

Multivariate regressions

Lecture 9

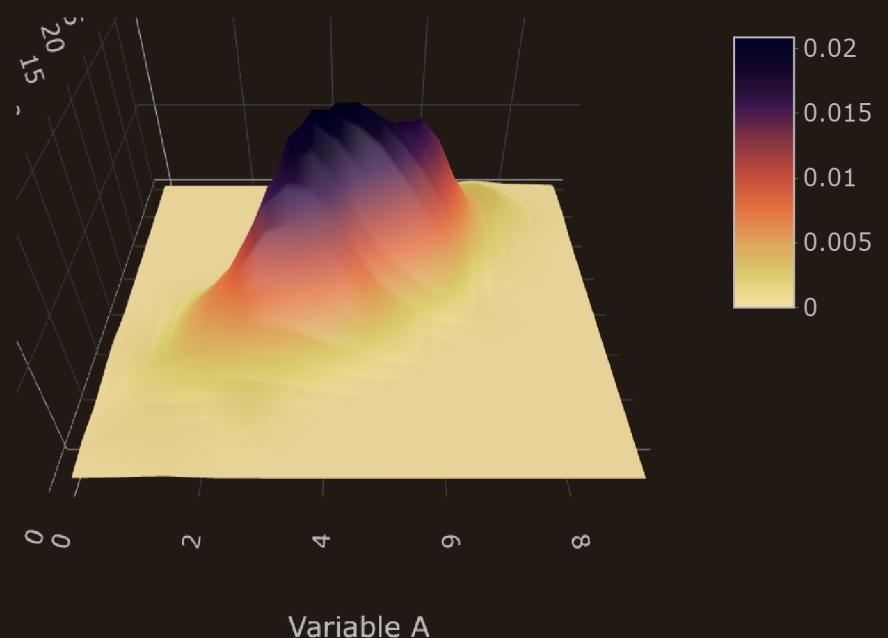
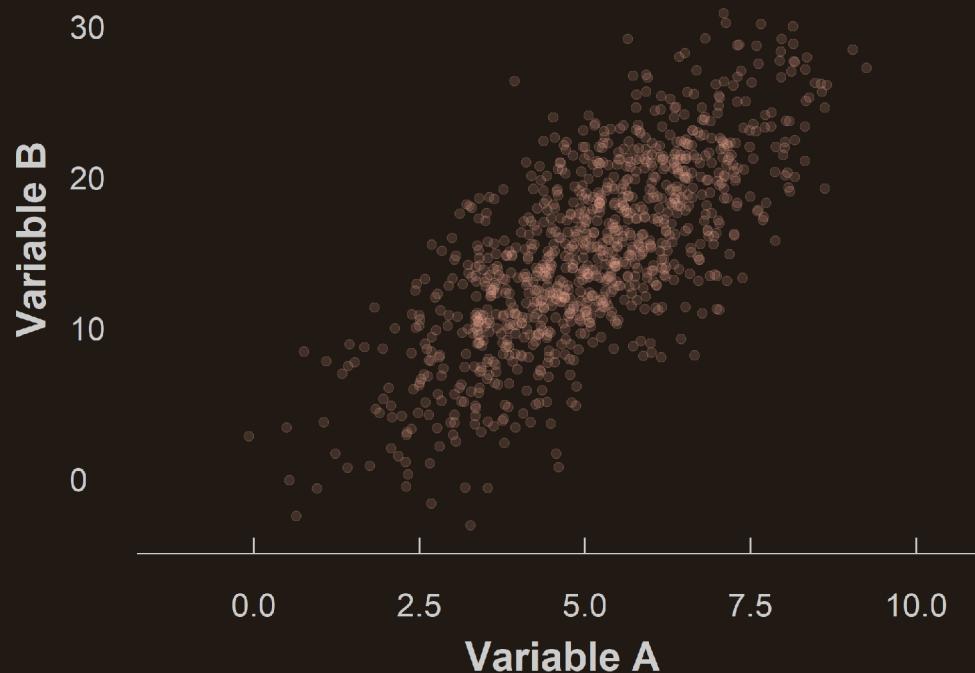
Louis SIRUGUE

CPES 2 - Fall 2022

Quick reminder

1. Joint distribution

The **joint distribution** shows the possible **values** and associated **frequencies** for **two variables** simultaneously





Quick reminder

1. Joint distribution

→ When describing a joint distribution, we're interested in the relationship between the two variables

- The **covariance** quantifies the joint deviation of two variables from their respective mean
 - It can take values from $-\infty$ to ∞ and depends on the unit of the data

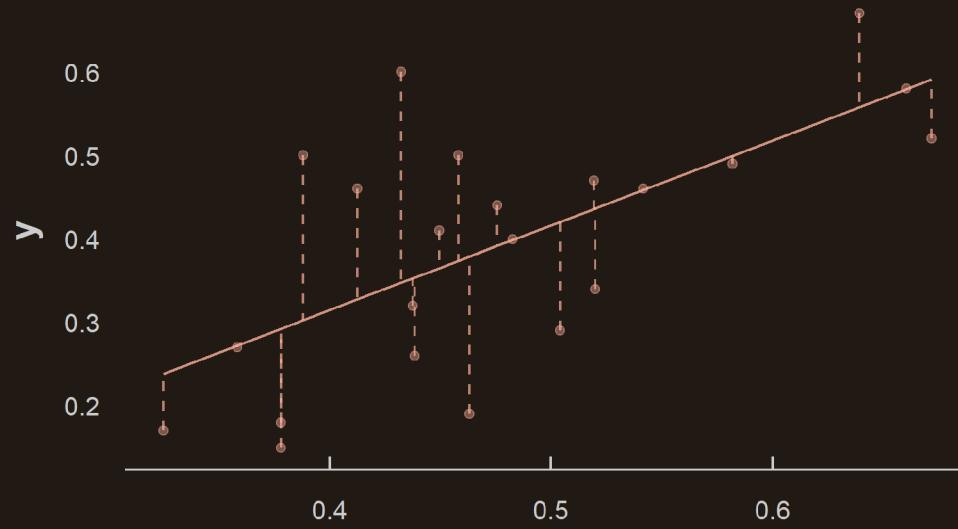
$$\text{Cov}(x, y) = \frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})(y_i - \bar{y})$$

- The **correlation** is the covariance of two variables divided by the product of their standard deviation
 - It can take values from -1 to 1 and is independent from the unit of the data

$$\text{Corr}(x, y) = \frac{\text{Cov}(x, y)}{\text{SD}(x) \times \text{SD}(y)}$$

Quick reminder

2. Regression



```
## 
## Call:
## lm(formula = y ~ x, data = data)
## 
## Coefficients:
## (Intercept)          x
## -0.09129        1.01546
```

- This can be expressed with the **regression equation**:

$$y_i = \hat{\alpha} + \hat{\beta}x_i + \hat{\varepsilon}_i$$

- Where $\hat{\alpha}$ is the **intercept** and $\hat{\beta}$ the **slope** of the **line** $\hat{y}_i = \hat{\alpha} + \hat{\beta}x_i$, and $\hat{\varepsilon}_i$ the **distances** between the points and the line

$$\hat{\beta} = \frac{\text{Cov}(x_i, y_i)}{\text{Var}(x_i)}$$

$$\hat{\alpha} = \bar{y} - \hat{\beta} \times \bar{x}$$

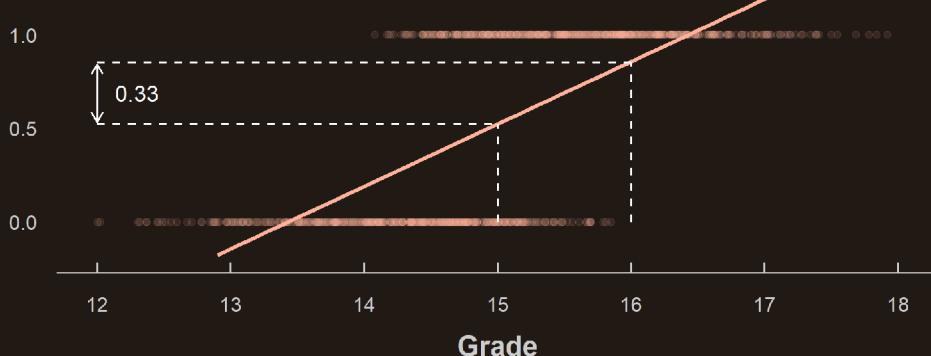
- $\hat{\alpha}$ and $\hat{\beta}$ minimize $\hat{\varepsilon}_i$

Quick reminder

3. Binary variables

Binary **dependent** variables

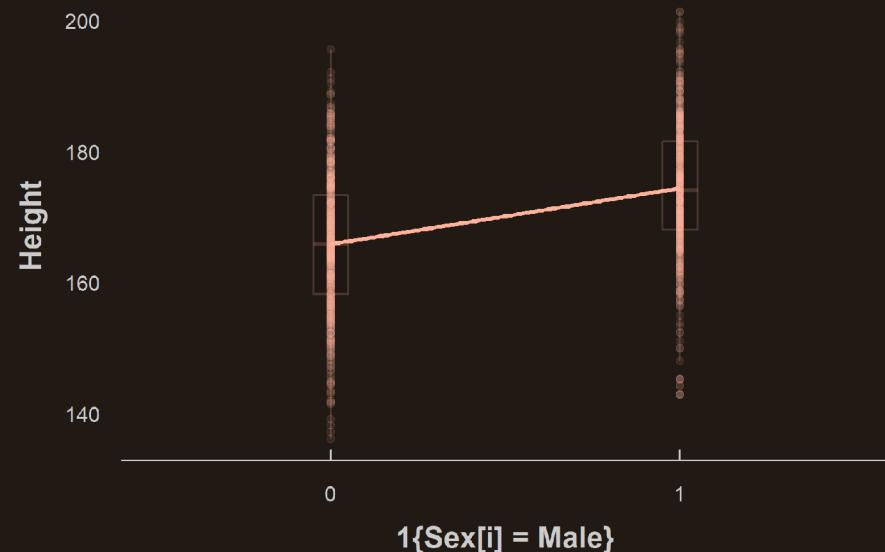
- The **fitted values** can be viewed as **probabilities**
 - $\hat{\beta}$ is the expected increase in the probability that $y = 1$ for a one unit increase in x



- We call that a **Linear Probability model**

Binary **independent** variables

- The x variable should be viewed as a **dummy 0/1**
 - $\hat{\beta}$ is the difference between the average y for the group $x = 1$ and the group $x = 0$



Warm up practice

10 : 00

- 1) Open the `asec.csv` data containing sex, race, weekly work hours, and annual earnings (\$)
- 2) Regress the earnings variable on the sex variable
- 3) Check that the slope coefficient is equal to the difference between male and female average earnings

You've got 10 minutes!

Solution

1) Open the `asec.csv` data containing sex, race, weekly work hours, and annual earnings (\$)

```
asec <- read.csv("asec.csv")
```

2) Regress the earnings variable on the sex variable

```
lm(Earnings ~ Sex, asec)
```

```
##  
## Call:  
## lm(formula = Earnings ~ Sex, data = asec)  
##  
## Coefficients:  
## (Intercept)      SexMale  
##           50915        21612
```

Solution

3) Check that the slope coefficient is equal to the difference between male and female average earnings

```
asec %>%  
  
  # Group the data by sex  
  group_by(Sex) %>%  
  
  # Summarise mean earnings -> 2x2 dataset  
  summarise(Mean = mean(Earnings)) %>%  
  
  # Put means in columns instead of rows -> 1x2 dataset  
  pivot_wider(names_from = Sex, values_from = Mean) %>%  
  
  # Compute the difference in means  
  mutate(Difference = Male - Female)
```

```
## # A tibble: 1 x 3  
##   Female   Male Difference  
##     <dbl>   <dbl>      <dbl>  
## 1 50915.  72527.    21612.
```



Today: Multivariate regressions

1. Adding variables

- 1.1. Continuous variables
- 1.2. Discrete variables

2. Control variables

- 2.1. Motivation
- 2.2. Discrete controls
- 2.3. Continuous controls

3. Interactions

- 3.1. Motivation
- 3.2. Discrete interactions
- 3.3. Continuous interactions

4. Wrap up!



Today: Multivariate regressions

1. Adding variables

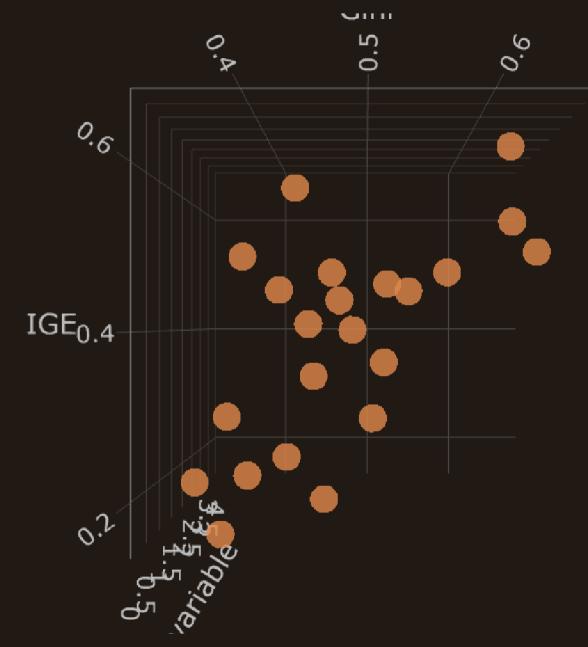
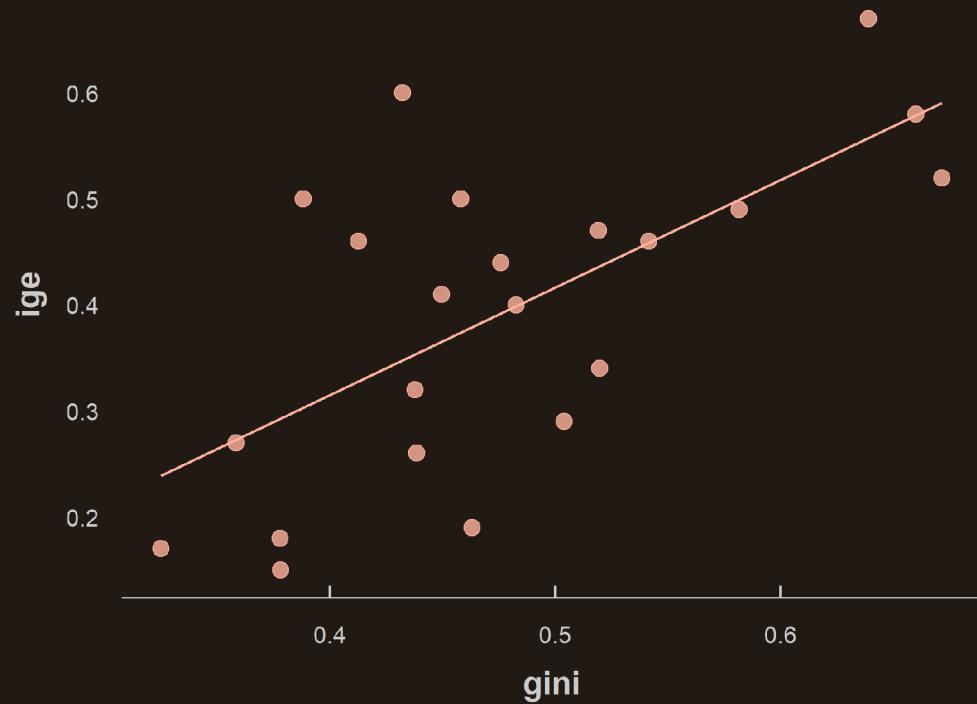
- 1.1. Continuous variables
- 1.2. Discrete variables



1. Adding variables

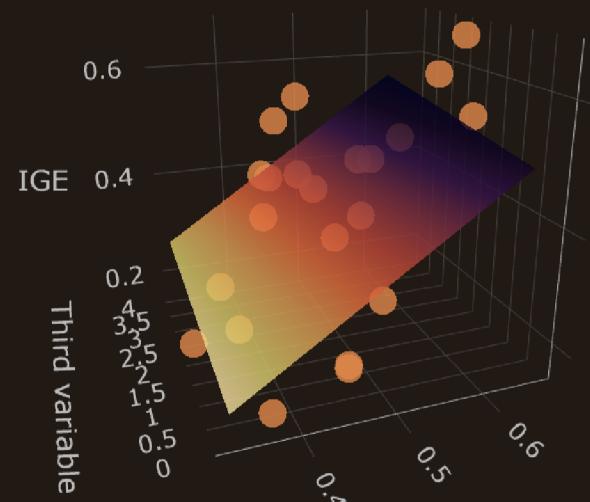
1.1. Continuous variables

- So far we focused on two-variable relationships
- What about three variable? (*pivot the plot*)



1. Adding variables

1.1. Continuous variables



- In this case we must fit a **plane**
 - It is characterized by **3 parameters**
 - And can be expressed as:
$$y_i = \hat{\alpha} + \hat{\beta}_1 x_{1,i} + \hat{\beta}_2 x_{2,i} + \hat{\varepsilon}_i$$
- $\hat{\alpha}$ is still the **intercept**
 - The value of \hat{y} (height) when $x_1 = x_2 = 0$
- And now there are **2 slopes**
 - $\hat{\beta}_1$ along the x_1 axis and $\hat{\beta}_2$ along the x_2 axis



1. Adding variables

1.1. Continuous variables

- The **same** applies with **more than 2** independent variables
 - We would fit a **hyperplane** with as many dimension as x variables
 - We would obtain one intercept and one slope per x variables

$$y_i = \hat{\alpha} + \hat{\beta}_1 x_{1,i} + \hat{\beta}_2 x_{2,i} + \dots + \hat{\beta}_k x_{k,i} + \hat{\varepsilon}_i$$

- We can estimate the parameters of these hyperplanes in **lm()**
 - **Additional variables** must be introduced after a **+ sign**

```
lm(ige ~ gini + third_variable, ggcurve)
```

```
##  
## Call:  
## lm(formula = ige ~ gini + third_variable, data = ggcurve)  
##  
## Coefficients:  
## (Intercept)          gini  third_variable  
## -0.09536           0.98153          0.01122
```



1. Adding variables

1.2. Discrete variables

- So far we've been working with **binary** categorical variables:
 - Accepted vs. Rejected, Male vs. Female
 - But what about discrete variables with **more than two categories?**
- Take for instance the **race** variable:

```
asec %>%  
  group_by(Race) %>%  
  tally()
```

```
## # A tibble: 3 x 2  
##   Race     n  
##   <chr> <int>  
## 1 Black    6835  
## 2 Other    6950  
## 3 White   50551
```

*How can we use this variable
as an independent variable
in our regression framework?*



1. Adding variables

1.2. Discrete variables

- Remember how we converted our **2-category** variable into **1 dummy** variable
 - We can convert an **n-category** variable into **n-1 dummy** variables

Sex	Male	Race	Black	Other
Female	0	White	0	0
Female	0	White	0	0
Female	0	Black	1	0
Male	1	Black	1	0
Male	1	Other	0	1
Male	1	Other	0	1

→ *But why do we omit one category every time?*

- Because it would be redundant
- We only need 2 dummies for 3 groups:
 - White:** Black = **0** & Other = **0**
 - Black:** Black = **1** & Other = **0**
 - Other:** Black = **0** & Other = **1**

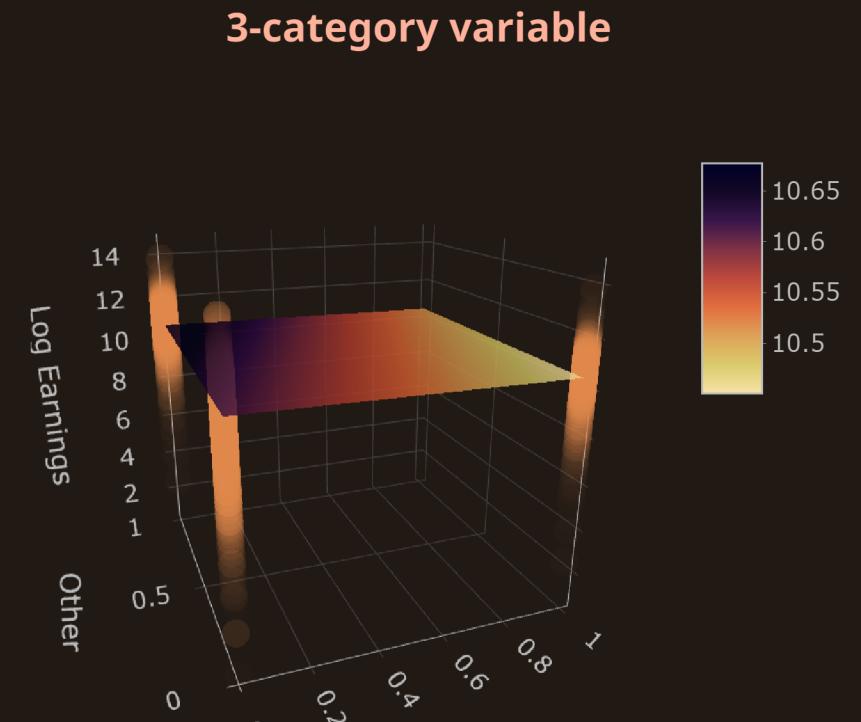
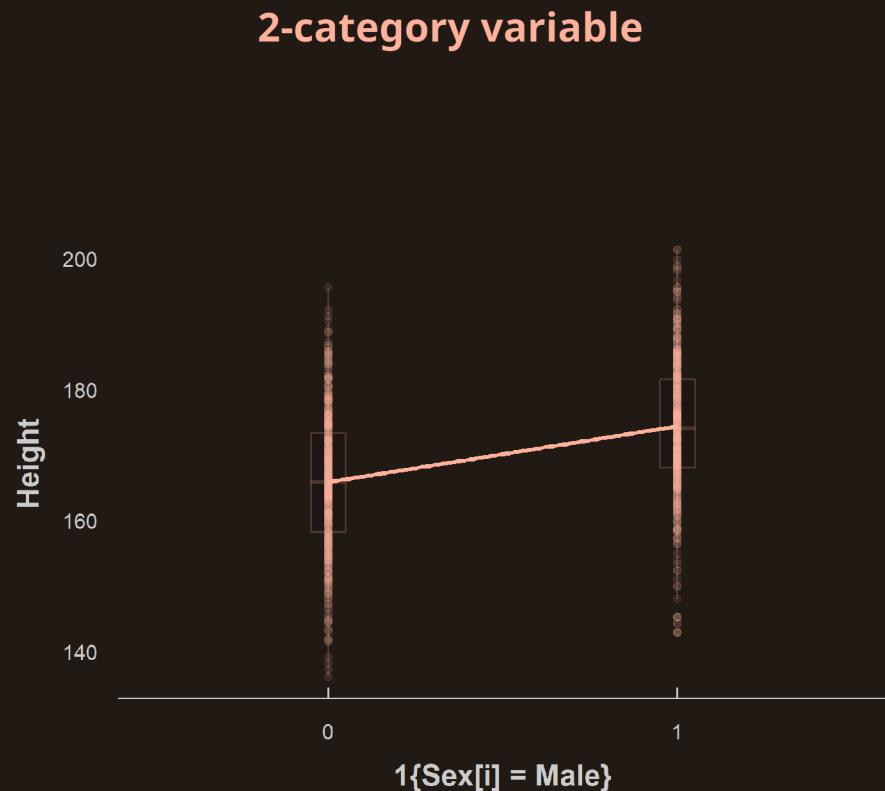
$\hat{\alpha}$ is the expected \hat{y} when $x_k = 0 \forall k$

- Thus it does the job for the omitted groups!
- This group is called the **reference group**
- $\hat{\beta}_k$ are interpreted **relative** to that group



1. Adding variables

1.2. Discrete variables





1. Adding variables

1.2. Discrete variables

- This **plane** can be expressed as:

$$\text{Earnings}_i = \hat{\alpha} + \hat{\beta}_1 1\{\text{Race}_i = \text{Other}\} + \hat{\beta}_2 1\{\text{Race}_i = \text{White}\} + \hat{\varepsilon}_i$$

- And the **average** incomes for each group equal:

- Black:** $\hat{\alpha} + 0\hat{\beta}_1 + 0\hat{\beta}_2 = \hat{\alpha}$
- Other:** $\hat{\alpha} + 1\hat{\beta}_1 + 0\hat{\beta}_2 = \hat{\alpha} + \hat{\beta}_1$
- White:** $\hat{\alpha} + 0\hat{\beta}_1 + 1\hat{\beta}_2 = \hat{\alpha} + \hat{\beta}_2$

```
##  
## Call:  
## lm(formula = Earnings ~ Race, data = asec)  
##  
## Coefficients:  
## (Intercept)    RaceOther    RaceWhite  
##      50577       17477       12303
```

		Average by group
Race	Mean earnings	
Black	50577.49	
Other	68054.63	
White	62880.49	



1. Adding variables

1.2. Discrete variables

- By **default**, `lm()` sorts categories by **alphabetical** order
 - So every coefficient should be **interpreted relative** to the group which is first alphabetically
- But usually this is **not** the most **intuitive**
 - You may want everything to be relative to the **majority group**
 - Or to any group that has reasons to be the **reference**
- The **relevel()** function allows you to **change the reference** category
 - But it works **only on factor** variables

```
asec <- asec %>%
  mutate(Race_fct = relevel(as.factor(Race),
                           "White"))

lm(Earnings ~ Race_fct, asec)
```

```
##
## Call:
## lm(formula = Earnings ~ Race_fct, data = asec)
##
## Coefficients:
##   (Intercept)  Race_fctBlack  Race_fctOther
##             62880           -12303            5174
```



1. Adding variables

1.2. Discrete variables

- The **factor class** is made for variables whose values **indicate** different **groups**
 - Values are just **arbitrary group classifiers**

```
individuals <- as.factor(c(1, 2, 3, 4, 5))
individuals[1]
```

```
## [1] 1
## Levels: 1 2 3 4 5
```

- With **factors**, R understands that the different values **do not mean anything**
 - And applying **standard operations** to factors **does not make sense**

```
individuals * 2
```

```
## Warning in Ops.factor(individuals, 2): '*' not meaningful for factors
## [1] NA NA NA NA NA
```



1. Adding variables

1.2. Discrete variables

- What you can also do is **create the dummies yourself**:

```
asec <- asec %>%
  mutate(Black = as.numeric(Race == "Black"),
        Other = as.numeric(Race == "Other"))
```

```
lm(Earnings ~ Black + Other, asec)
```

```
##  
## Call:  
## lm(formula = Earnings ~ Black + Other, data = asec)  
##  
## Coefficients:  
## (Intercept)      Black       Other  
##       62880     -12303      5174
```

→ This might be the **safest** option



1. Adding variables

1.2. Discrete variables

- But a **categorical** variable must **not** be introduced **as numeric** in `lm()`

```
asec <- asec %>%
  mutate(num_cat = case_when(Race == "White" ~ 0,
                             Race == "Black" ~ 1,
                             Race == "Other" ~ 2))
```

```
lm(Earnings ~ num_cat, asec)
```

```
##
## Call:
## lm(formula = Earnings ~ num_cat, data = asec)
##
## Coefficients:
## (Intercept)      num_cat
##       62093.8        119.6
```

→ `lm()` used our **categorical** variable as a **continuous** variable



1. Adding variables

1.2. Discrete variables

- Use the **factor** class

```
asec <- asec %>%
  mutate(fac_cat = as.factor(num_cat))
```

```
lm(Earnings ~ fac_cat, asec)
```

```
##
## Call:
## lm(formula = Earnings ~ fac_cat, data = asec)
##
## Coefficients:
## (Intercept)      fac_cat1      fac_cat2
##           62880        -12303         5174
```

→ *Converting all your **categorical** variables into **factors** is also a **safe** option*



Overview

1. Adding variables ✓

- 1.1. Continuous variables
- 1.2. Discrete variables

2. Control variables

- 2.1. Motivation
- 2.2. Discrete controls
- 2.3. Continuous controls

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4. Wrap up!



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2. Control variables

2.1. Motivation

- But **why** would we include **additional variables** in our regressions?
 - The main reason is to **control** for potential **confounders**
- Consider estimating the **relationship** between **income** and exposure air **pollution** in the Paris region

$$\text{Pollution}_i = \hat{\alpha}_1 + \hat{\beta}_1 \text{Income}_i + \hat{\varepsilon}_i$$

- You would probably expect that $\hat{\beta}_1 < 0$
 - Meaning that **higher income** earners live in **less polluted** areas
 - But the closer from **Paris** the higher the **rents** and the closer the **ring-road**
 - This phenomenon might counteract this effect and pull $\hat{\beta}_1$ towards 0
- But how to **remove** the **impact** that **distance** from Paris has on the relationship?
 - **Including it** in the regression would make the corresponding coefficient **absorb the confounding effect**
 - In that case we would call distance a **control variable**

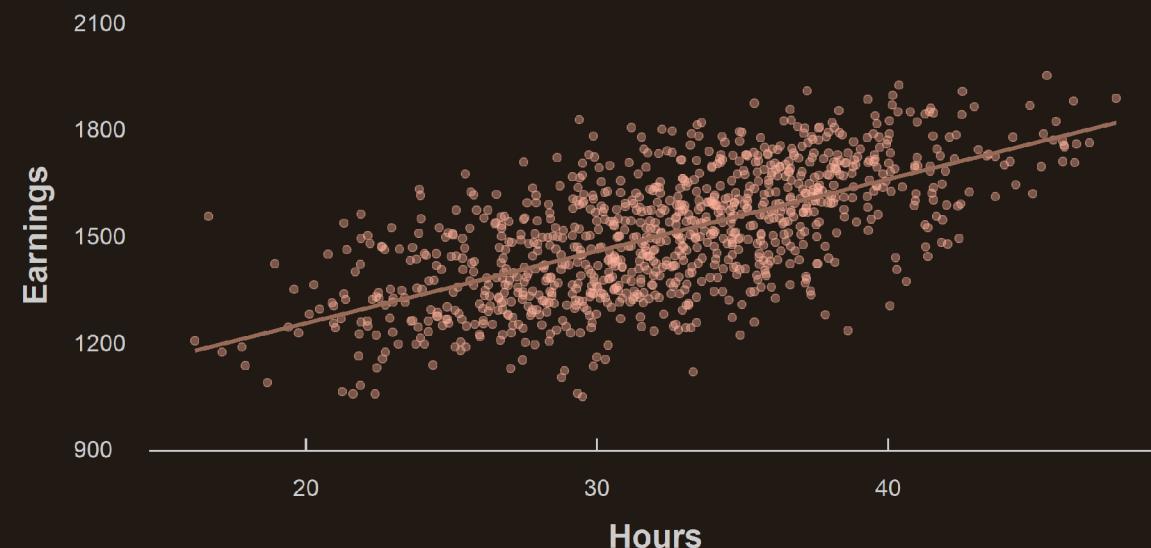
$$\text{Pollution}_i = \hat{\alpha}_2 + \hat{\beta}_2 \text{Income}_i + \hat{\beta}_3 \text{Distance}_i + \hat{\varepsilon}_i$$



2. Control variables

2.2. Discrete

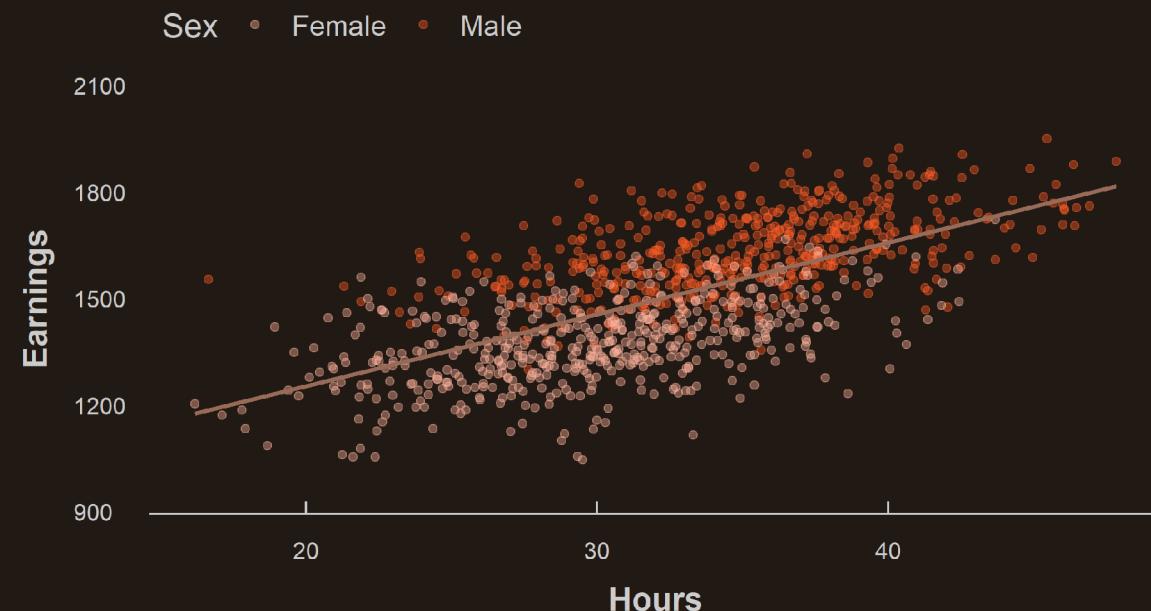
- The most **common control** variable is probably **sex/gender**
 - It may play a role in the **relationship** between **earnings** and **hours worked** for instance
 - The fact that **women** work **part time** more often and **earn less** contribute to the relationship
 - Just like distance did in the previous example



2. Control variables

2.2. Discrete

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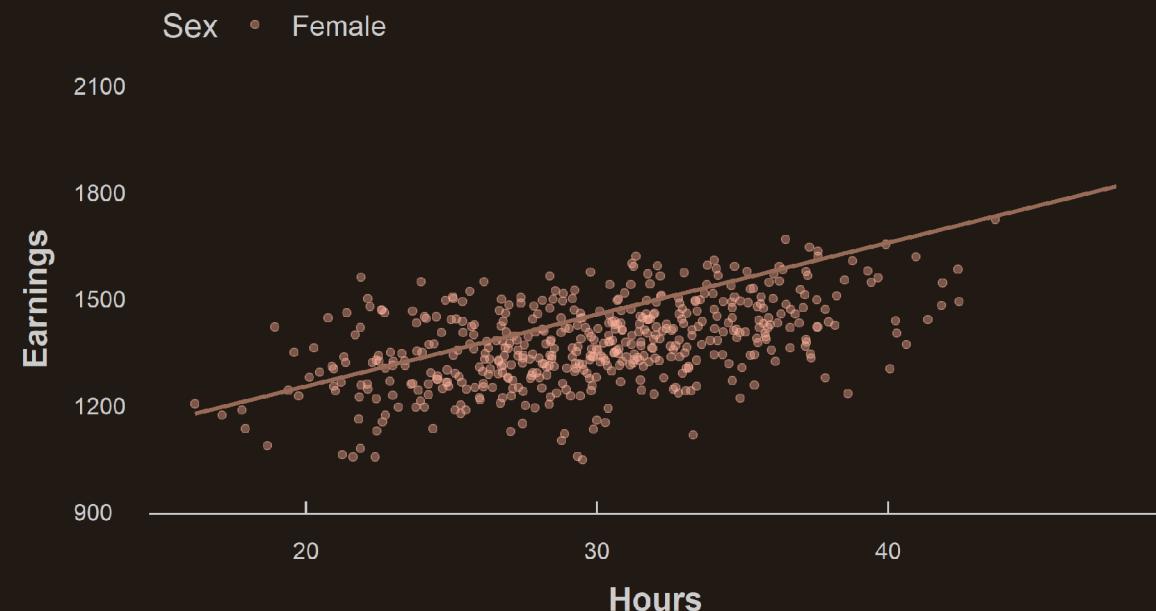




2. Control variables

2.2. Discrete

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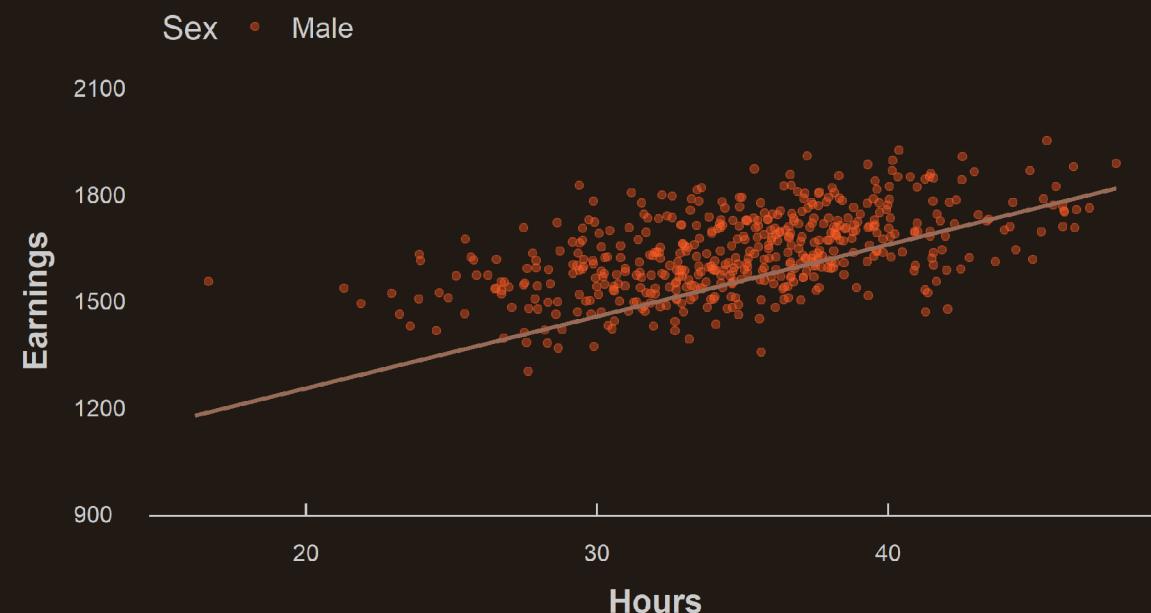




2. Control variables

2.2. Discrete

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 - It may play a role in the **relationship** between **earnings** and **hours worked** for instance
 - The fact that **women** work **part time** more often and **earn less** contribute to the relationship
 - Just like distance did in the previous example

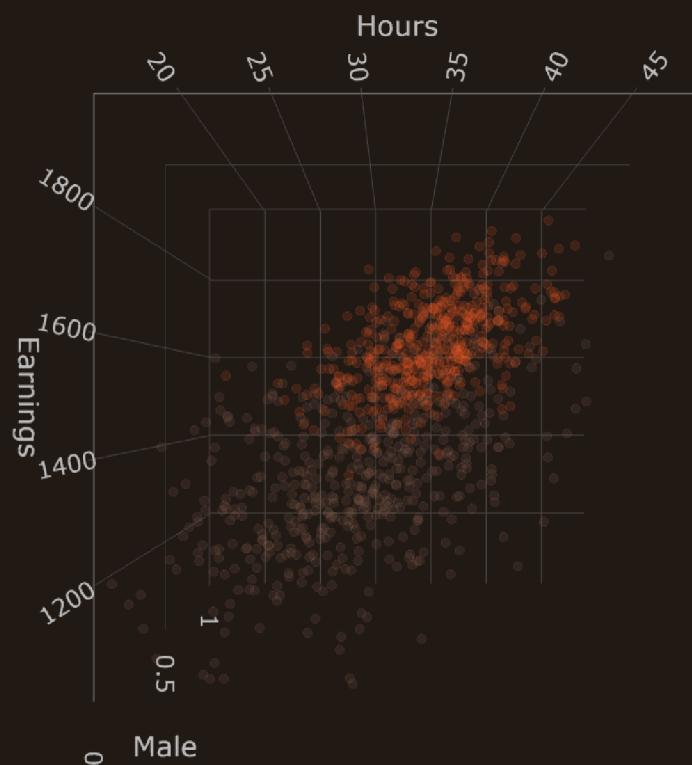


2. Control variables

2.2. Discrete

→ The **relationship** is indeed **inflated** by the sex variable

- Because being a **male** is positively **correlated** with **both x and y**
- **Controlling** for sex would **solve that problem** by absorbing this effect
- Controlling for a **discrete** variable amounts to allow **one intercept per category**
- Giving **two parallel fitted lines** which are the intersections of the plane and the scatterplots

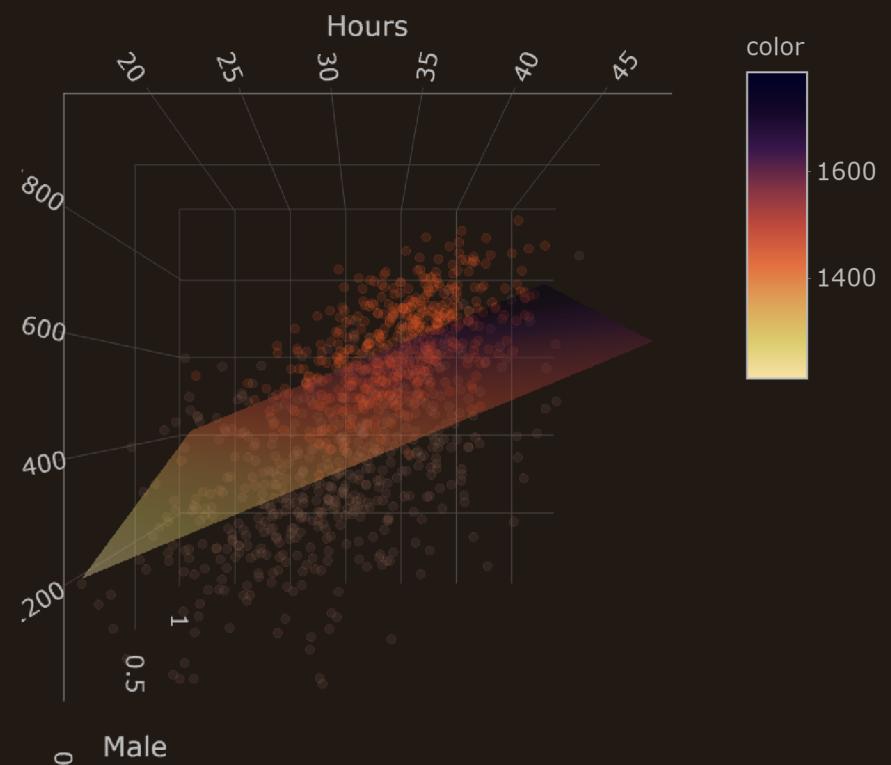


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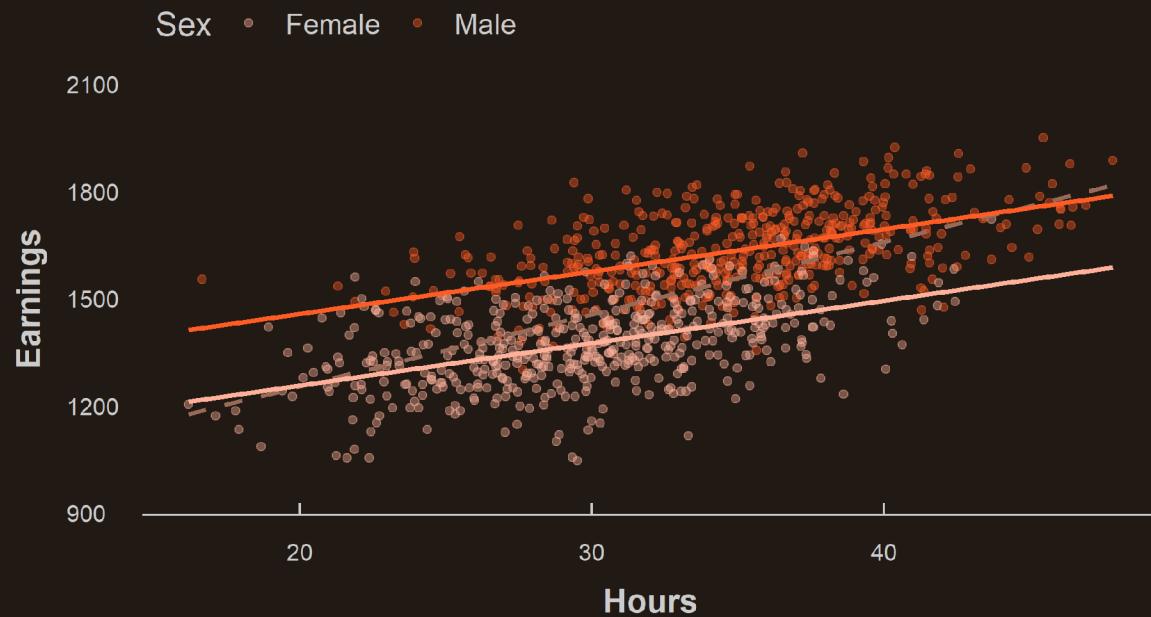


2. Control variables

2.2. Discrete

$$\text{Earnings}_i = \hat{\alpha} + \hat{\beta}_1 \text{Hours}_i + \hat{\beta}_2 \mathbf{1}\{\text{Sex}_i = \text{Male}\} + \hat{\varepsilon}_i$$

```
## (Intercept)          Hours      SexMale
## 1019.34269       11.86326    200.98782
```



Graphical counterpart

$\hat{\alpha}$: Intercept of the reference group

$\hat{\beta}_1$: Common slope

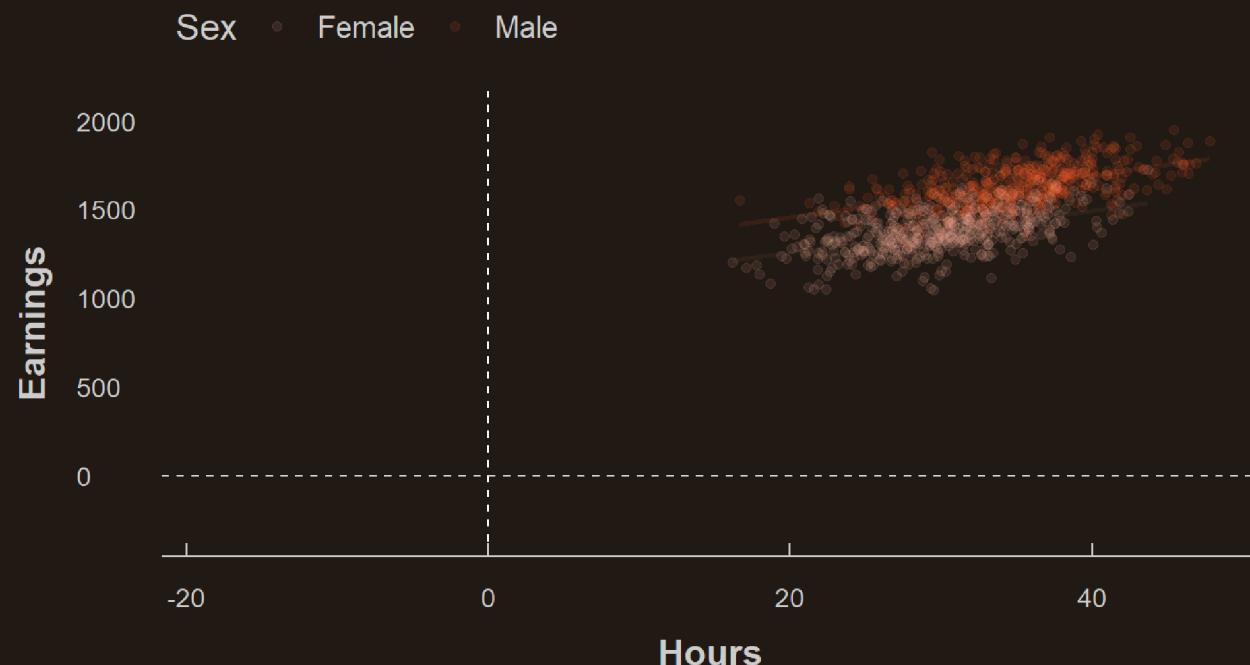
$\hat{\beta}_2$: Gap between the two lines

$\hat{\alpha} + \hat{\beta}_2$: Intercept of the other group

2. Control variables

2.2. Discrete

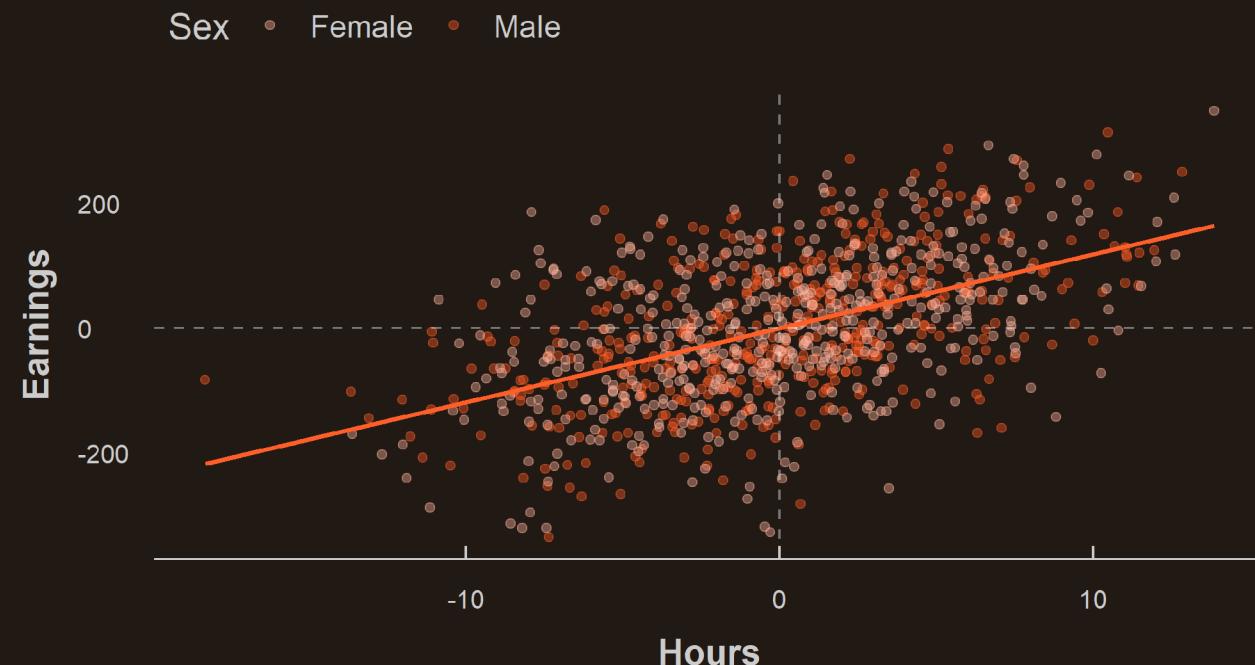
- We can **obtain** this common **slope** by:
 1. **Demeaning** earnings and hours by group
 2. **Regressing** the demeaned earnings on the hours



2. Control variables

2.2. Discrete

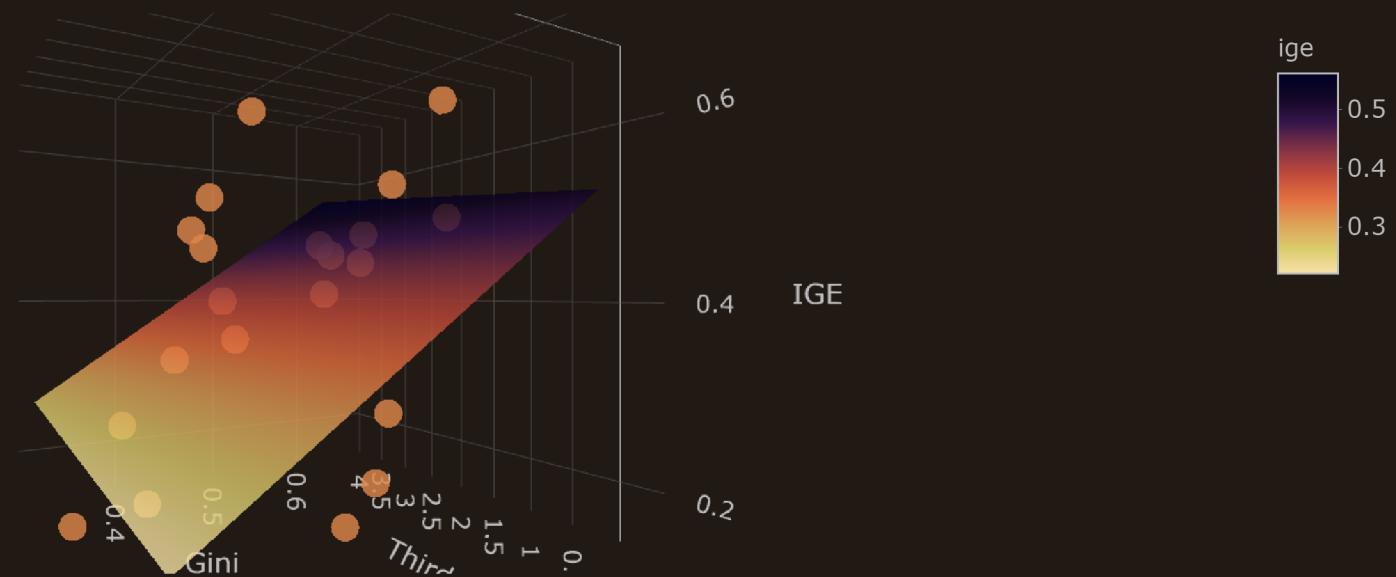
- Note that once we **control** for third variable
 1. As we move along the x axis, this **third variable remains constant**
 2. Here, as the number of **hours increases** the probability to be a **male does not increase anymore**



2. Control variables

2.3. Continuous

- The **same** idea apply when we control for **continuous** variables
 - Including it in the regression allows to **account for another dimension**
 - Such that when x moves this variable **remains constant**
 - This **nets out** the relationship between x and y from the potential **confounding effect** of this variable
 - This is why we call it **controlling for something**



Practice

08 : 00

1) Using the `asec` data, regress (yearly) earnings on (weekly) hours worked

2) Regress earnings on hours worked controlling for sex

3) Interpret the difference between the results from 1) and 2)

You've got 8 minutes!

Solution

1) Using the asec data, regress (yearly) earnings on (weekly) hours worked

```
lm(Earnings ~ Hours, asec)$coefficients
```

```
## (Intercept)      Hours  
## -20038.85     2077.79
```

2) Regress earnings on hours worked controlling for sex

```
lm(Earnings ~ Hours + Sex, asec)$coefficients
```

```
## (Intercept)      Hours      SexMale  
## -22296.150    1953.829   13794.385
```

Solution

3) Interpret the difference between the results from 1) and 2)

- The **slope** is still positive **less steep**
 - In the **first regression** as the number of **hours increases** the probability to be a **male** **does increase** as well
 - Because **males** tend to **earn more** this **contributes** to the positive **relationship** between Hours and Earnings
 - In the **second regression, controlling** for sex allows to maintain the probability to be a **male constant** along the hour axis to **remove this effect**



Overview

1. Adding variables ✓

- 1.1. Continuous variables
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- 2.1. Motivation
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3. Interactions

3.1. Motivation

- Now we know how to **remove** the **confounding effect** of a third variable by **controlling** for it
 - But what if the main **relationship varies** depending on the value of the **third variable**?
- Let's get back to the previous example

$$\text{Pollution}_i = \hat{\alpha} + \hat{\beta}_1 \text{Income}_i + \hat{\beta}_2 \text{Distance}_i + \hat{\epsilon}_i$$

- The **equation imposes** that the **effect** of income on pollution is **constant**: $\hat{\beta}_2$
 - But what if the relationship was actually not the same close to Paris than further away?
 - Maybe that the closer from Paris the larger the effect (higher segregation, ...)
- But how to **capture how the relationship** between income and pollution varies with distance?
 - We should allow for it in the equation!
 - By **adding a term** that depends both on income and distance
 - What we use is their **product**, and we call that an **interaction**

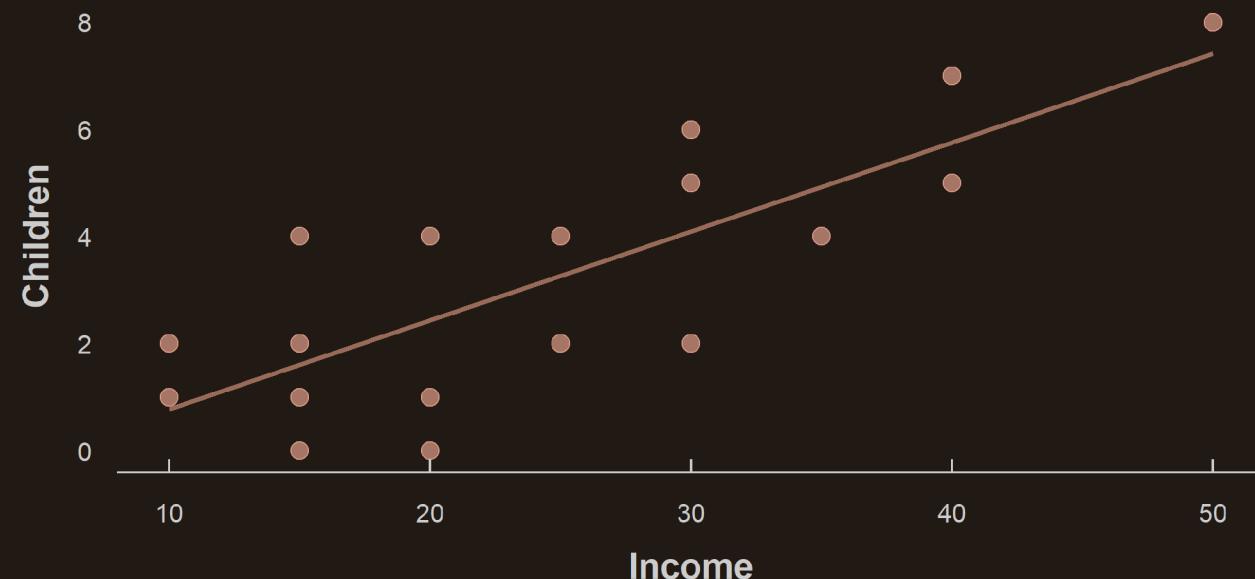
$$\text{Pollution}_i = \hat{\alpha}_2 + \hat{\beta}_3 \text{Income}_i + \hat{\beta}_4 \text{Distance}_i + \hat{\beta}_5 (\text{Distance}_i \times \text{Income}_i) + \hat{\epsilon}_i$$



3. Interactions

3.2. Discrete

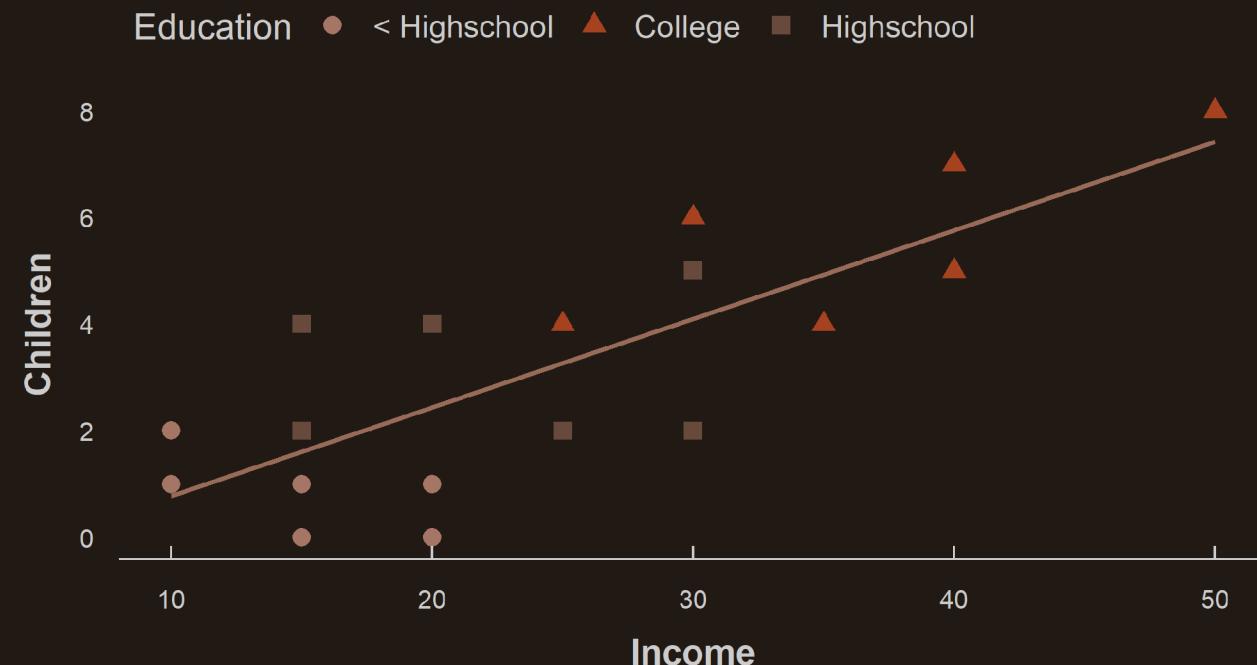
- Take for instance the following **relationship** between **household income** and the **number of children**



3. Interactions

3.2. Discrete

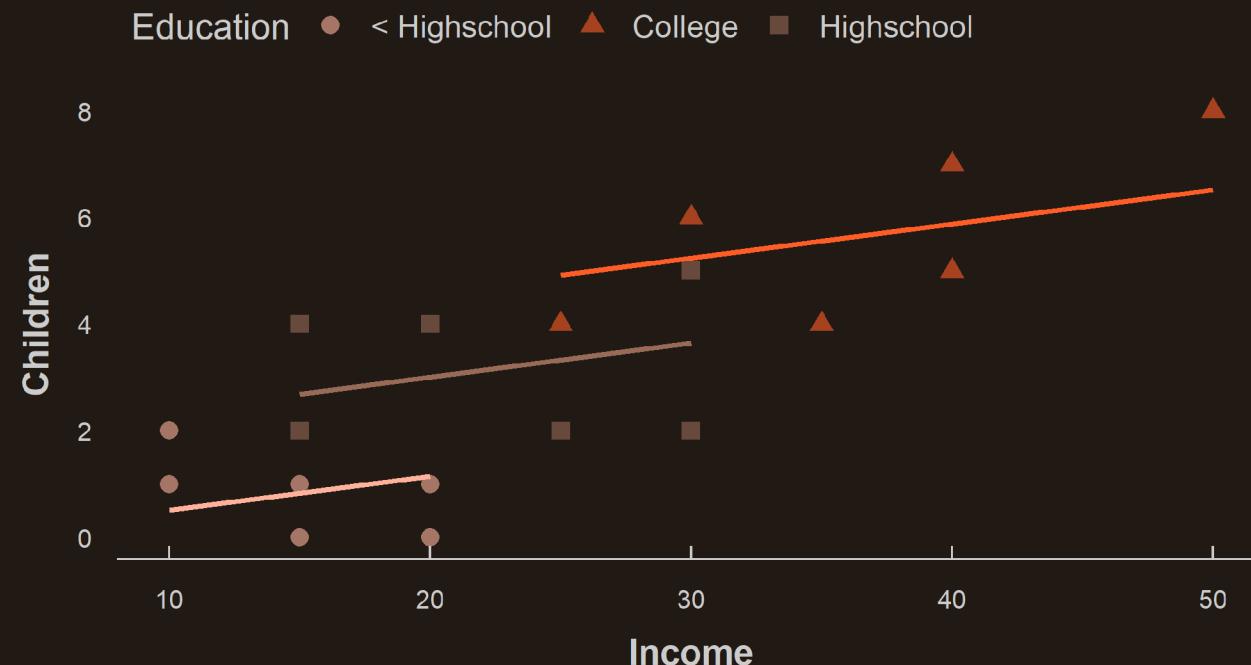
- Take for instance the following **relationship** between **household income** and the **number of children**
 - The level of **education** seems to **play a role** in the relationship



3. Interactions

3.2. Discrete

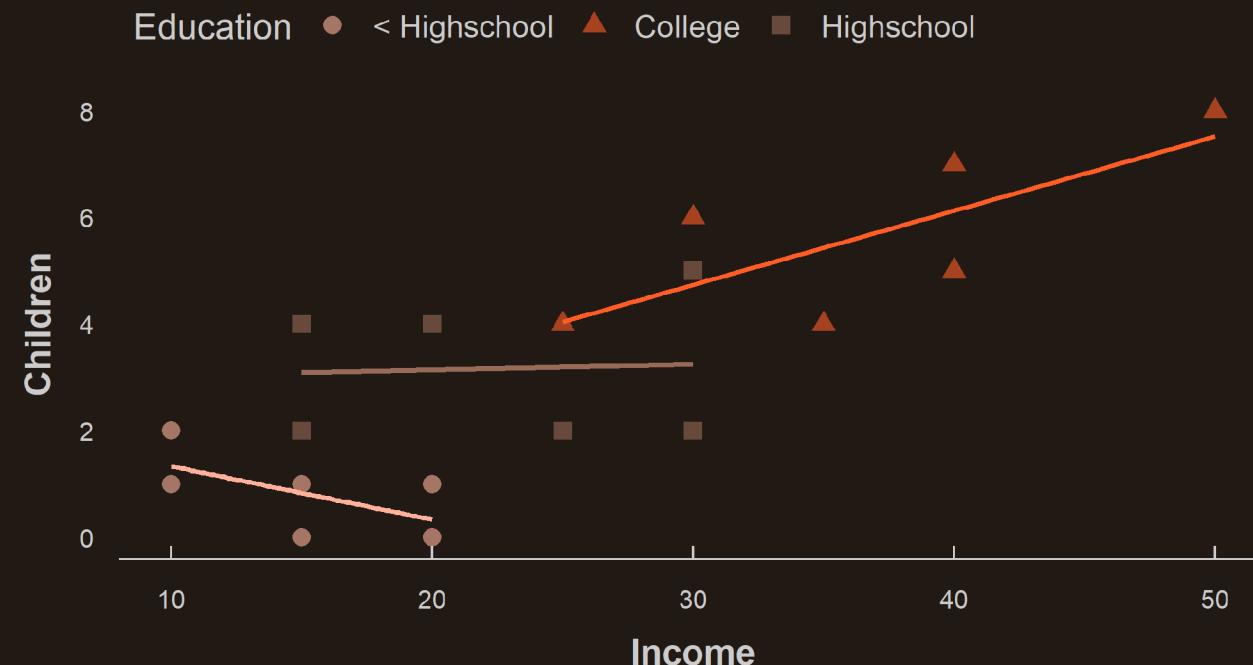
- Take for instance the following **relationship** between **household income** and the **number of children**
 - The level of **education** seems to **play a role** in the relationship
 - But simply **controlling** for education does **not** seem **sufficient**



3. Interactions

3.2. Discrete

- This is because the **relationship** between income and children **varies with education**
 - **Interacting** income with education allows to **account for that**
 - Like **controlling** allows for **different intercepts**, **interacting** allows for **different slopes**





3. Interactions

3.2. Discrete

→ It is clearly **equivalent to regressing children on income separately per education group**

$$\text{Income}_i = \hat{\alpha} + \hat{\beta}_1 \text{Children}_i + \quad \text{Baseline equation}$$

$$+ \hat{\beta}_2 (<\text{Highschool})_i + \hat{\beta}_3 \text{Highschool}_i + \hat{\beta}_4 \text{College}_i + \quad \text{Allow for } \neq \text{slopes}$$

$$\text{Children}_i \times \left[\hat{\beta}_5 (<\text{Highschool})_i + \hat{\beta}_6 \text{Highschool}_i + \hat{\beta}_7 \text{College}_i \right] + \hat{\varepsilon}_i \quad \text{Allow for } \neq \text{intercepts}$$



3. Interactions

3.2. Discrete

→ It is clearly **equivalent to regressing children on income separately per education group**

$$\text{Income}_i = \hat{\alpha} + \hat{\beta}_1 \text{Children}_i + \underbrace{\hat{\beta}_2 (<\text{Highschool})_i}_{1} + \underbrace{\hat{\beta}_3 \text{Highschool}_i}_{0} + \underbrace{\hat{\beta}_4 \text{College}_i}_{0} + \text{Baseline equation}$$

$$\hat{\beta}_2 (\underbrace{<\text{Highschool}}_1)_i + \hat{\beta}_3 \underbrace{\text{Highschool}_i}_0 + \hat{\beta}_4 \underbrace{\text{College}_i}_0 + \text{Allow for } \neq \text{slopes}$$

$$\text{Children}_i \times \left[\underbrace{\hat{\beta}_5 (<\text{Highschool})_i}_1 + \underbrace{\hat{\beta}_6 \text{Highschool}_i}_0 + \underbrace{\hat{\beta}_7 \text{College}_i}_0 \right] + \hat{\varepsilon}_i \quad \text{Allow for } \neq \text{intercepts}$$

< Highschool: $\text{Income}_i = (\hat{\alpha} + \hat{\beta}_2) + (\hat{\beta}_1 + \hat{\beta}_5) \text{Children}_i + \hat{\varepsilon}_i$



3. Interactions

3.2. Discrete

→ It is clearly **equivalent to regressing children on income separately per education group**

$$\text{Income}_i = \hat{\alpha} + \hat{\beta}_1 \text{Children}_i + \hat{\beta}_2 \underbrace{(<\text{Highschool})_i}_{0} + \hat{\beta}_3 \underbrace{\text{Highschool}_i}_{1} + \hat{\beta}_4 \underbrace{\text{College}_i}_{0} + \text{Baseline equation}$$
$$\text{Children}_i \times \left[\hat{\beta}_5 \underbrace{(<\text{Highschool})_i}_{0} + \hat{\beta}_6 \underbrace{\text{Highschool}_i}_{1} + \hat{\beta}_7 \underbrace{\text{College}_i}_{0} \right] + \hat{\varepsilon}_i \quad \text{Allow for } \neq \text{slopes}$$
$$\text{Allow for } \neq \text{intercepts}$$

Highschool: $\text{Income}_i = (\hat{\alpha} + \hat{\beta}_3) + (\hat{\beta}_1 + \hat{\beta}_6) \text{Children}_i + \hat{\varepsilon}_i$



3. Interactions

3.2. Discrete

→ It is clearly **equivalent to regressing children on income separately per education group**

$$\text{Income}_i = \hat{\alpha} + \hat{\beta}_1 \text{Children}_i + \underbrace{\hat{\beta}_2 (<\text{Highschool})_i}_{0} + \underbrace{\hat{\beta}_3 \text{Highschool}_i}_{0} + \underbrace{\hat{\beta}_4 \text{College}_i}_{1} + \varepsilon_i \quad \text{Baseline equation}$$

$$\text{Children}_i \times \left[\underbrace{\hat{\beta}_5 (<\text{Highschool})_i}_{0} + \underbrace{\hat{\beta}_6 \text{Highschool}_i}_{0} + \underbrace{\hat{\beta}_7 \text{College}_i}_{1} \right] + \hat{\varepsilon}_i \quad \text{Allow for } \neq \text{slopes}$$

$$\text{College: } \text{Income}_i = (\hat{\alpha} + \hat{\beta}_4) + (\hat{\beta}_1 + \hat{\beta}_7) \text{Children}_i + \hat{\varepsilon}_i \quad \text{Allow for } \neq \text{intercepts}$$



3. Interactions

3.2. Discrete

→ It is clearly **equivalent to regressing children on income separately per education group**

$$\text{Income}_i = \hat{\alpha} + \hat{\beta}_1 \text{Children}_i + \quad \text{Baseline equation}$$

$$+ \hat{\beta}_2 (<\text{Highschool})_i + \hat{\beta}_3 \text{Highschool}_i + \hat{\beta}_4 \text{College}_i + \quad \text{Allow for } \neq \text{slopes}$$

$$\text{Children}_i \times \left[\hat{\beta}_5 (<\text{Highschool})_i + \hat{\beta}_6 \text{Highschool}_i + \hat{\beta}_7 \text{College}_i \right] + \hat{\varepsilon}_i \quad \text{Allow for } \neq \text{intercepts}$$

< Highschool: $\text{Income}_i = (\hat{\alpha} + \hat{\beta}_2) + (\hat{\beta}_1 + \hat{\beta}_5) \text{Children}_i + \hat{\varepsilon}_i$

Highschool: $\text{Income}_i = (\hat{\alpha} + \hat{\beta}_3) + (\hat{\beta}_1 + \hat{\beta}_6) \text{Children}_i + \hat{\varepsilon}_i$

College: $\text{Income}_i = (\hat{\alpha} + \hat{\beta}_4) + (\hat{\beta}_1 + \hat{\beta}_7) \text{Children}_i + \hat{\varepsilon}_i$



3. Interactions

3.3. Continuous

- The **same principle** applies to **continuous variables**:

$$\text{Pollution}_i = \hat{\alpha} + \hat{\beta}_1 \text{Income}_i + \hat{\beta}_2 \text{Distance}_i + \hat{\beta}_3 (\text{Distance}_i \times \text{Income}_i) + \hat{\epsilon}_i$$

- What is the **effect of** a 1-unit increase in **income here**?

$$\hat{\beta}_1 + \hat{\beta}_3 \text{Distance}_i$$

- The **coefficient** associated with the **interaction**, $\hat{\beta}_3$, indicates:
 - By how the **effect** of a 1-unit increase in **income** on pollution **varies with distance**
 - When **distance = 0** the effect of income is $\hat{\beta}_1$
 - For every **additional unit** of distance, the effect of income on pollution **increases by** $\hat{\beta}_3$

→ *Don't omit to include your interaction variable as a control in the regression*



Overview

1. Adding variables ✓

- 1.1. Continuous variables
- 1.2. Discrete variables

2. Control variables ✓

- 2.1. Motivation
- 2.2. Discrete controls
- 2.3. Continuous controls

3. Interactions ✓

- 3.1. Motivation
- 3.2. Discrete interactions
- 3.3. Continuous interactions

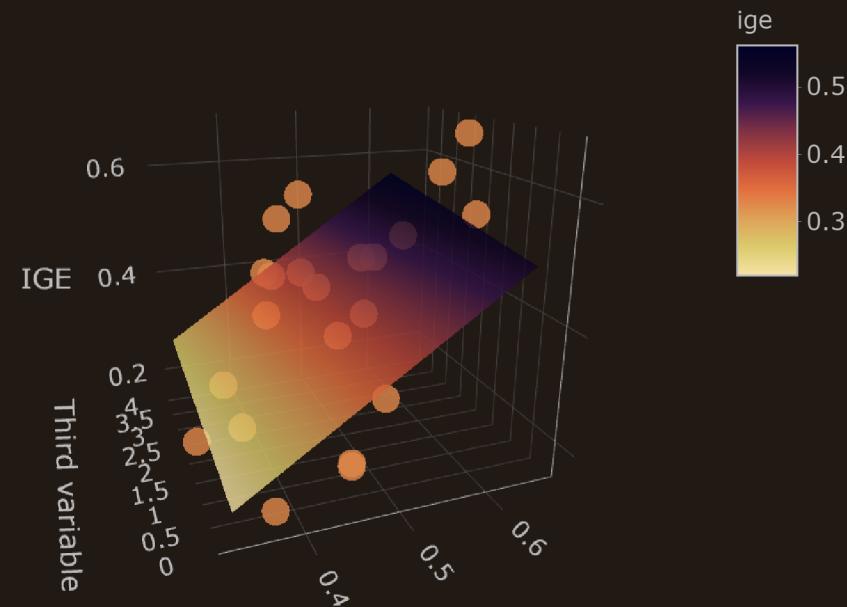
4. Wrap up!

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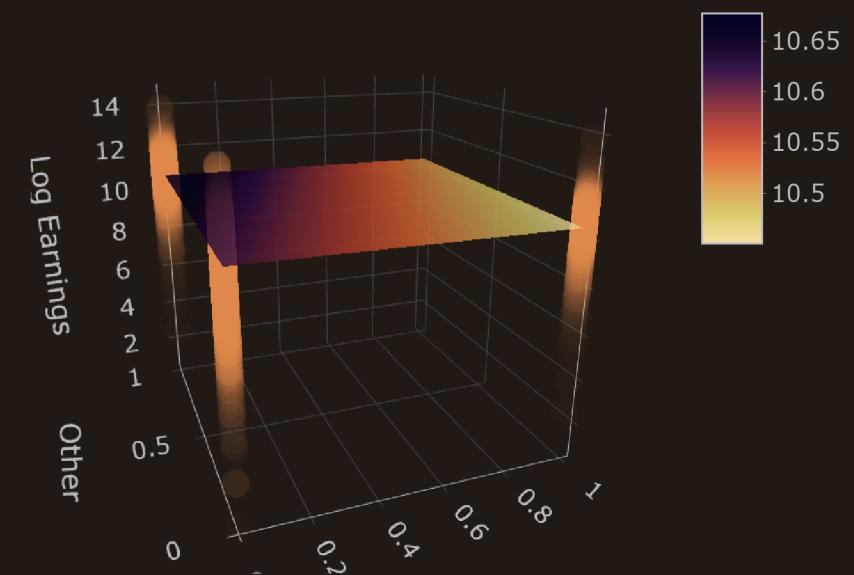
1. Multivariate regressions

- Adding a second independent **variable** in the regression amounts to **fitting a plane** instead of a line
 - Adding a third variable would fit an hyperplane of dimension 3 and so on

Adding a continuous variable



Adding a discrete variable

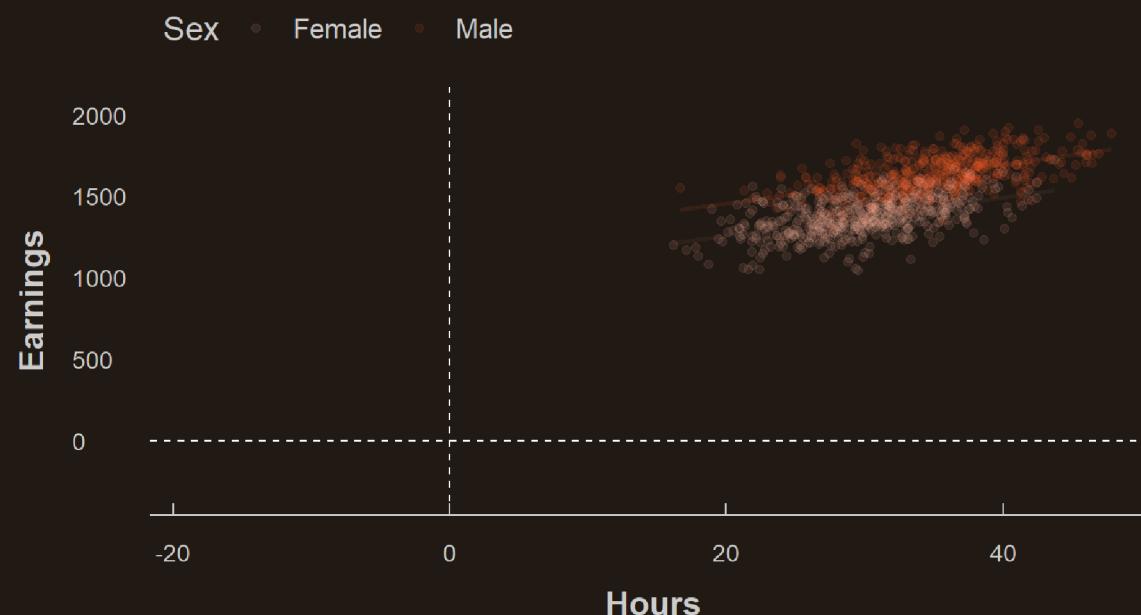


4. Wrap up!

2. Control variables

- Adding a third variable z **removes** its potential **confounding effect** from the relationship between x and y
 - As we move along the x axis, the **third variable remains constant**

$$\hat{y}_i = \hat{\alpha} + \hat{\beta}_1 x + \hat{\beta}_2 z + \hat{\varepsilon}_i$$



4. Wrap up!

3. Interactions

- Adding an **interaction** term with z allows to see **how the effect** of x on y **varies** with z
 - If z is **discrete**, it amounts to **regressing** y on x **separately** for each z group

$$\hat{y}_i = \hat{\alpha} + \hat{\beta}_1 x + \hat{\beta}_2 z + \hat{\beta}_3(x \times z) + \hat{\varepsilon}_i$$

