

# Randomization and matching

## Session 7

PMAP 8521: Program evaluation  
Andrew Young School of Policy Studies

# Plan for today

**The magic of randomization**

**How to analyze RCTs**

**The "gold" standard**

**Adjustment with matching**

# The magic of randomization

# Why randomize?

## Fundamental problem of causal inference

$$\delta_i = Y_i^1 - Y_i^0 \quad \text{in real life is} \quad \delta_i = Y_i^1 - ???$$

Individual-level effects are impossible to observe!

There are no individual counterfactuals!

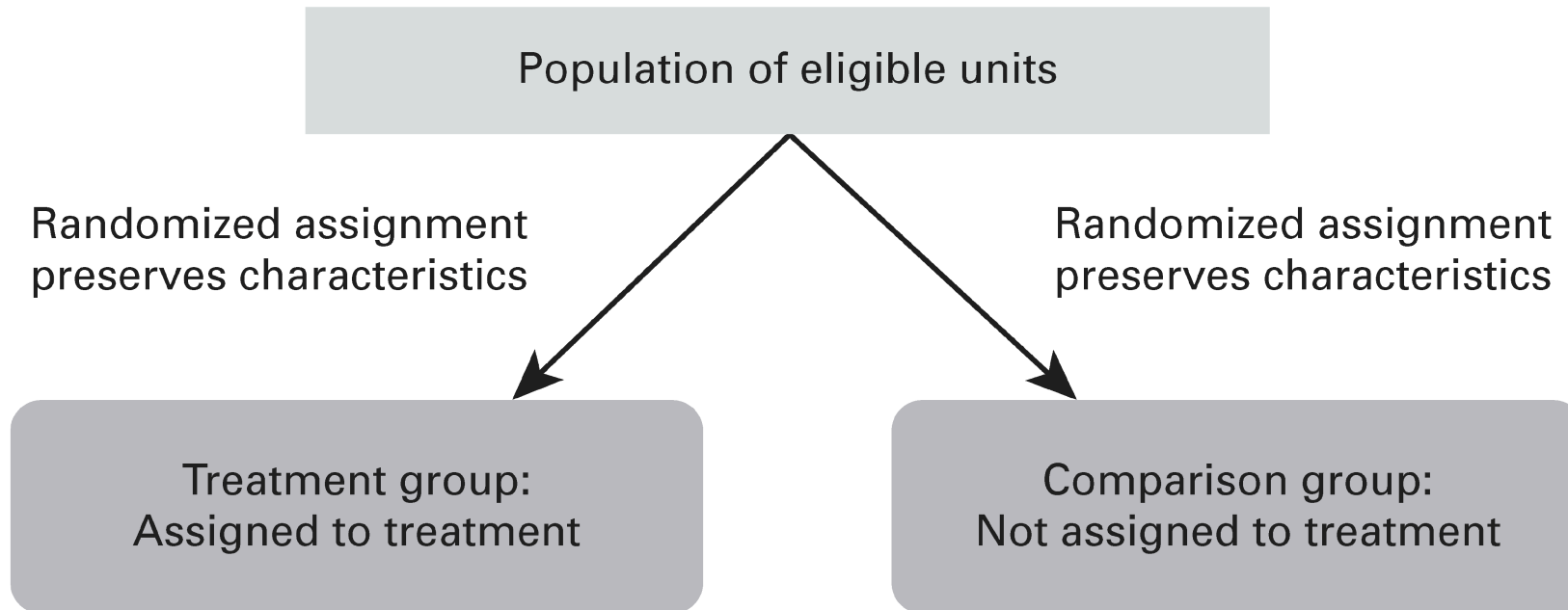
# Why randomize?

$$\delta = (\bar{Y} \mid P = 1) - (\bar{Y} \mid P = 0)$$

**Comparing average outcomes only works  
if groups that received/didn't receive  
treatment look the same**

# Why randomize?

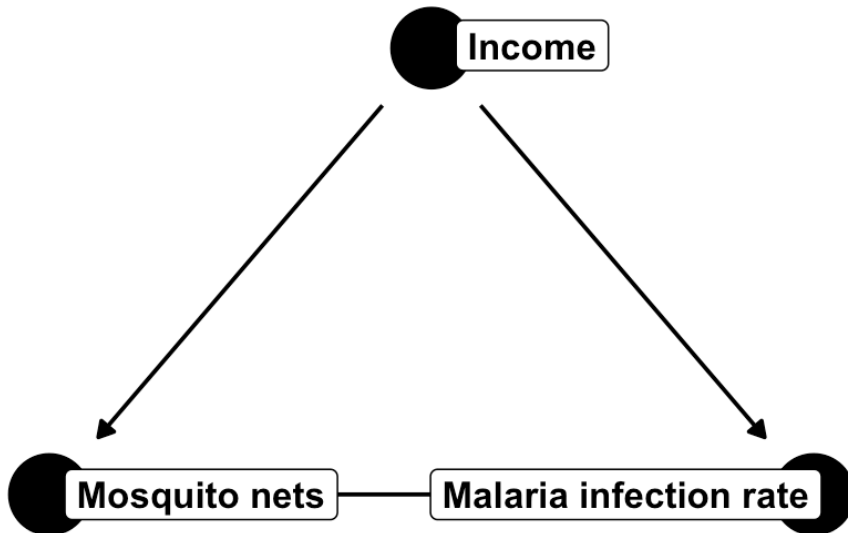
**With big enough samples, the magic of randomization helps make comparison groups comparable**



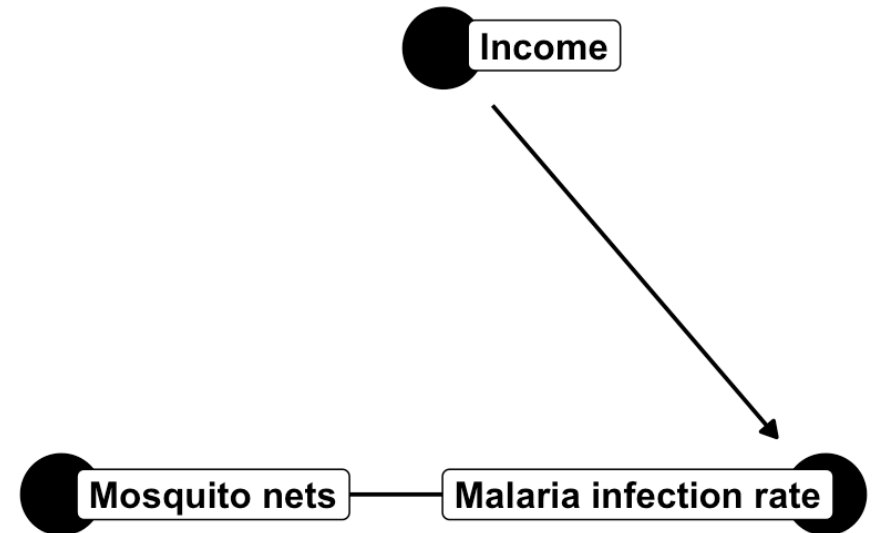
# RCTs and DAGs

$$E[\text{Malaria infection rate} \mid \text{do}(\text{Mosquito net})]$$

Observational DAG

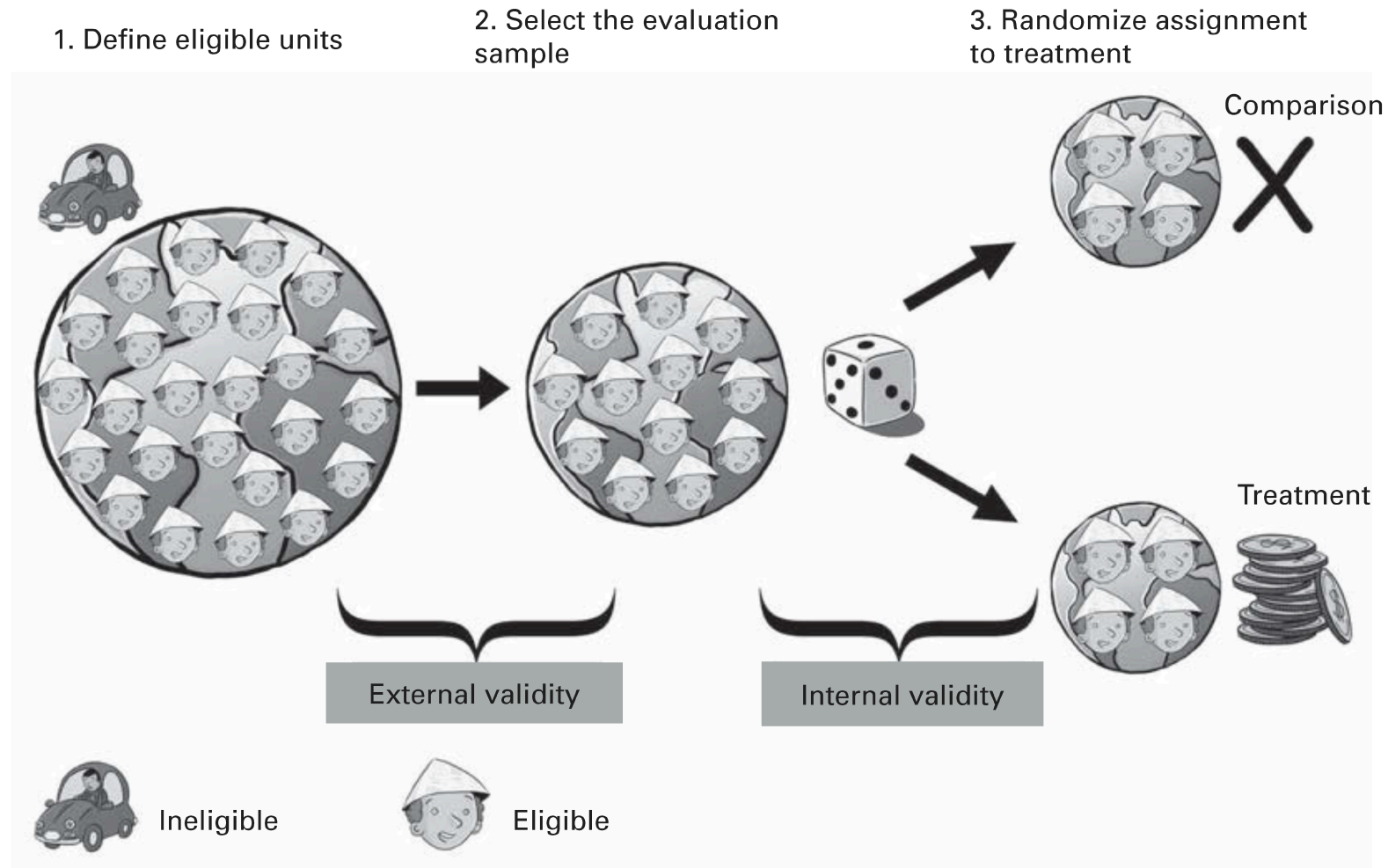


Experimental DAG



When you *do()* X, delete all arrows into X; confounders don't influence treatment!

# How to randomize?



# Random assignment

Coins

Dice

Unbiased lottery

Random numbers + threshold

Atmospheric noise

# How big of a sample?

A training program causes incomes to rise by \$40

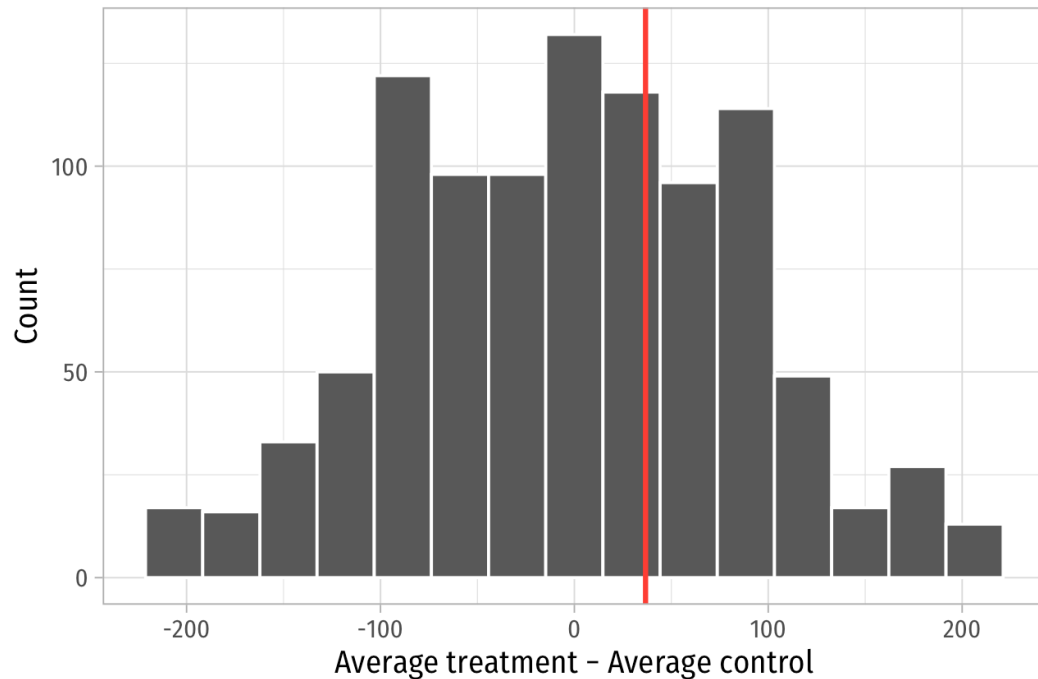
| Person | Group     | Before | After  | Difference |
|--------|-----------|--------|--------|------------|
| 295    | Control   | 122.09 | 229.04 | 106.95     |
| 126    | Treatment | 205.60 | 199.84 | -5.76      |
| 400    | Control   | 133.25 | 130.40 | -2.85      |
| 94     | Treatment | 270.11 | 206.56 | -63.54     |
| 250    | Control   | 344.37 | 222.89 | -121.49    |
| 59     | Treatment | 312.41 | 268.06 | -44.35     |

# Power

## Enroll 10 participants

Simulated world with no difference

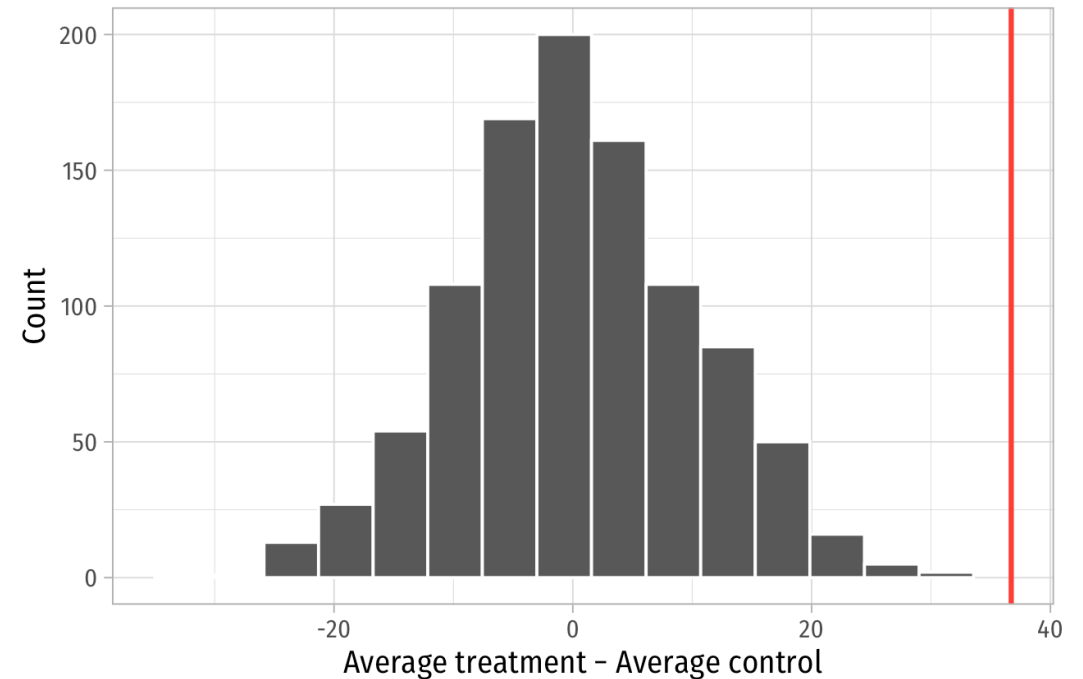
$N = 10$ ;  $p = 0.886$



## Enroll 200 participants

Simulated world with no difference

$N = 200$ ;  $p = < 0.001$



# What's the right sample size?

Use a statistical power calculator to make sure you can potentially detect an effect

statistical power calculator



# How to analyze RCTs

# How to analyze RCTs

**Surprisingly easy, statistically!**

**Step 1: Check that key demographics and other confounders are balanced**

**Step 2: Find difference in average outcome in treatment and control groups**

# Example RCT

.small-code[

```
imaginary_program
```

```
## [38;5;246m# A tibble: 800 × 6 [39m
##   person treatment    age sex    income_after male_num
##   [3m [38;5;246m<int> [39m [23m [3m [38;5;246m<chr> [39m [23m
## [38;5;250m 1 [39m      498 Control      45 Female      179.
## [38;5;250m 2 [39m      308 Treatment    37 Male        247.
## [38;5;250m 3 [39m      677 Control      35 Female      369.
## [38;5;250m 4 [39m        31 Treatment    39 Female      203.
## [38;5;250m 5 [39m      543 Control      36 Female      190.
```

# 1. Check balance

```
imaginary_program %>%  
  group_by(treatment) %>%  
  summarize(avg_age = mean(age),  
            prop_male = mean(sex == "Male"))
```

```
## [38;5;246m# A tibble: 2 × 3 [39m
```

```
##   treatment avg_age prop_male
```

```
##   [3m [38;5;246m<chr> [39m [23m
```

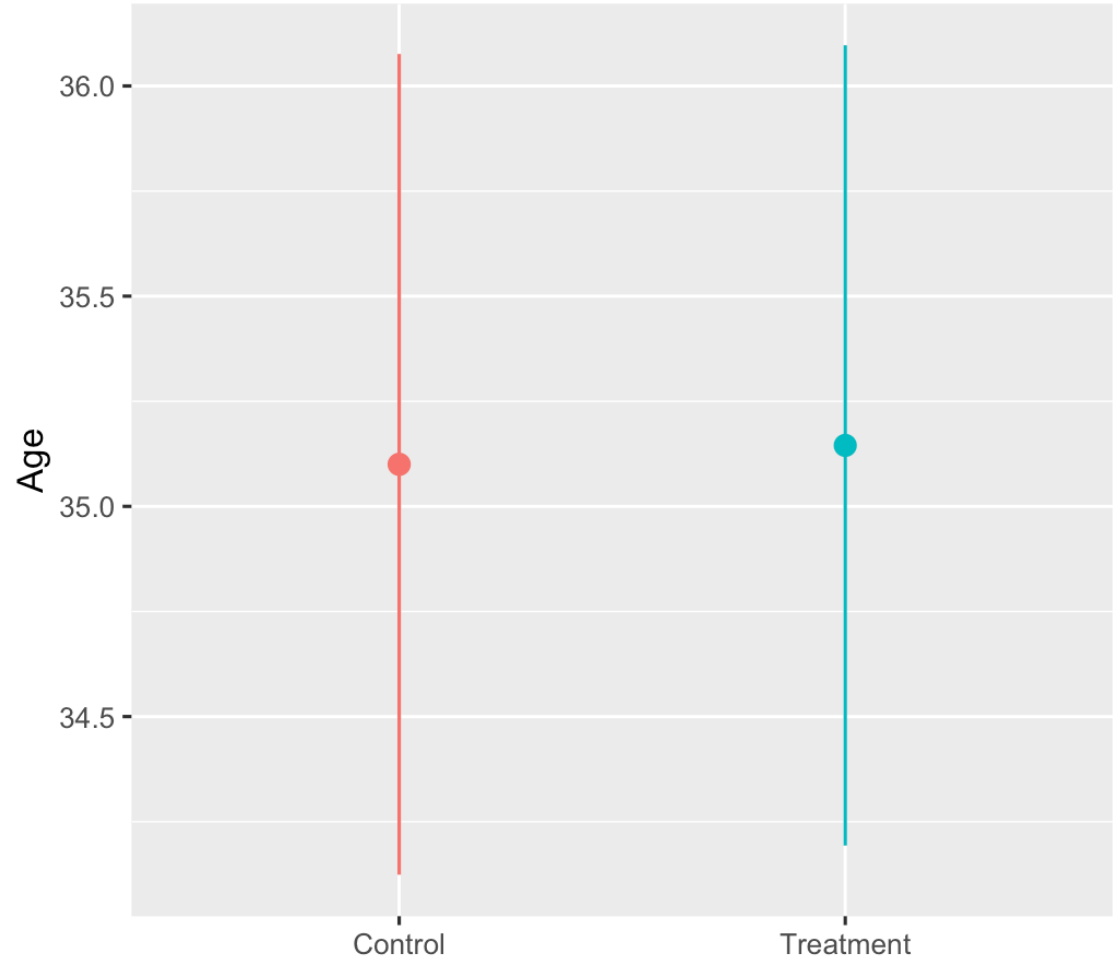
```
[3m [38;5;246m<dbl> [39m [
```

```
## [38;5;250m1 [39m Control      35.1      0.562
```

```
## [38;5;250m2 [39m Treatment    35.1      0.512
```

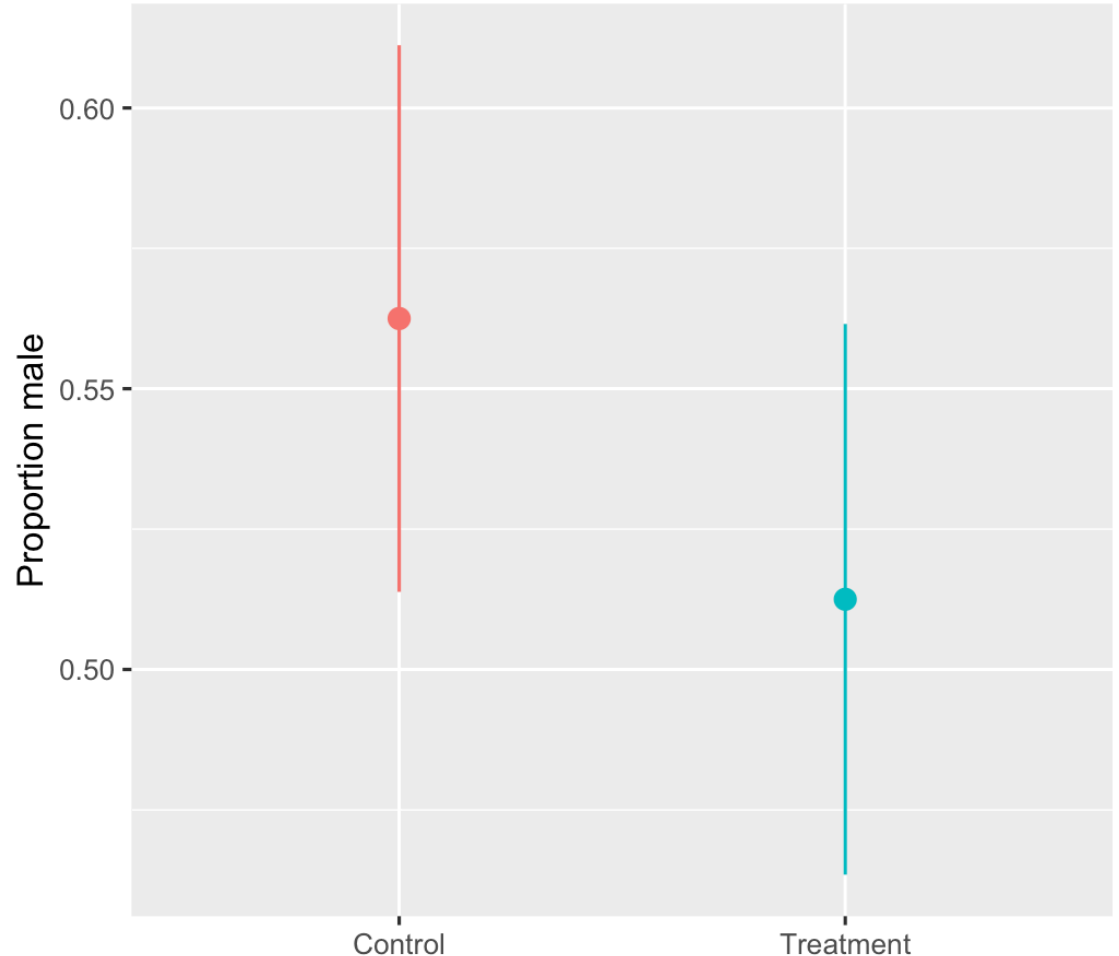
# 1. Check balance

```
ggplot(imaginary_program,  
       aes(x = treatment, y = age,  
           color = treatment)) +  
  stat_summary(geom = "pointrange",  
              fun.data = "mean_se",  
              fun.args = list(mult=1.96)) +  
  guides(color = FALSE) +  
  labs(x = NULL, y = "Age")
```



# 1. Check balance

```
ggplot(imaginary_program,  
  aes(x = treatment, y = male_num,  
    color = treatment)) +  
  stat_summary(geom = "pointrange",  
    fun.data = "mean_se",  
    fun.args = list(mult=1.96)) +  
  guides(color = FALSE) +  
  labs(x = NULL, y = "Proportion male")
```



## 2. Calculate difference

.left-code[

Group means

```
imaginary_program %>%  
  group_by(treatment) %>%  
  summarize(avg_outcome = mean(income_after))
```

```
## [38;5;246m# A tibble: 2 × 2 [39m
```

```
##   treatment avg_outcome
```

```
##   [3m [38;5;246m<chr> [39m [23m
```

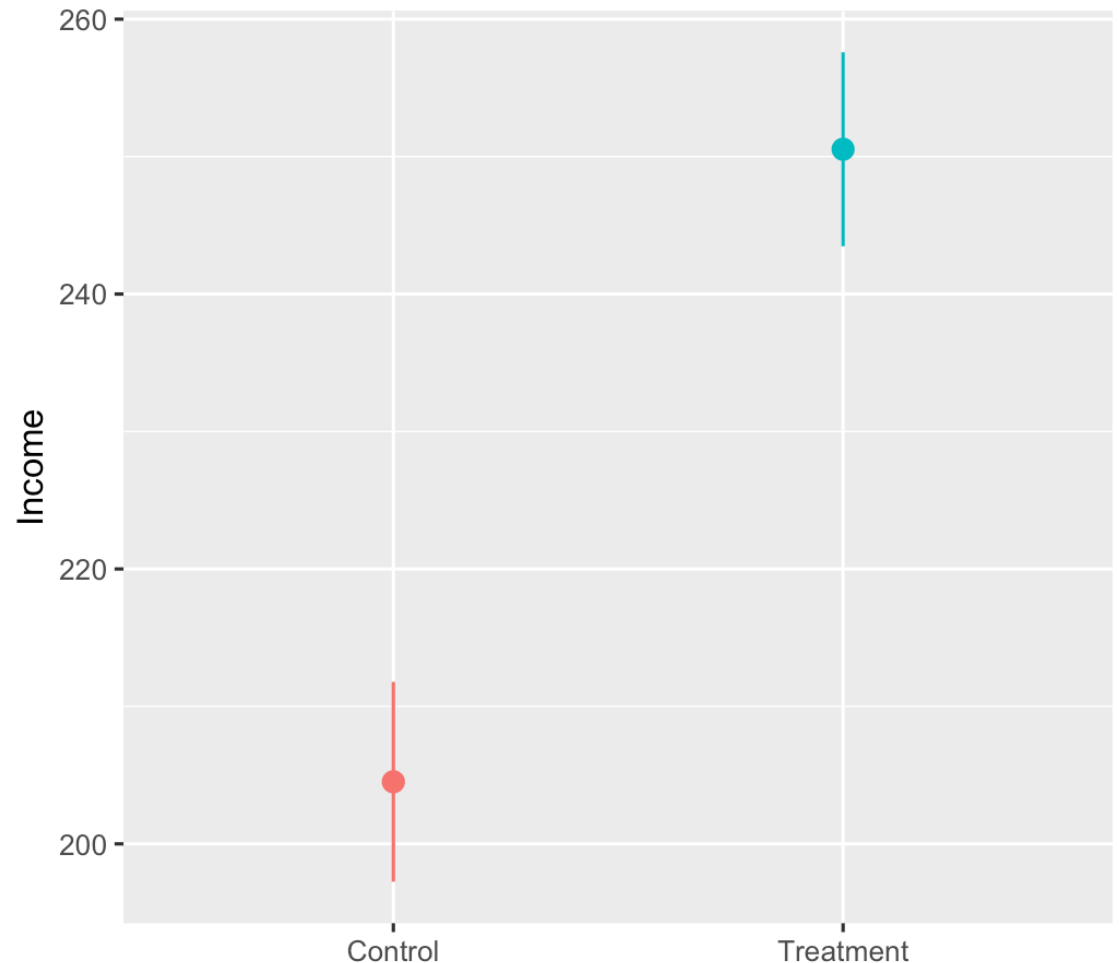
```
[3m [38;5;246m<dbl> [
```

```
## [38;5;250m1 [39m Control          205.
```

```
## [38;5;250m2 [39m Treatment         251.
```

## 2a. Show difference

```
ggplot(imaginary_program,  
  aes(x = treatment,  
      y = income_after,  
      color = treatment)) +  
  stat_summary(geom = "pointrange",  
    fun.data = "mean_se",  
    fun.args = list(mult=1.96)) +  
  guides(color = FALSE) +  
  labs(x = NULL, y = "Income")
```



# Should you control for stuff?

**No!**

**All arrows into the treatment node are removed;  
there's theoretically no confounding!**

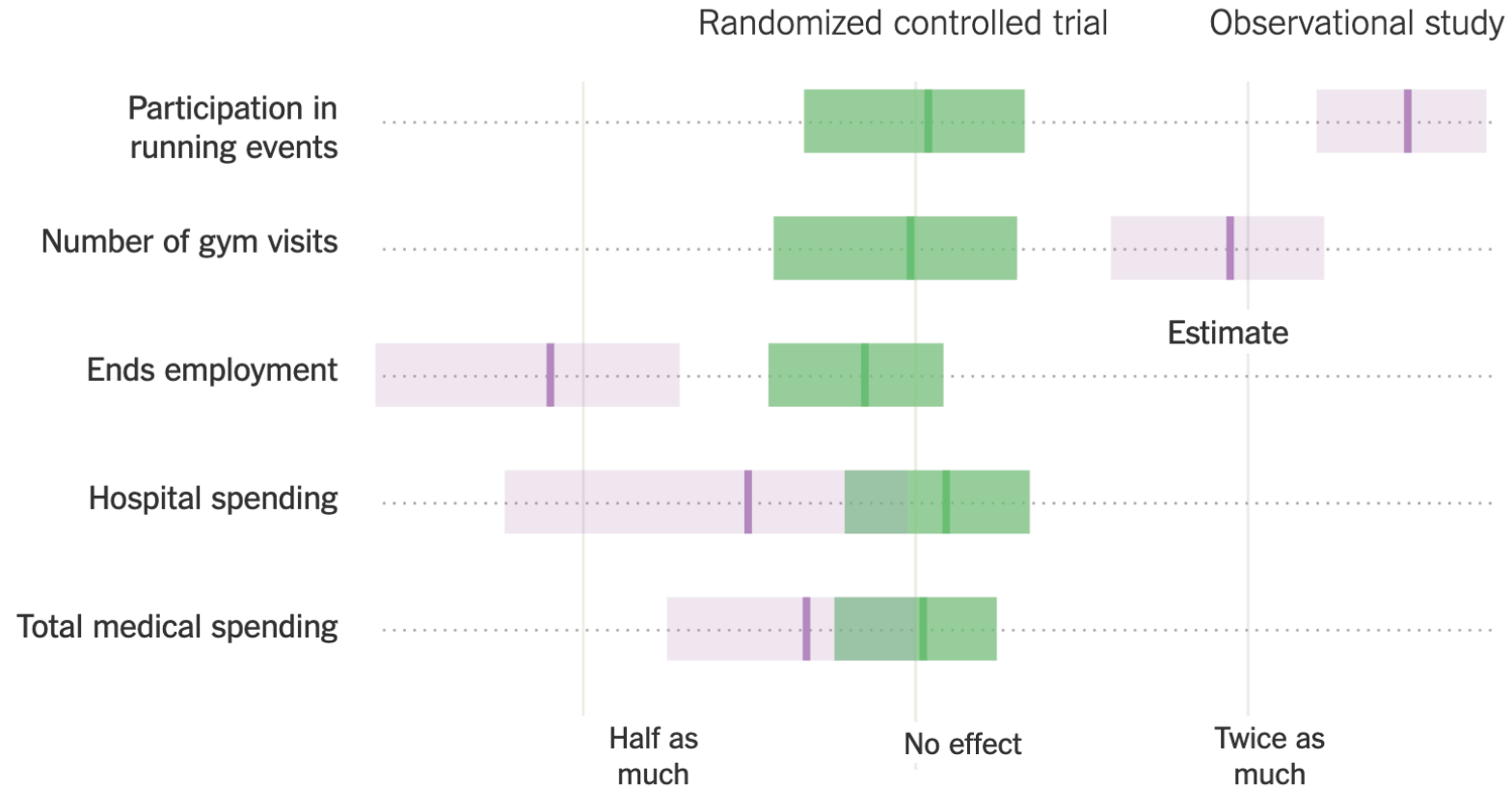
# The "gold" standard

# Types of research

**Experimental studies vs.  
observational studies**

**Which is better?**

# How the Illinois Wellness Program Affected ...



Source: What Do Workplace Wellness Programs Do? Evidence from the Illinois Workplace Wellness Study



rct "gold standard"



All



Shopping



News



V

[BJOG](#). Author manuscript; available in PMC 2018 Dec 1.

Published in final edited form as:

[BJOG. 2018 Dec; 125\(13\): 1716.](#)

Published online 2018 Jun 19. doi: [10.1111/1471-0528.15199](#)

PMCID: PMC6235704

NIHMSID: NIHMS966617

PMID: [29916205](#)

About 636,000 results (0.67 seconds)

## Randomised controlled trials—the gold standard for effectiveness research

[Eduardo Hariton](#), MD, MBA<sup>1</sup> and [Joseph J. Locascio](#), PhD<sup>2</sup>

► [Author information](#) ► [Copyright and License information](#) [Disclaimer](#)

The publisher's final edited version of this article is available at [BJOG](#)

See other articles in PMC that [cite](#) the published article.

## Randomized Assignment of Treatment

When a program is assigned at random—that is, using a lottery—over a large eligible population, we can generate a robust estimate of the counterfactual. *Randomized assignment of treatment is considered the gold standard of impact evaluation.* It uses a random process, or chance, to decide who is granted access to the program and who is not.<sup>1</sup> Under randomized assignment, every eligible unit (for example, an individual, household, business,



Business

# 3 share Nobel Prize in economics for 'experimental approach' to solving poverty

Esther Duflo, who at 46 is the award's youngest winner, shares the honor with fellow MIT economist Abhijit Banerjee and Harvard's Michael Kremer

Pioneers in fight against poverty win 2019 Nobel economics prize



J-PAL

ABDUL LATIF JAMEEL POVERTY ACTION LAB



Massachusetts Institute of Technology (MIT) @MIT · 5h

Professors Esther Duflo and Abhijit Banerjee, co-directors of MIT's @JPAL, receive congratulations on the big news this morning. They share in the #NobelPrize in economic sciences "for their experimental approach to alleviating global poverty."

Photo: Bryce Vickmark



12

112

510



**RCTs are great!**

**Super impractical to do  
all the time though!**

# "Gold standard"

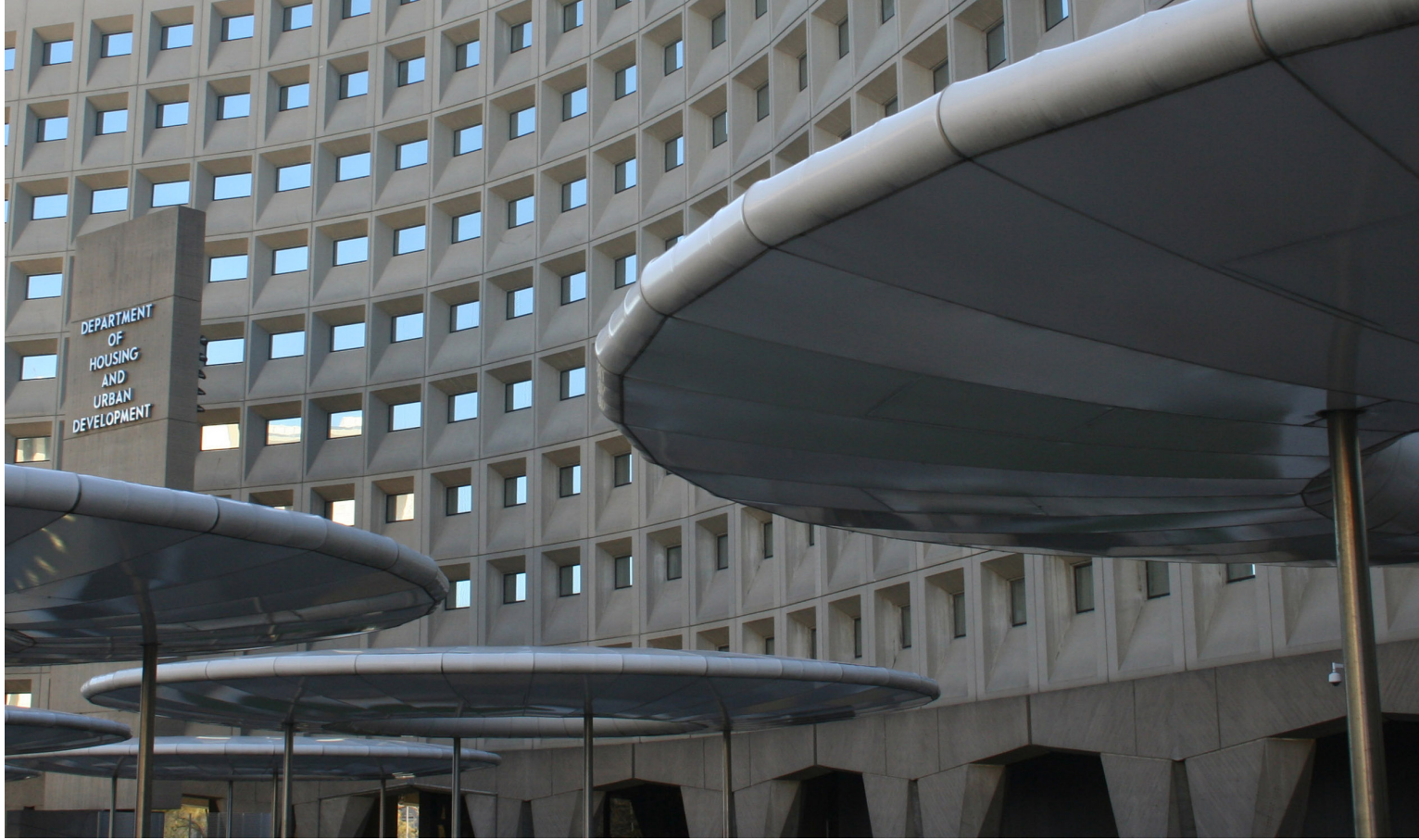
"Gold standard" implies that all causal inferences will be valid if you do the experiment right

We don't care if studies are experimental or not

We care if our causal inferences are valid

RCTs are a helpful baseline/rubric for other methods

# Moving to Opportunity



# RCTs and validity

**Randomization fixes a ton of internal validity issues**

## **Selection**

**Treatment and control groups are comparable; people don't self-select**

## **Trends**

**Maturation, secular trends, seasonality, regression to the mean all generally average out**

# RCTs and validity

**RCTs don't fix attrition!**

**Worst threat to internal validity for RCTs**

**If attrition is correlated  
with treatment, that's bad**

**People might drop out because of the treatment,  
or because they got/didn't get into the control group**

# Addressing attrition

Recruit as effectively as possible

You don't just want weird/WEIRD participants

Get people on board

Get participants invested in the experiment

Collect as much baseline information as possible

Check for randomization of attrition

# RCTs and validity

**Randomization failures**

**Check baseline pre-data**

**Noncompliance**

**Some people assigned to treatment won't take it;  
some people assigned to control will take it**

**Intent-to-treat (ITT) vs. Treatment-on-the-treated (TTE)**

# Other limitations

**RCTs don't magically fix construct validity or statistical conclusion validity**

**RCTs definitely don't magically fix external validity**



# The Nobel Prize in economics goes to three groundbreaking antipoverty researchers

In the last 20 years, development economics has been transformed. These researchers are the reason why.

By Kelsey Piper | Oct 14, 2019, 3:30pm EDT

## Empiricism and development economics

The transformation of development economics into an intensely empirical field that leans heavily on randomized controlled trials hasn't been uncontroversial, and many of **the responses** to the Nobel Prize announcement acknowledge that controversy.

Critics have **complained that** randomization feels much more scientific than other approaches but doesn't necessarily answer our questions any more definitively. **Others worry** that the focus on small-scale questions — Do wristbands increase vaccination rates? Do textbooks improve school performance? — might distract us from addressing larger, structural contributors to poverty.

# When to randomly assign

Demand for treatment exceeds supply

Treatment will be phased in over time

Treatment is in equipoise (genuine uncertainty)

Local culture open to randomization

When you're a nondemocratic monopolist

When people won't know (and it's ethical!)

When lotteries are going to happen anyway

# When to **not** randomly assign

When you need immediate results

When it's unethical or illegal

When it's something that happened in the past

When it involves universal ongoing phenomena

# Adjustment with matching

TABLE 2.1  
The college matching matrix

| Applicant<br>group | Student | Private |        |       | Public    |            |                  | 1996<br>earnings |
|--------------------|---------|---------|--------|-------|-----------|------------|------------------|------------------|
|                    |         | Ivy     | Leafy  | Smart | All State | Tall State | Altered<br>State |                  |
| A                  | 1       |         | Reject | Admit |           | Admit      |                  | 110,000          |
|                    | 2       |         | Reject | Admit |           | Admit      |                  | 100,000          |
|                    | 3       |         | Reject | Admit |           | Admit      |                  | 110,000          |
| B                  | 4       | Admit   |        |       | Admit     |            | Admit            | 60,000           |
|                    | 5       | Admit   |        |       | Admit     |            | Admit            | 30,000           |
| C                  | 6       |         | Admit  |       |           |            |                  | 115,000          |
|                    | 7       |         | Admit  |       |           |            |                  | 75,000           |
| D                  | 8       | Reject  |        |       | Admit     | Admit      |                  | 90,000           |
|                    | 9       | Reject  |        |       | Admit     | Admit      |                  | 60,000           |

*Note:* Enrollment decisions are highlighted in gray.

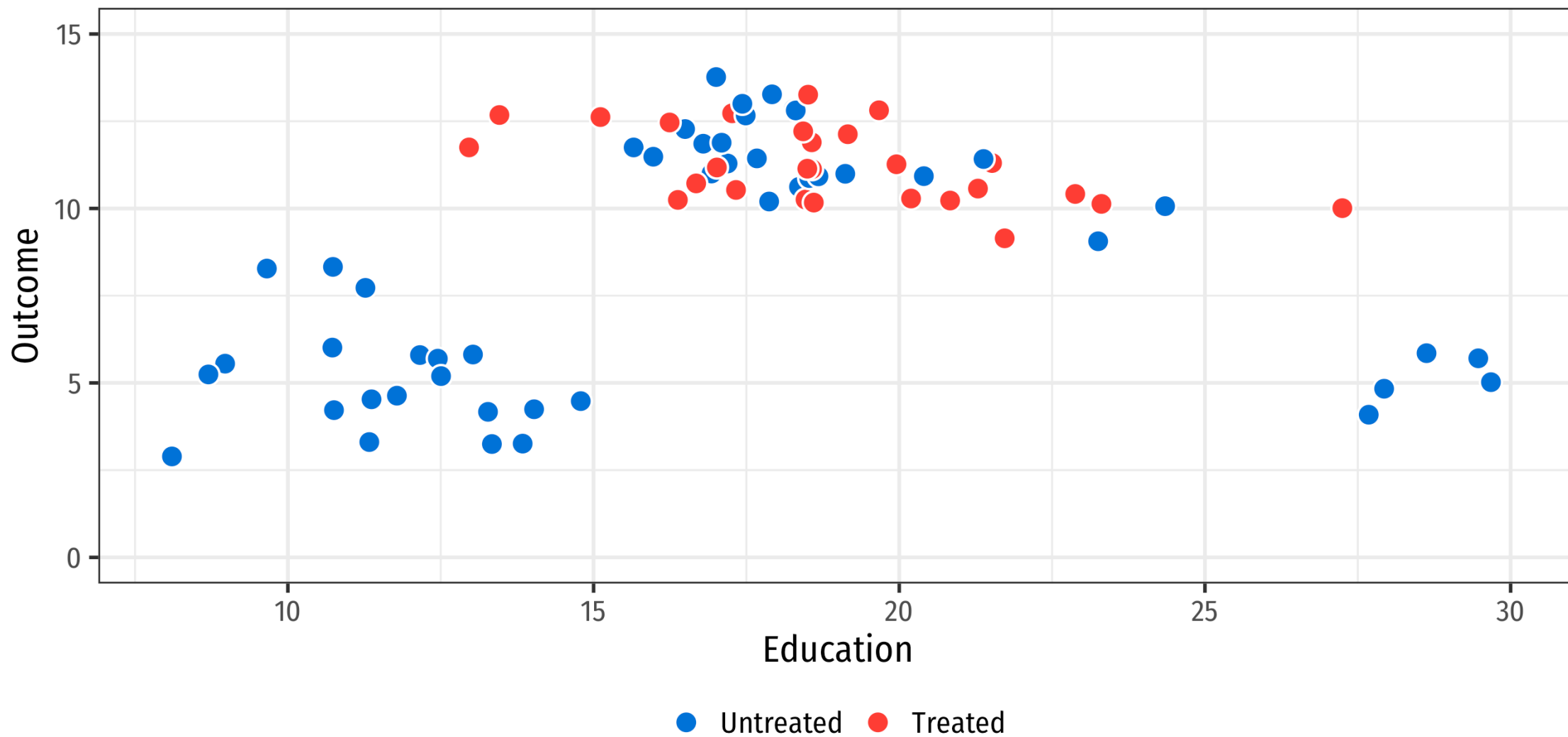
# Why match?

**Reduce model dependence**

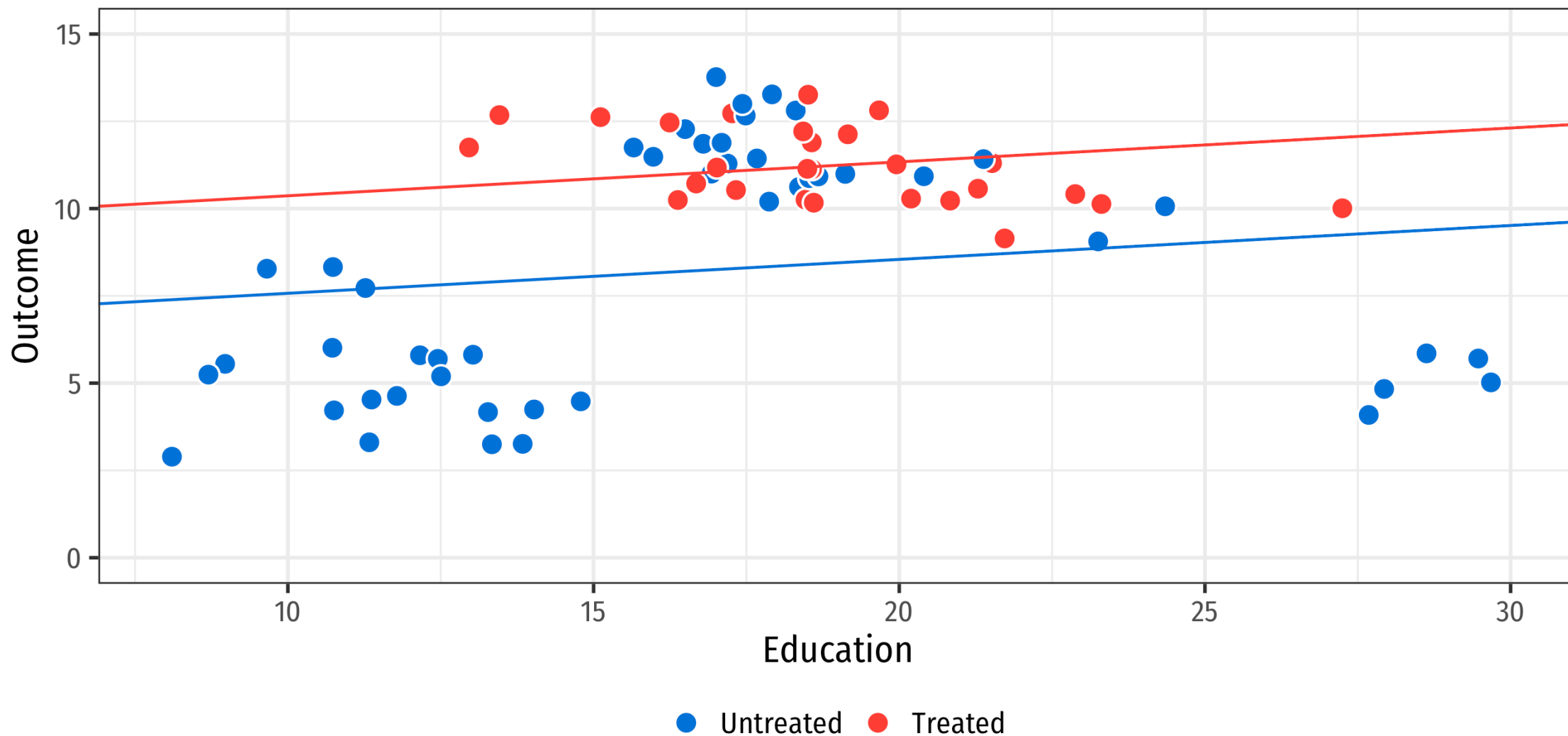
**Imbalance → model dependence → researcher discretion → bias**

**Compare apples to apples**

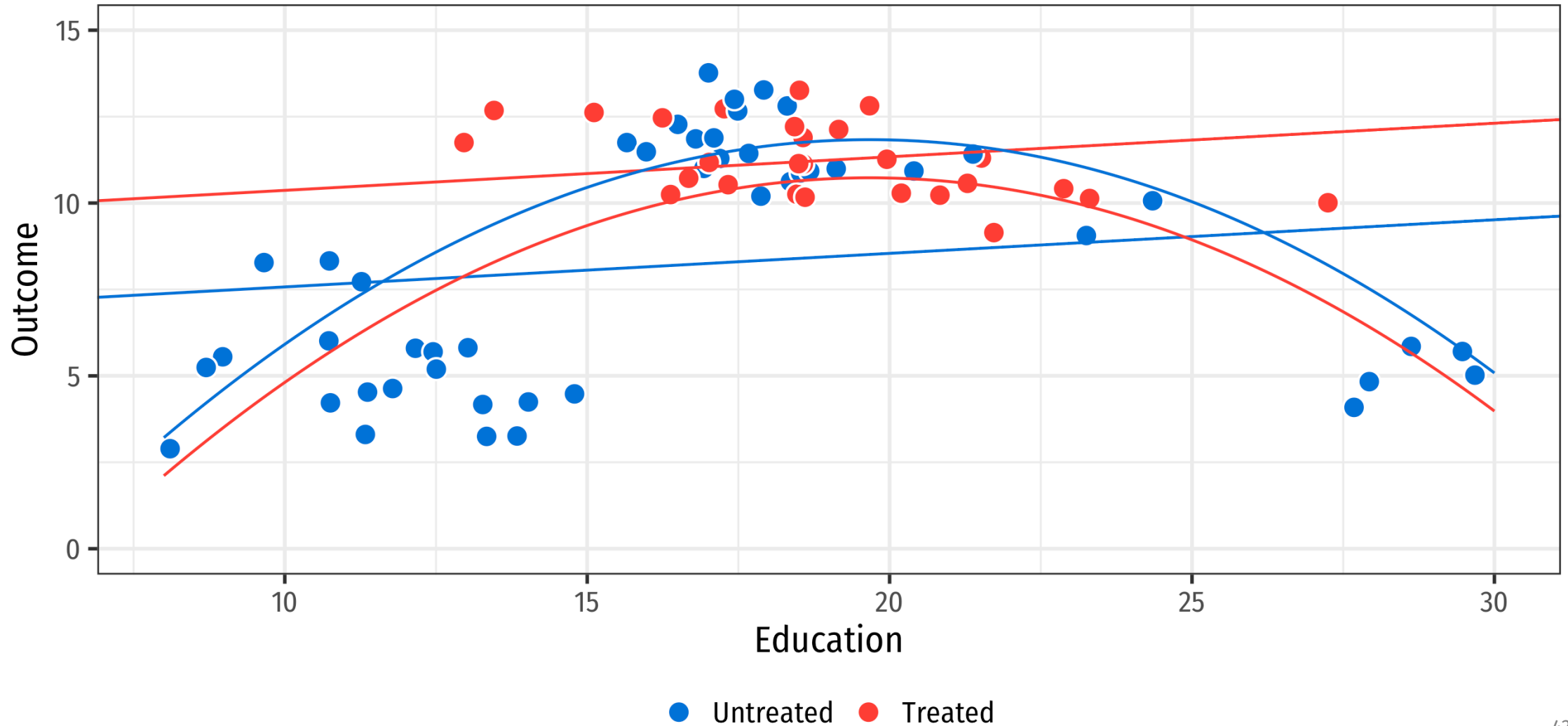
**It's a way to adjust for backdoors!**

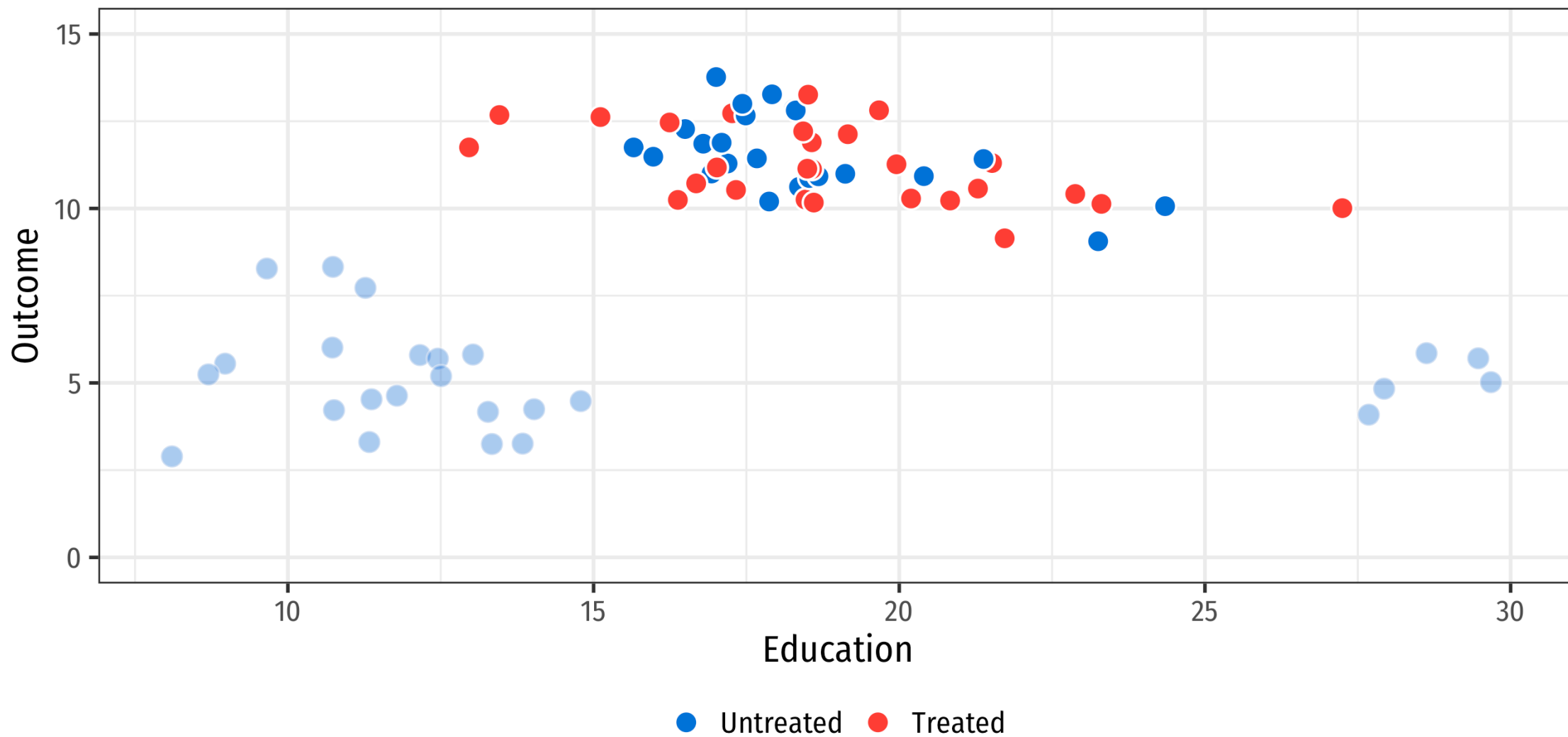


$$\text{Outcome} = \beta_0 + \beta_1 \text{Education} + \beta_2 \text{Treatment}$$

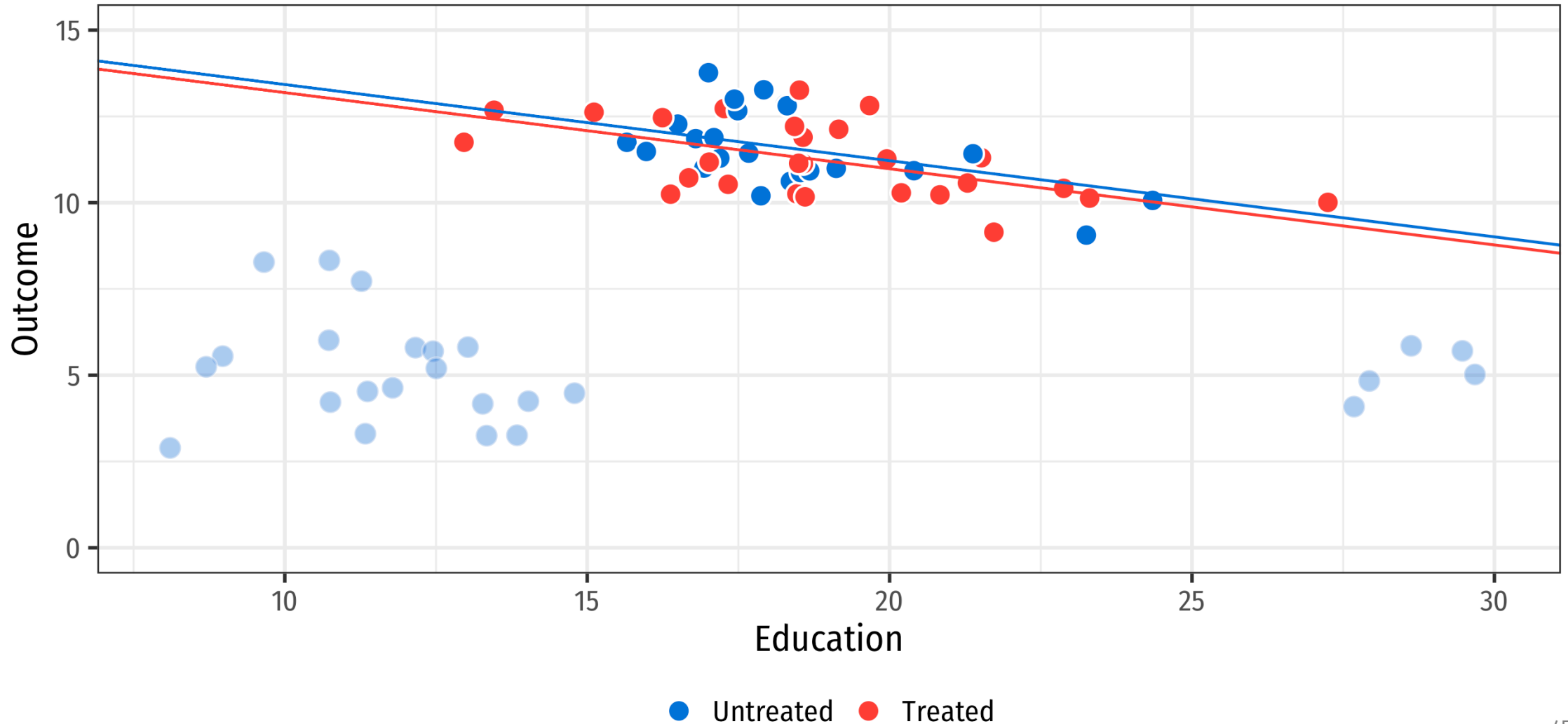


$$\text{Outcome} = \beta_0 + \beta_1 \text{Education} + \beta_2 \text{Education}^2 + \beta_3 \text{Treatment}$$

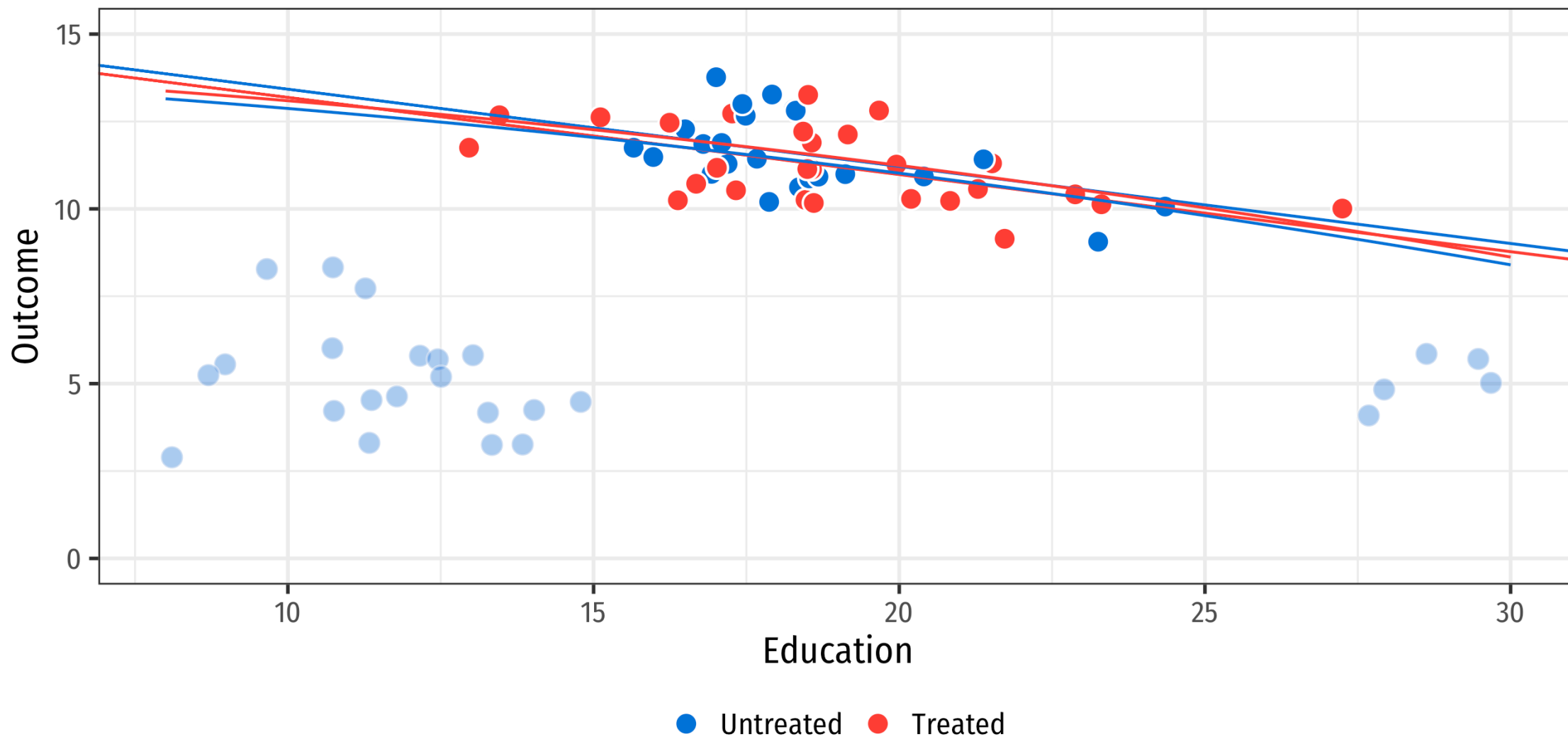




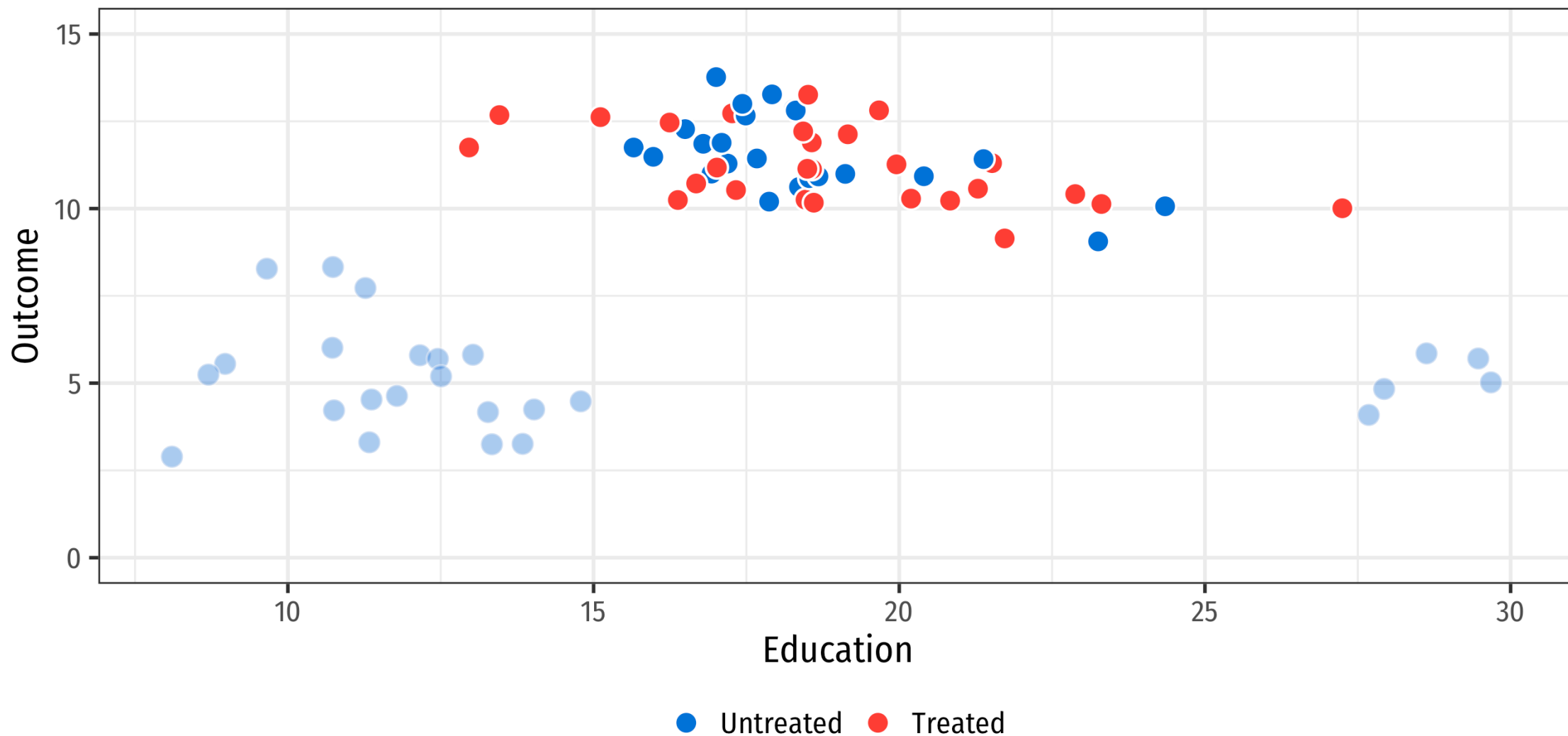
$$\text{Outcome} = \beta_0 + \beta_1 \text{Education} + \beta_2 \text{Treatment}$$



$$\text{Outcome} = \beta_0 + \beta_1 \text{Education} + \beta_2 \text{Education}^2 + \beta_3 \text{Treatment}$$



**How do we know that we can remove these points?**



# General process for matching

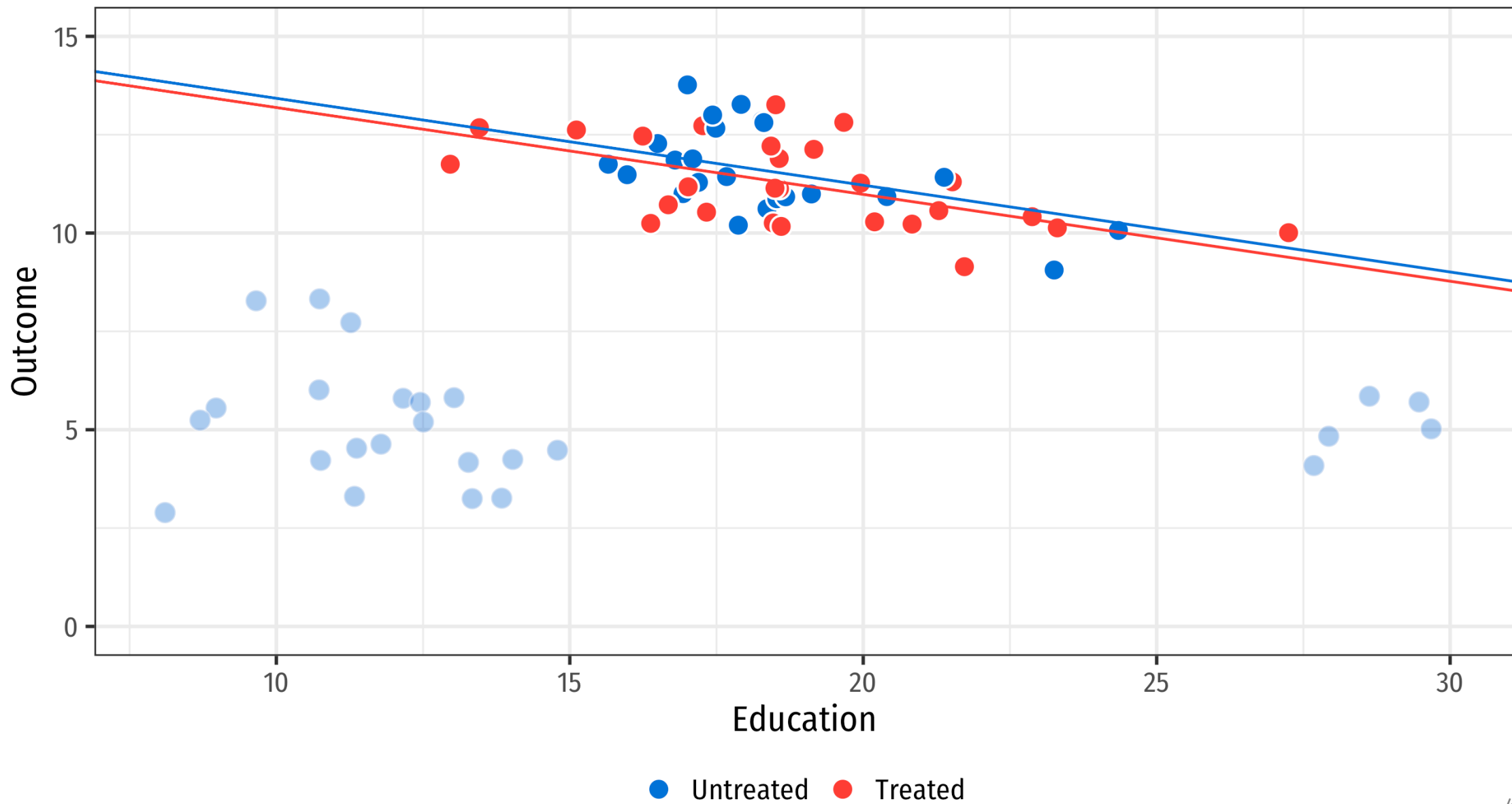
## Step 1. Preprocessing

**Do something to guess or model the assignment to treatment**

**Use what you know about the DAG to inform this guessing!**

## Step 2. Estimation

**Use the new trimmed/preprocessed data to build a model, calculate difference in means, etc.**



# Different methods

**Nearest neighbor matching (NN)**

**Mahalanobis distance / Euclidean distance**

~~**Propensity score matching (PSM)**~~

**Inverse probability weighting (IPW)**

**(and lots of other methods we're not covering!)**

# Nearest neighbor matching

**Find untreated observations that are very close/similar to treated observations based on confounders**

**Lots of mathy ways to measure distance**

**Mahalanobis and Euclidean distance are fairly common**

## US MARKETS

# There's a 70% chance of recession in the next six months, new study from MIT and State Street finds

PUBLISHED WED, FEB 5 2020·12:20 PM EST | UPDATED WED, FEB 5 2020·4:13 PM EST



**Pippa Stevens**  
@PIPPASTEVEN13

SHARE



## KEY POINTS

- A new study from the MIT Sloan School of Management and State Street Associate says there's a 70% chance that a recession will occur in the next six months.
- The researches used a scientific approach initially developed to measure human skulls to determine how the relationship of four factors compares to prior recessions.
- The index currently stands at 76%. Looking at data back to 1916, the researchers found that once the index topped 70%, the likelihood of a recession rose to 70%.

## TRENDING NOW



**House passes \$2.2 trillion Democratic coronavirus stimulus bill**



**Trump suggests he won't 'allow' rule changes for next debates with Biden**



**Top Trump aide Hicks tests positive for coronavirus after traveling with president**

## US MARKETS

# There's a 70% chance of recession in the next six months, new study from MIT and State Street finds

PUBLISHED WED, FEB 5 2020·12:20 PM EST | UPDATED WED, FEB 5 2020·4:13 PM EST



Pippa Stevens  
@PIPPASTEVEN13

SHARE [f](#) [t](#) [in](#) [✉](#)

## That's just Mahalanobis matching!

### KEY POINTS

- A new study from the MIT Sloan School of Management and State Street Associate says there's a 70% chance that a recession will occur in the next six months.
- The researches used a scientific approach initially developed to measure human skulls to determine how the relationship of four factors compares to prior recessions.
- The index currently stands at 76%. Looking at data back to 1916, the researchers found that once the index topped 70%, the likelihood of a recession rose to 70%.



House passes \$2.2 trillion Democratic coronavirus stimulus bill



Trump suggests he won't 'allow' rule changes for next debates with Biden



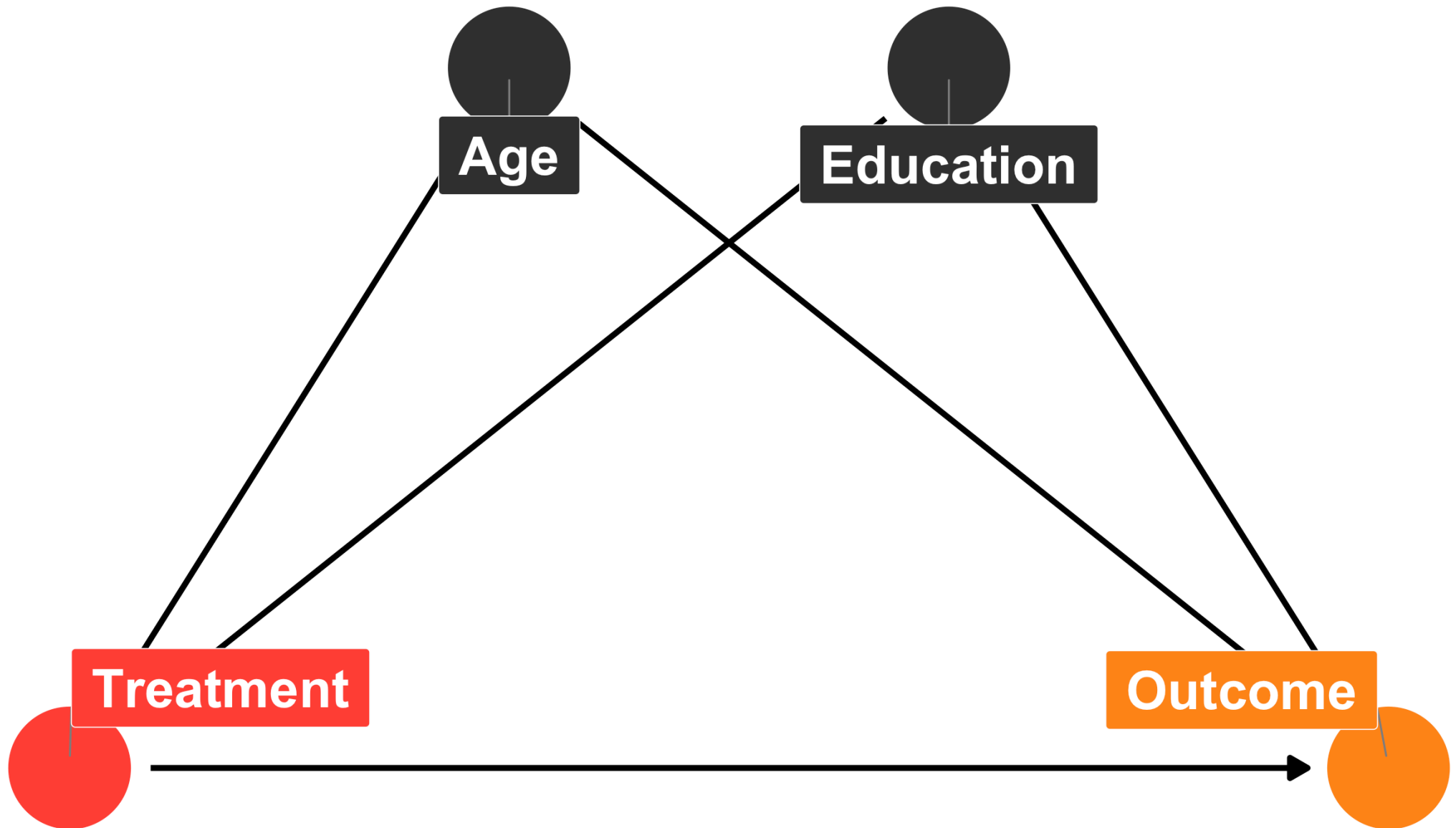
Top Trump aide Hicks tests positive for coronavirus after traveling with president

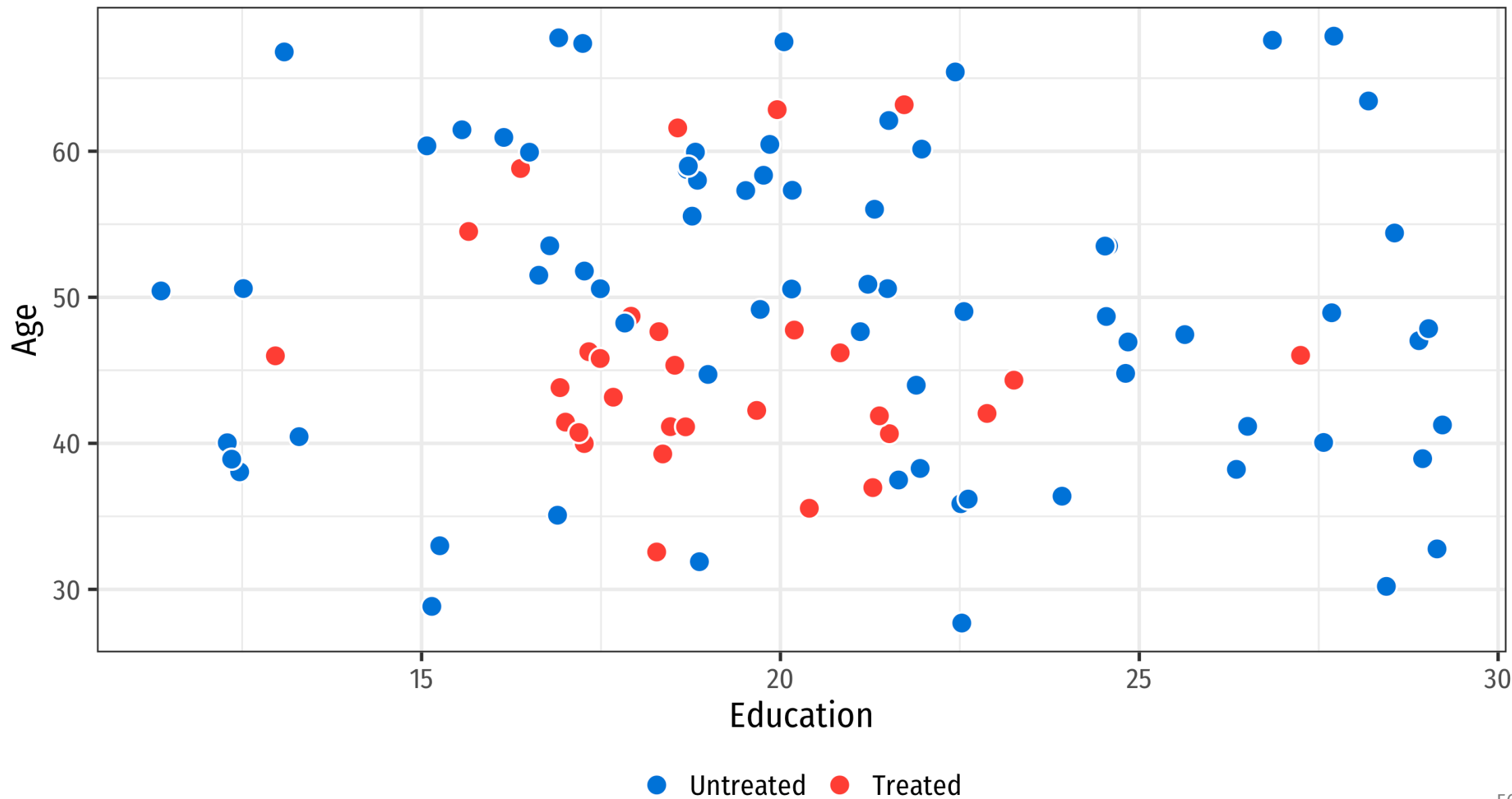
# Matching and eugenics

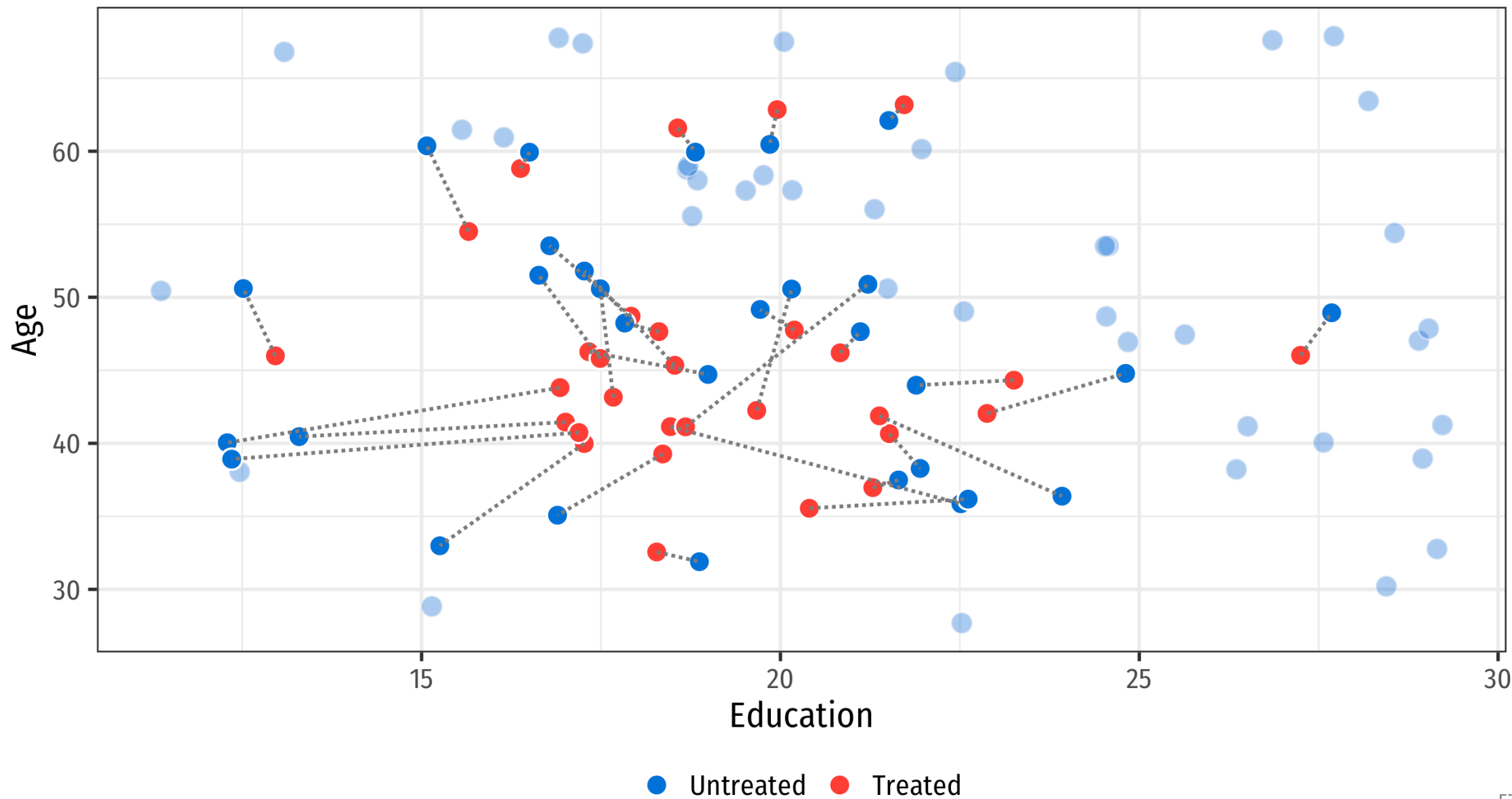
**Prasanta Chandra Mahalanobis**

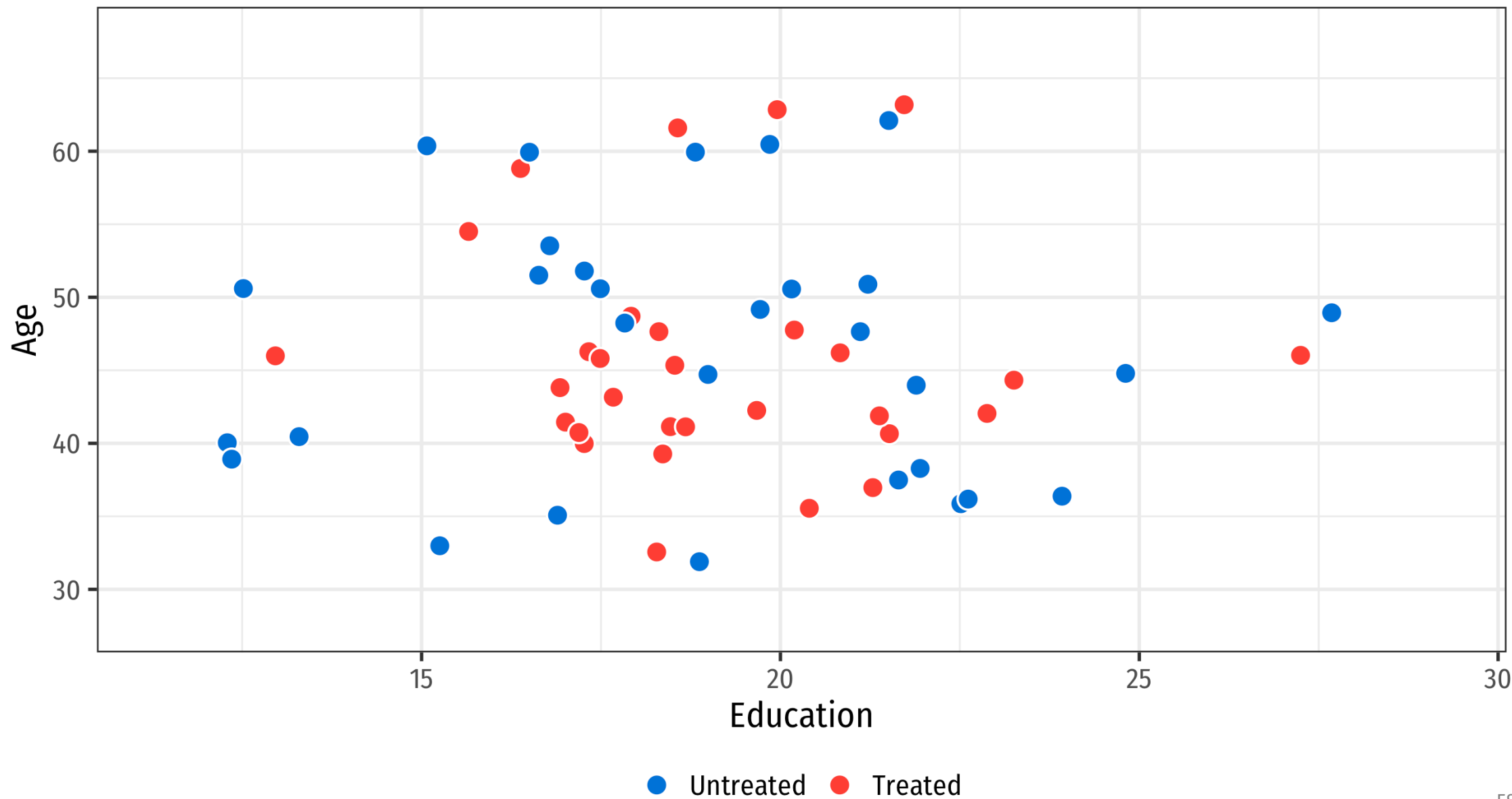


**Tried to prove brain size  
differences between castes;  
low-key eugenicist**



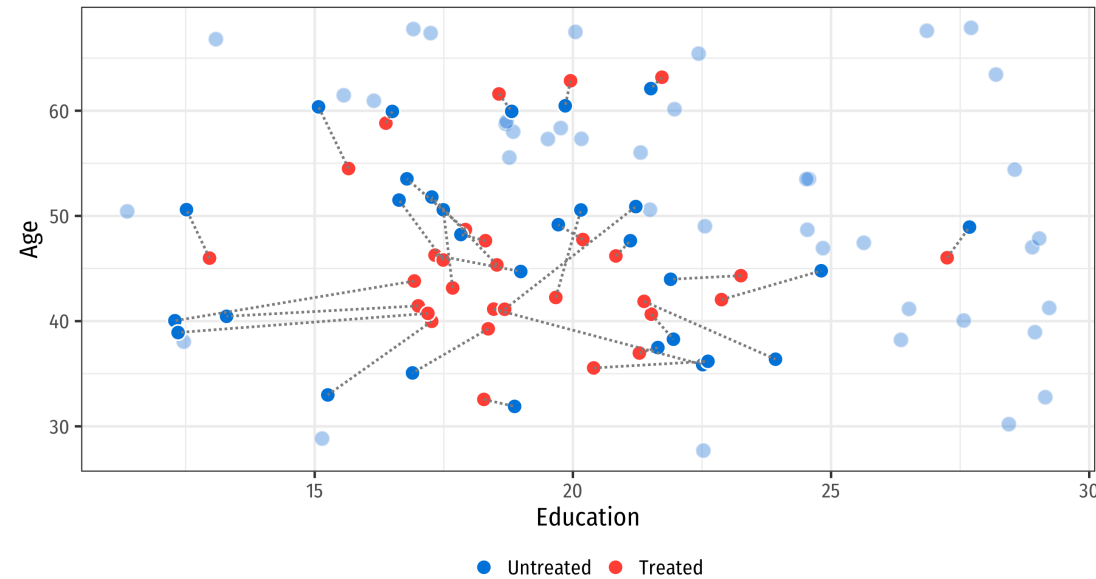






# Potential problems with matching

Nearest neighbor matching can be greedy!



**Solution: Don't throw everything away!**

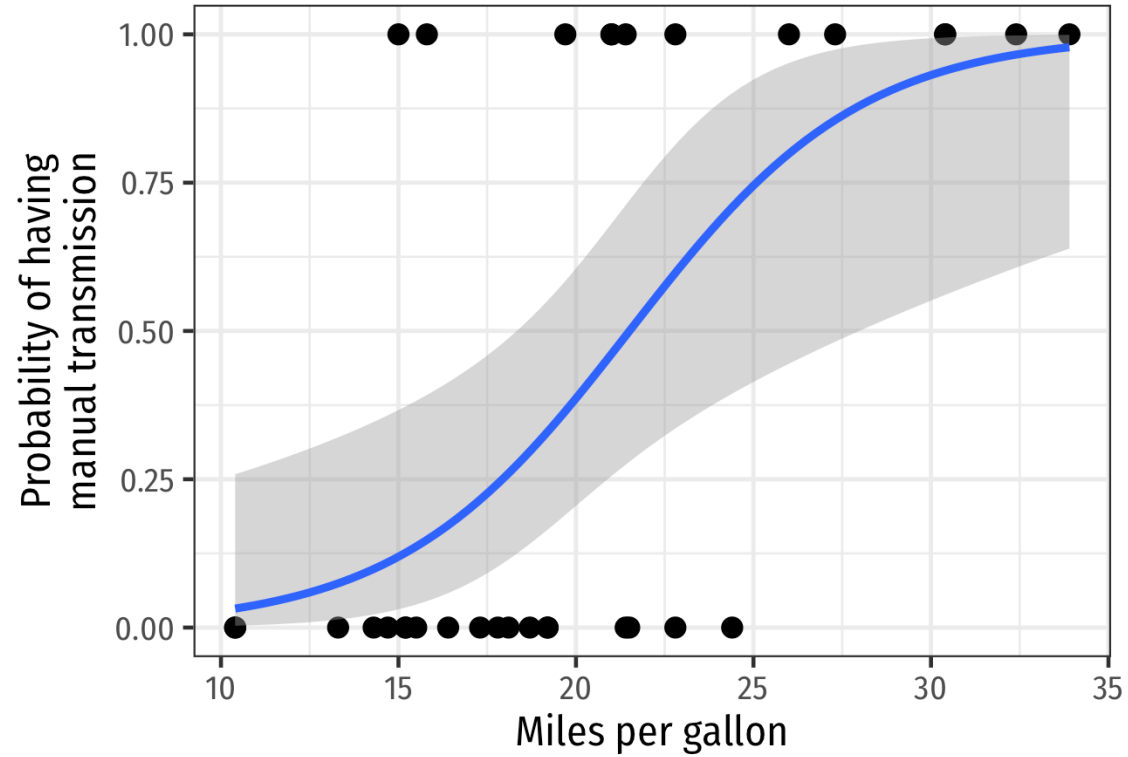
# Propensity scores

**Predict the probability of assignment to treatment using a model**

**Logistic regression, probit regression, machine learning, etc.**

**Here's logistic regression:**

$$\log \frac{p_{\text{Treated}}}{1 - p_{\text{Treated}}} = \beta_0 + \beta_1 \text{Education} + \beta_2 \text{Age}$$



$$\log \frac{p_{\text{Manual}}}{1 - p_{\text{Manual}}} = \beta_0 + \beta_1 \text{MPG}$$

```
model_transmission <- glm(am ~ mpg, data = mtcars, family = binomial(link = "logit"))
```

**Log odds** (default coefficient unit of measurement; fairly uninterpretable)

**Odds ratios** ( $e^{\beta}$ ; centered around 1: 1.5 means 50% more likely; 0.75 means 25% less likely)

`.pull-right-wide.small-code[`

```
tidy(model_transmission)
```

```
## [38;5;246m# A tibble: 2 × 5 [39m
```

```
##      term      estimate std.error statistic
```

```
##      [3m [38;5;246m<chr> [39m [23m          [
```

```
tidy(model_transmission,  
      exponentiate = TRUE)
```

```
## [38;5;250m1 [39m (Intercept)      - [31m6 [39m
```

```
## [38;5;250m2 [39m mpg              0.307
```

```
## [38;5;246m# A tibble: 2 × 5 [39m
```

```
##      term      estimate std.error statistic p.value
```

```
##      [3m [38;5;246m<chr> [39m [23m          [3m [38;5;246m<dbl> [39m
```

## Plug all the values of MPG into the model and find the predicted probability of manual transmission

```
augment(model_transmission, data = mtcars, type.predict = "response")
```

```
## # A tibble: 32 x 3
##       mpg      am .fitted
##   <dbl> <dbl>   <dbl>
## 1    21         1  0.461
## 2    21         1  0.461
## 3   22.8         1  0.598
## 4   21.4         0  0.492
## 5   18.7         0  0.297
## 6   18.1         0  0.260
## 7   14.3         0  0.0986
## 8   24.4         0  0.708
## 9   22.8         0  0.598
## 10  19.2         0  0.330
## # ... with 22 more rows
```

**Row 7 is highly unlikely to be manual (1)**

**Row 8 is highly likely to be manual**

# Propensity score matching

**Super popular method**

**There are mathy reasons why it's not great  
for matching *for identification purposes***

**Propensity scores are fine!  
Using them for matching isn't!**



# Why Propensity Scores Should Not Be Used for Matching

Gary King<sup>1</sup> and Richard Nielsen<sup>2</sup>

<sup>1</sup> *Institute for Quantitative Social Science, Harvard University, 1737 Cambridge Street, Cambridge, MA 02138, USA.*

*Email: [king@harvard.edu](mailto:king@harvard.edu), URL: <http://GaryKing.org>*

<sup>2</sup> *Department of Political Science, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, USA. Email: [rnielsen@mit.edu](mailto:rnielsen@mit.edu), URL: <http://www.mit.edu/~rnielsen>*

---

## Abstract

We show that propensity score matching (PSM), an enormously popular method of preprocessing data for causal inference, often accomplishes the opposite of its intended goal—thus increasing imbalance, inefficiency, model dependence, and bias. The weakness of PSM comes from its attempts to approximate a completely randomized experiment, rather than, as with other matching methods, a more efficient fully blocked randomized experiment. PSM is thus uniquely blind to the often large portion of imbalance that can be eliminated by approximating full blocking with other matching methods. Moreover, in data balanced enough to approximate complete randomization, either to begin with or after pruning some observations, PSM approximates random matching which, we show, increases imbalance even relative to the original data. Although these results suggest researchers replace PSM with one of the other available matching methods, propensity scores have other productive uses.

*Keywords:* matching, propensity score matching, coarsened exact matching, Mahalanobis distance matching, model dependence

# Weighting

Make some observations more important than others

|            | <b>Young</b> | <b>Middle</b> | <b>Old</b> |
|------------|--------------|---------------|------------|
| Population | 30%          | 40%           | 30%        |
| Sample     | 60%          | 30%           | 10%        |

# Weighting

Make some observations more important than others

|            | Young                 | Middle                  | Old                 |
|------------|-----------------------|-------------------------|---------------------|
| Population | 30%                   | 40%                     | 30%                 |
| Sample     | 60%                   | 30%                     | 10%                 |
| Weight     | 30 / 60<br><b>0.5</b> | 40 / 30<br><b>1.333</b> | 30 / 10<br><b>3</b> |

Multiply weights by average values  
(or us in regression) to adjust for importance

# Inverse probability weighting

Use propensity scores to weight observations by how "weird" they are

Observations with high probability of treatment who don't get it (and vice versa) have higher weight

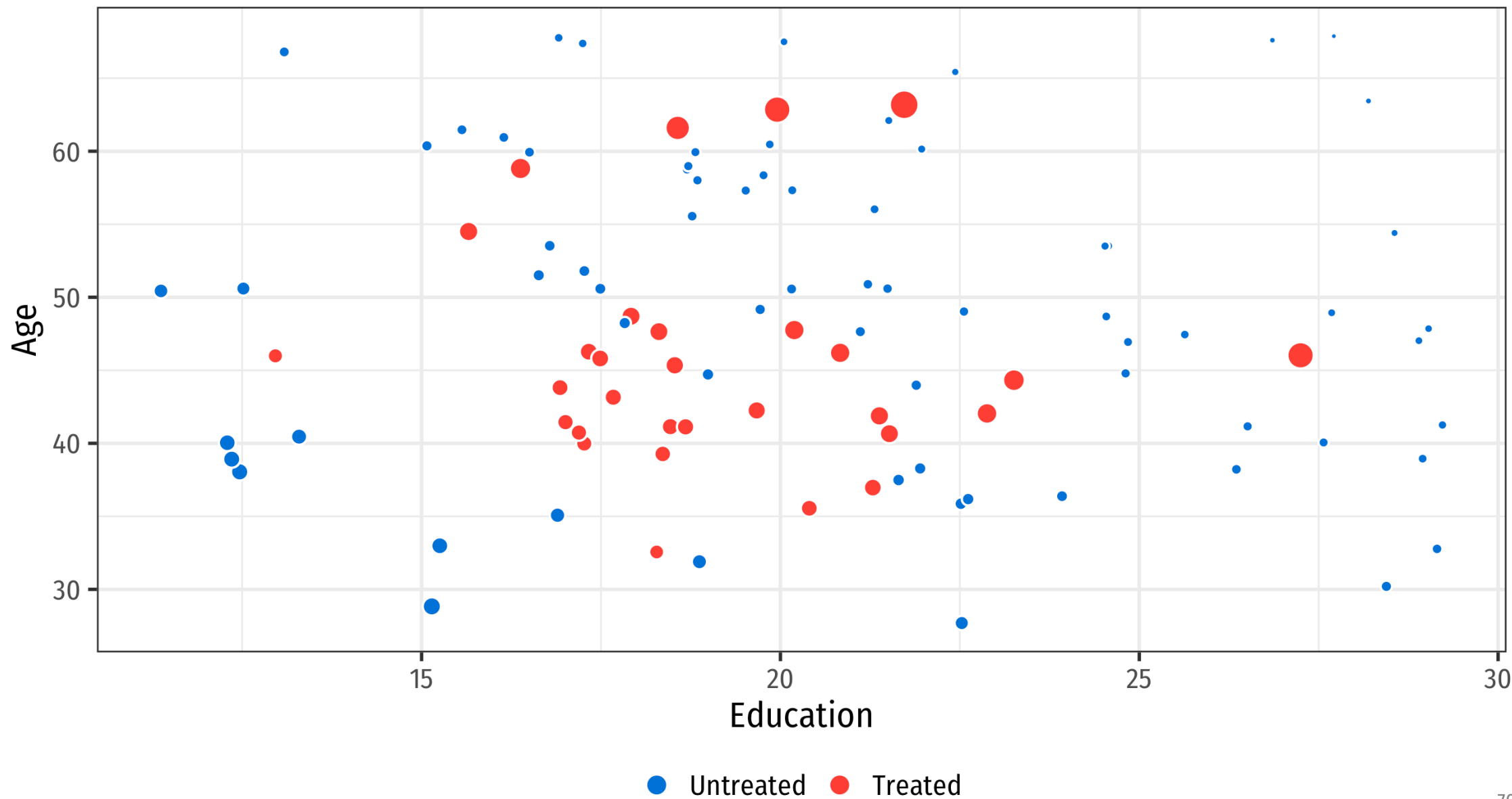
$$\frac{\text{Treatment}}{\text{Propensity}} + \frac{1 - \text{Treatment}}{1 - \text{Propensity}}$$

```
augment(model_transmission, data = mtcars, type.predict = "response") %>%
  select(mpg, am, propensity = .fitted) %>%
  mutate(ip_weight = (am / propensity) + ((1 - am) / (1 - propensity)))
```

```
## # A tibble: 32 x 4
##      mpg      am propensity ip_weight
##    <dbl> <dbl>      <dbl>    <dbl>
##  1    21      1    0.461      2.17
##  2    21      1    0.461      2.17
##  3   22.8      1    0.598      1.67
##  4   21.4      0    0.492      1.97
##  5   18.7      0    0.297      1.42
##  6   18.1      0    0.260      1.35
##  7   14.3      0    0.0986     1.11
##  8   24.4      0    0.708      3.43
##  9   22.8      0    0.598      2.49
## 10   19.2      0    0.330      1.49
### ... with 22 more rows
```

**Row 7 is highly unlikely to be manual and isn't.  
Boring! Low IPW.**

**Row 8 is highly likely to be manual, but isn't.  
That's weird! High IPW.**



# Examples!