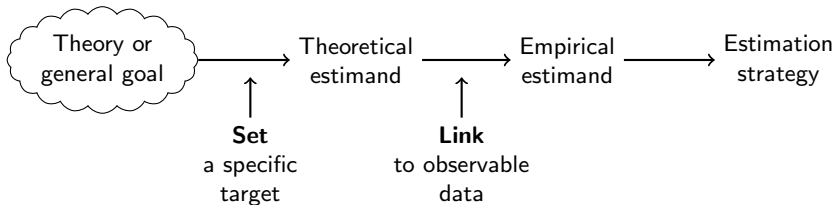
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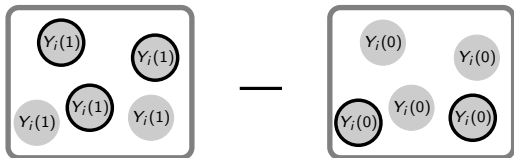
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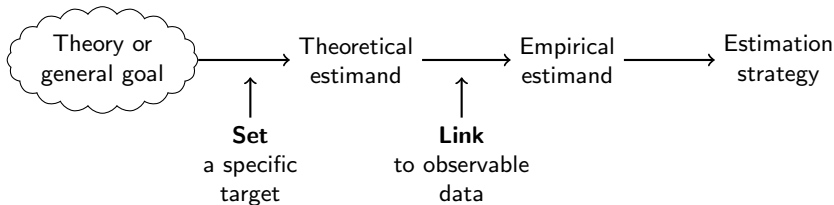
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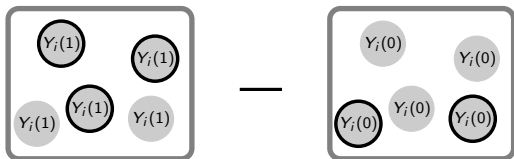
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## Definition

A quantity involving  
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## Example



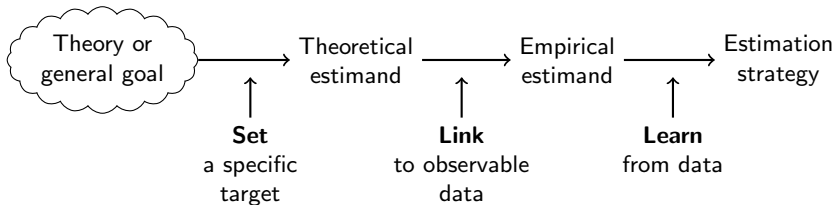
$$\vec{X} \xrightarrow{\quad} T \xrightarrow{\quad} Y$$

A curved arrow also points from  $\vec{X}$  to  $Y$ , representing a direct relationship or transformation.

Pearl 2009, Imbens and Rubin 2015,  
Morgan and Winship 2015, Elwert and Winship 2014



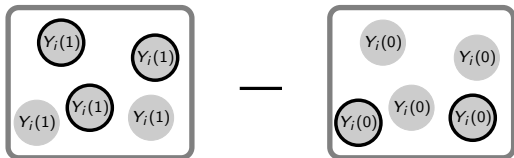
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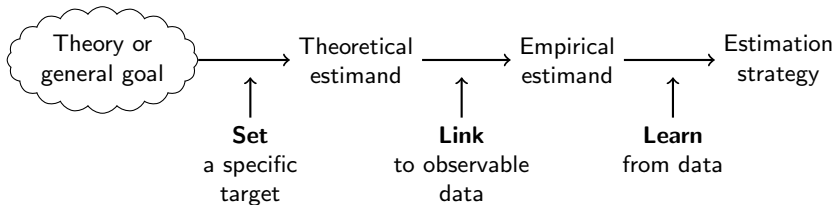
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An algorithm  
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## Example



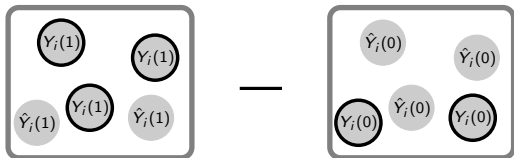
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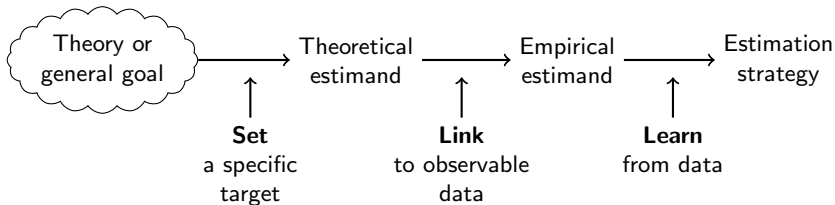
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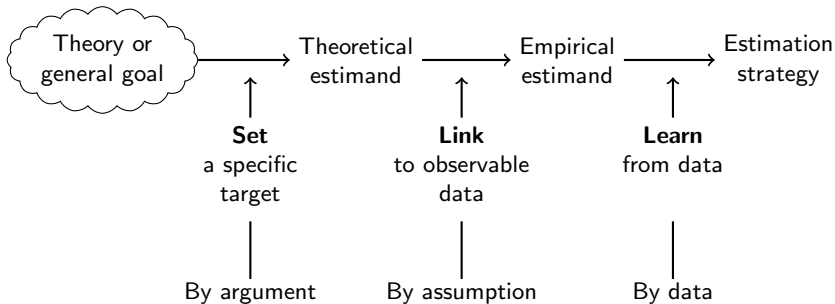
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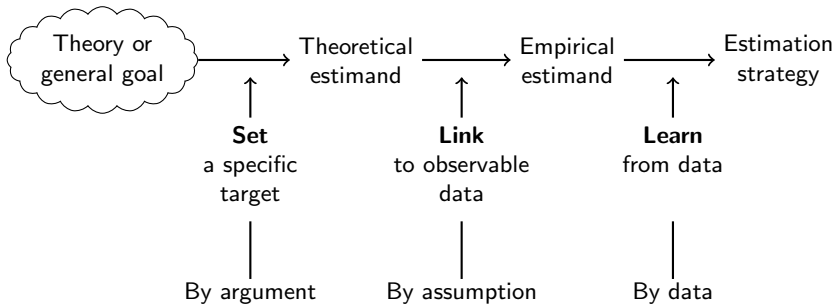
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## Plan for today

- Intro: What this looks like in practice
- Example: Revisiting a published paper
- Group exercises: Together we will state precise research goals



# 1. Set the target quantity.



## Describe a population

What is the proportion employed  
among U.S. resident women ages 21–35?



## Describe a population

What is the proportion employed  
among U.S. resident women ages 21–35?

Woman 1  
Woman 2  
Woman 3  
Woman 4





## Describe a population

What is the proportion employed  
among U.S. resident women ages 21–35?

|         | <u>Employed?</u> |
|---------|------------------|
| Woman 1 | 1                |
| Woman 2 | 0                |
| Woman 3 | 1                |
| Woman 4 | 1                |



## Describe population subgroups

What is the proportion employed among U.S. resident women ages 21–35, comparing mothers to non-mothers?



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What is the proportion employed among U.S. resident women ages 21–35, comparing mothers to non-mothers?

|          | <u>Employed?</u> |              | <u>Employed?</u> |
|----------|------------------|--------------|------------------|
| Mother 1 | 0                | Non-Mother 1 | 1                |
| Mother 2 | 0                | Non-Mother 2 | 0                |
| Mother 3 | 0                | Non-Mother 3 | 1                |
| Mother 4 | 1                | Non-Mother 4 | 1                |



## Causal effect in a population

What is the causal effect of motherhood on employment among U.S. resident women ages 21–35?



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Woman 1

Woman 2

Woman 3

Woman 4



## Causal effect in a population

What is the causal effect of motherhood on employment among U.S. resident women ages 21–35?

|         | Would be<br>employed if<br>a mother?<br>$Y(1)$ |
|---------|--|
| Woman 1 | 0  |
| Woman 2 | 0  |
| Woman 3 | 0  |
| Woman 4 | 1  |



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|         | Would be<br>employed if<br>a mother?<br>$Y(1)$ | Would be<br>employed if<br>a non-mother?<br>$Y(0)$ |
|---------|--|--|
| Woman 1 | 0  | 1  |
| Woman 2 | 0  | 0  |
| Woman 3 | 0  | 1  |
| Woman 4 | 1  | 1  |



## Causal effect in a population

What is the causal effect of motherhood on employment among U.S. resident women ages 21–35?

|         | Would be<br>employed if<br>a mother?<br>$Y(1)$ | Would be<br>employed if<br>a non-mother?<br>$Y(0)$ | Causal<br>effect<br>$Y(1) - Y(0)$ |
|---------|--|--|-----------------------------------|
| Woman 1 | 0  | 1  | -1                                |
| Woman 2 | 0  | 0  | 0                                 |
| Woman 3 | 0  | 1  | -1                                |
| Woman 4 | 1  | 1  | 0                                 |





### Describe population subgroups

What is the proportion employed among U.S. resident women ages 21–35, comparing mothers to non-mothers?

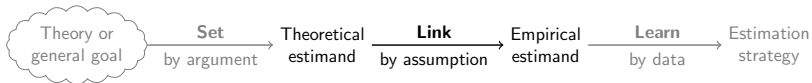
|          | Employed? |              | Employed? |
|----------|-----------|--------------|-----------|
| Mother 1 | 0         | Non-Mother 1 | 1         |
| Mother 2 | 0         | Non-Mother 2 | 0         |
| Mother 3 | 0         | Non-Mother 3 | 1         |
| Mother 4 | 1         | Non-Mother 4 | 1         |

### Causal effect in a population

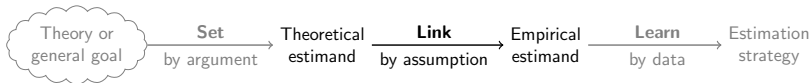
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|---------|--|--|--------------------------------|
| Woman 1 | 0  | 1  | -1                             |
| Woman 2 | 0  | 0  | 0                              |
| Woman 3 | 0  | 1  | -1                             |
| Woman 4 | 1  | 1  | 0                              |

Very  
**different**  
research  
goals



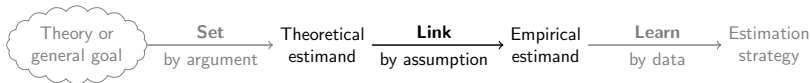
## 2. Link to observables



## Causal effect in a population

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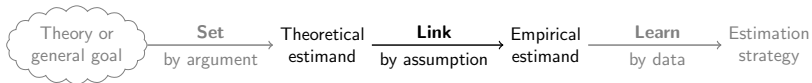
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|---------|--|--|-----------------------------------|
| Woman 1 | 0  | 1  | -1                                |
| Woman 2 | 0  | 0  | 0                                 |
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| Woman 4 | 1  | 1  | 0                                 |



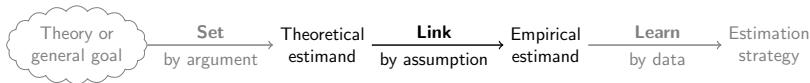
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|---------|--|--|-----------------------------------|
| Woman 1 | 0  | ?  | ?                                 |
| Woman 2 | 0  | ?  | ?                                 |
| Woman 3 | ?  | 1  | ?                                 |
| Woman 4 | ?  | 1  | ?                                 |



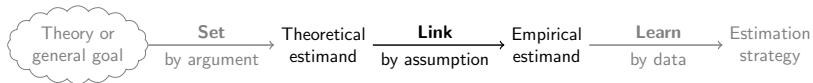
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|---------|--|--|-----------------------------------|
|         | <hr/>  | <hr/>  | <hr/>                             |
| Woman 1 | 0  | ?  | ?                                 |
| Woman 2 | 0  | ?  | ?                                 |
| Woman 3 | ?  | 1  | ?                                 |
| Woman 4 | ?  | 1  | ?                                 |



### Subpopulation

- Age 30
- College-educated
- Employed last year

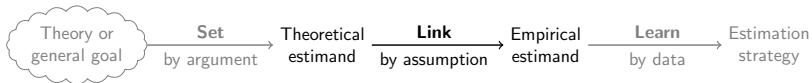
|         | Would be<br>employed if<br>a mother?<br><u><math>Y(1)</math></u> | Would be<br>employed if<br>a non-mother?<br><u><math>Y(0)</math></u> | Causal<br>effect<br><u><math>Y(1) - Y(0)</math></u> |
|---------|--|--|---|
| Woman 1 | 0  | ?  | ?   |
| Woman 2 | 0  | ?  | ?   |
| Woman 3 | ?  | 1  | ?   |
| Woman 4 | ?  | 1  | ?   |



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|---------|--|--|---|
| Woman 1 | 0  | ?  | ?   |
| Woman 2 | 0  | ?  | ?   |
| Woman 3 | 0?   | 1  | ?   |
| Woman 4 | 0?   | 1  | ?   |

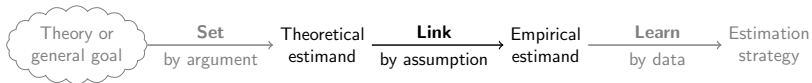


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|---------|--|--|---|
| Woman 1 | 0  | 1?   | ?   |
| Woman 2 | 0  | 1?   | ?   |
| Woman 3 | 0?   | 1  | ?   |
| Woman 4 | 0?   | 1  | ?   |

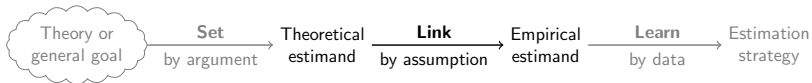




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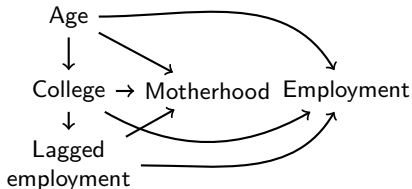
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|---------|--|--|---|
| Woman 1 | 0  | 1?   | -1?   |
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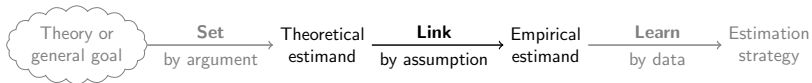


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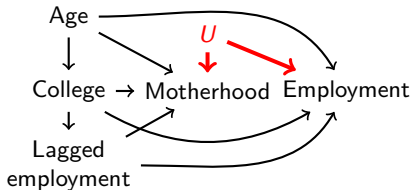


|         | Would be<br>employed if<br>a mother?<br>$Y(1)$ | Would be<br>employed if<br>a non-mother?<br>$Y(0)$ | Causal<br>effect<br>$Y(1) - Y(0)$ |
|---------|--|--|-----------------------------------|
| Woman 1 | 0  | 1?   | -1?                               |
| Woman 2 | 0  | 1?   | -1?                               |
| Woman 3 | 0?   | 1  | -1?                               |
| Woman 4 | 0?   | 1  | -1?                               |

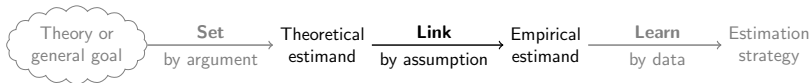


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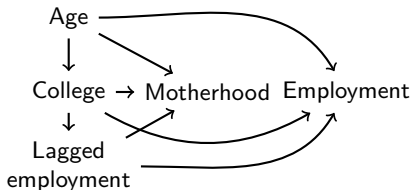


|         | Would be<br>employed if<br>a mother?<br>$Y(1)$ | Would be<br>employed if<br>a non-mother?<br>$Y(0)$ | Causal<br>effect<br>$Y(1) - Y(0)$ |
|---------|--|--|-----------------------------------|
| Woman 1 | 0  | 1?   | -1?                               |
| Woman 2 | 0  | 1?   | -1?                               |
| Woman 3 | 0?   | 1  | -1?                               |
| Woman 4 | 0?   | 1  | -1?                               |

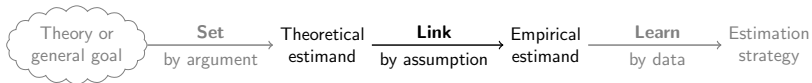


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|---------|--|--|-----------------------------------|
| Woman 1 | 0  | 1?   | -1?                               |
| Woman 2 | 0  | 1?   | -1?                               |
| Woman 3 | 0?   | 1  | -1?                               |
| Woman 4 | 0?   | 1  | -1?                               |



### Subpopulation

- Age 30
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### Getting the population

- 1) Do this in every subpopulation
- 2) Aggregate over subpopulations

|         | Would be<br>employed if<br>a mother?<br>$Y(1)$ | Would be<br>employed if<br>a non-mother?<br>$Y(0)$ | Causal<br>effect<br>$Y(1) - Y(0)$ |
|---------|--|--|-----------------------------------|
| Woman 1 | 0  | 1?   | -1?                               |
| Woman 2 | 0  | 1?   | -1?                               |
| Woman 3 | 0?   | 1  | -1?                               |
| Woman 4 | 0?   | 1  | -1?                               |



### 3. Learn from data



### Subpopulation

- Age 30
- College-educated
- Employed last year

|         | Would be<br>employed if<br>a mother?<br>$Y(1)$ |
|---------|--|
| Woman 1 | 0  |
| Woman 2 | 0  |
| Woman 3 | 0?   |
| Woman 4 | 0?   |



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- Age 30
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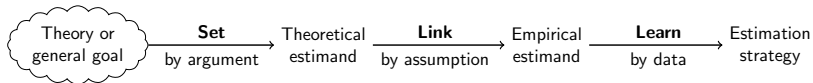
|         | Would be<br>employed if<br>a mother?<br>$Y(1)$ |
|---------|--|
| Woman 1 | 0  |
| Woman 2 | 0  |
| Woman 3 | 0?   |
| Woman 4 | 0?   |



### Learn

Do this better  
with machine  
learning

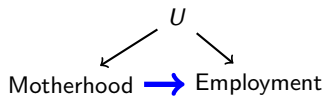
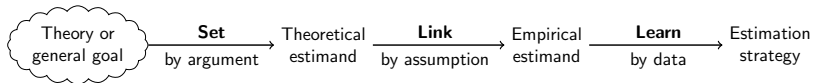


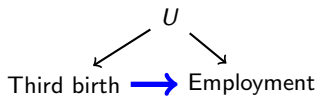
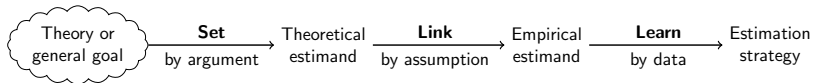


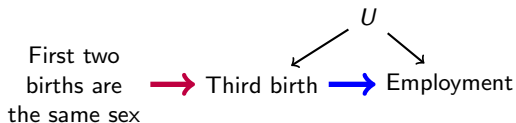
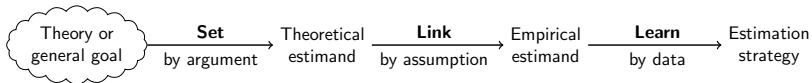
# Example

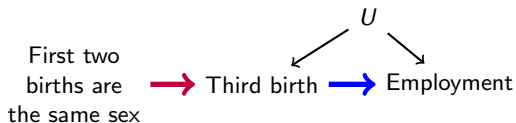


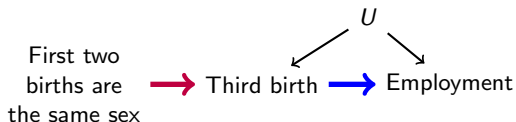
Motherhood → Employment











## Mechanics of instrumental variables

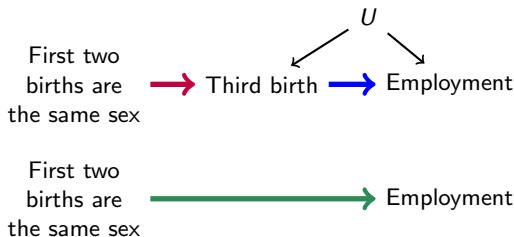
$$\text{blue arrow} = \frac{\text{green arrow}}{\text{red arrow}}$$

(Note: This can be made more precise)



### But wait!

Not everyone is affected by this instrument

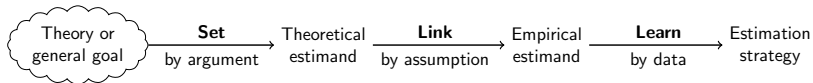


### Mechanics of instrumental variables

$$\xrightarrow{\text{blue}} = \frac{\xrightarrow{\text{green}}}{\xrightarrow{\text{red}}}$$

(Note: This can be made more precise)





**Four Subpopulations**

(Angrist, Imbens, & Rubin 1996)



## Four Subpopulations

(Angrist, Imbens, & Rubin 1996)

**Always-Takers.** Third kid no matter what.

First two births same sex  $\overset{0}{- - -} \rightarrow$  Third birth  $\xrightarrow{\quad}$  Employment

*(Note: A red dashed double-headed arrow is positioned above the 'Third birth' text in the original image.)*



## Four Subpopulations

(Angrist, Imbens, & Rubin 1996)

**Always-Takers.** Third kid no matter what.

First two births same sex  $\overset{0}{- - -} \rightarrow$  Third birth  $\xrightarrow{\quad}$  Employment

**Never-Takers.** Sticking with two kids, no matter what.

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## Four Subpopulations

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**Compliers.** Third kid if and only if the first two are the same sex.

First two births same sex  $\overset{+1}{- - -} \rightarrow$  Third birth  $\xrightarrow{\quad}$  Employment



## Four Subpopulations

(Angrist, Imbens, & Rubin 1996)

**Always-Takers.** Third kid no matter what.

First two births same sex  $\overset{0}{- - -} \rightarrow$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment

**Never-Takers.** Sticking with two kids, no matter what.

First two births same sex  $\overset{0}{- - -} \rightarrow$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment

**Compliers.** Third kid if and only if the first two are the same sex.

First two births same sex  $\overset{+1}{- - -} \rightarrow$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment

**Defiers.** Third kid if and only if the first two are NOT the same sex.

First two births same sex  $\overset{-1}{- - -} \rightarrow$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment



## Four Subpopulations

(Angrist, Imbens, & Rubin 1996)

**Always-Takers.** Third kid no matter what.

First two births same sex  $\overset{0}{- - -} \rightarrow$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment

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First two births same sex  $\overset{0}{- - -} \rightarrow$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment

**Compliers.** Third kid if and only if the first two are the same sex.

First two births same sex  $\overset{+1}{- - -} \rightarrow$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment

~~**Defiers.**~~ (assumed away) Third kid if and only if the first two are NOT the same sex.

First two births same sex  $\overset{-1}{- - -} \rightarrow$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment



## Four Subpopulations

(Angrist, Imbens, & Rubin 1996)

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First two births same sex  $\overset{+1}{- - -} \rightarrow$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment

~~**Defiers.**~~ <sup>(assumed away)</sup> Third kid if and only if the first two are NOT the same sex.

First two births same sex  $\overset{-1}{- - -} \rightarrow$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment



## Takeaway

Instrumental variables estimates the average causal effect among a particular **target population**: compliers

**Compliers.** Third kid if and only if the first two are the same sex.

First two births same sex  $\overset{+1}{- - - \rightarrow}$  Third birth  $\xrightarrow{\hspace{1cm}}$  Employment

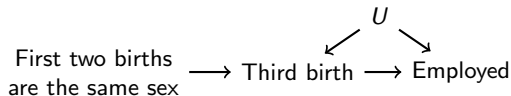
*(Note: A dashed red arrow points from "Employment" back to "Third birth")*





## Vague estimand

Effect of motherhood  
on employment

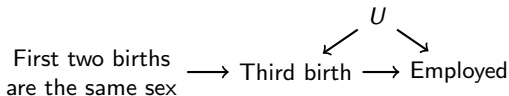




## Vague estimand

Effect of motherhood  
on employment

## Precise estimand





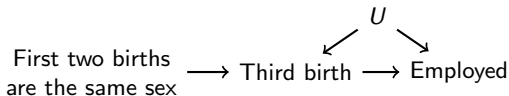
## Vague estimand

Effect of motherhood  
on employment

## Precise estimand

Effect of having **3 vs. 2 children**

**unit-specific  
quantity**





## Vague estimand

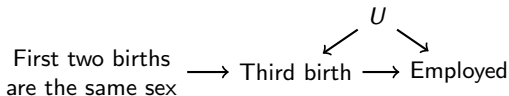
Effect of motherhood on employment

target population



## Precise estimand

Effect of having 3 vs. 2 children among those with at least two children who would have a third birth if and only if the first two were of the same sex





## Precise estimand

Effect of having 3 vs. 2 children  
among those with at least two children who  
would have a third birth if and only if the  
first two were of the same sex

$\approx 4\%$  of all mothers



## Precise estimand

Effect of having  
1 vs. 0 children  
among all women

## Precise estimand

Effect of having 3 vs. 2 children  
among those with at least two children who  
would have a third birth if and only if the  
first two were of the same sex

$\approx 4\%$  of all mothers



### Precise estimand A

Effect of having  
1 vs. 0 children  
among all women

### Precise estimand B

Effect of having 3 vs. 2 children  
among those with at least two children who  
would have a third birth if and only if the  
first two were of the same sex

$\approx 4\%$  of all mothers



### Precise estimand A

Effect of having  
1 vs. 0 children  
among all women

### Precise estimand B

Effect of having 3 vs. 2 children  
among those with at least two children who  
would have a third birth if and only if the  
first two were of the same sex

$\approx 4\%$  of all mothers

**The estimand you choose affects your argument.**





### Precise estimand A

Effect of having  
1 vs. 0 children  
among all women

### Precise estimand B

Effect of having 3 vs. 2 children  
among those with at least two children who  
would have a third birth if and only if the  
first two were of the same sex

$\approx 4\%$  of all mothers

**The estimand you choose affects your argument.**

Choice A) By what assumptions can we learn that?



### Precise estimand A

Effect of having  
1 vs. 0 children  
among all women

### Precise estimand B

Effect of having 3 vs. 2 children  
among those with at least two children who  
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first two were of the same sex

$\approx 4\%$  of all mothers

**The estimand you choose affects your argument.**

Choice A) By what assumptions can we learn that? (**link** step is hard)



### Precise estimand A

Effect of having  
1 vs. 0 children  
among all women

### Precise estimand B

Effect of having 3 vs. 2 children  
among those with at least two children who  
would have a third birth if and only if the  
first two were of the same sex

$\approx 4\%$  of all mothers

**The estimand you choose affects your argument.**

Choice A) By what assumptions can we learn that? (**link** step is hard)

Choice B) Why does this quantity matter for theory?



### Precise estimand A

Effect of having  
1 vs. 0 children  
among all women

### Precise estimand B

Effect of having 3 vs. 2 children  
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$\approx 4\%$  of all mothers

**The estimand you choose affects your argument.**

Choice A) By what assumptions can we learn that? (**link** step is hard)

Choice B) Why does this quantity matter for theory? (**set** step is hard)

# Group exercises

## Group exercises: Plan

1. We will give you a vague research question
2. In groups, you will choose some way to make it precise
3. Our answers may differ. That is ok
4. We will come together and discuss

# Exercise 1

“Marriage has a large effect on the economic well-being of poor women.”

— A policymaker

What is the estimand or target quantity?

1. What is the unit-specific quantity?

- Define the unit of analysis
- Define the outcome
- Define the treatment variable (if any)
- Define the values to which the treatment is set (if any)

2. What is/are the target population(s) of units?

**Note:** There is no single right answer.

## Exercise 2

“Those whose parents attended college are more likely to complete college themselves”

— A sociologist

What is the estimand or target quantity?

1. What is the unit-specific quantity?
  - Define the unit of analysis
  - Define the outcome
  - Define the treatment variable (if any)
  - Define the values to which the treatment is set (if any)
2. What is/are the target population(s) of units?

**Note:** There is no single right answer.