

## Class 15 Endogeneity

Dr Wei Miao

UCL School of Management

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## Section 1

**Causal Inference with OLS**

# Causal Effect from Linear Regression Models

- **Task:** Tesco would like to understand the causal impact of customer *Income* on customer *Spending*
- Please run the two regressions on your laptop:
  - Regression 1:  $Spending \sim Income$
  - Regression 2:  $Spending \sim Income + Kidhome$

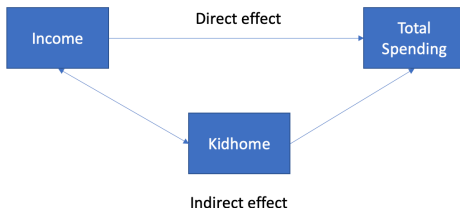
## Regression Results

	Model 1	Model 2
(Intercept)	−556.823*** (21.654)	−299.119*** (28.069)
Income	0.022*** (0.000)	0.019*** (0.000)
Kidhome		−230.610*** (16.945)
Num.Obs.	2000	2000
R <sup>2</sup>	0.629	0.661
R <sup>2</sup> Adj.	0.629	0.660
AIC	29 308.1	29 132.7
BIC	29 324.9	29 155.1
RMSE	367.45	351.51
Std.Errors	IID	IID

+  $p < 0.1$ , \*  $p < 0.05$ , \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$

- **Question:** if we want to evaluate income's causal effect on spending, which value (0.022, 0.019) should we use?

# Direct and Indirect Effects



- Direct Effect (causal effect)
  - Keeping other variables fixed (ceteris paribus)
  - Direct effect only
- Total Effect
  - Including side effects through other variables
  - Direct + indirect effects

## Causal Inference from Regression Models

- To obtain causal inference, we need to obtain the **direct effects** of an  $X$  variable on the outcome variable  $Y$ .
- **Total effects** include both direct effects and indirect effects (i.e., the impacts of other confounding variables).
- Therefore, it is important to include **all confounding variables**, which affect income and total spending at the same time, to control for the side effects from other variables.

## Practical Suggestions for Running Regression Models

- For causal inference tasks, we need to use business senses to decide which confounding variables to control, but the safest way is to include everything we have in the data.
- Sometimes, control variables may be statistically insignificant, they should **NOT** be removed because they still serve the purpose of control variables.
- If some variables are mechanically correlated, then we should not put all of them in the regression, to avoid perfect collinearity problems.

*Question: what is the best you can do with `data_full` to estimate the causal effect of income on spending?*

## Causal Inference from Regressions

Now we have included `Kidhome` to tease out the effect of kids, what problems do we still have which hinder us from getting causal effect of income on total spending?

- Due to data availability, we are never able to include all confounding variables in the regression.
- Strictly speaking, we can **never obtain causal effects from simple regression models** based on **non-experiment data**.
- Mathematically speaking, because we can never control all confounding factors, the error term is very likely to be correlated with income, violating  $E[\epsilon|X] = 0$ .



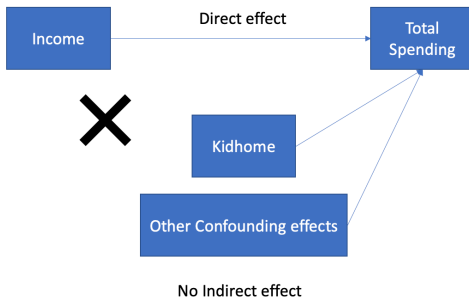
# RCTs and Causal Inference

- Why RCTs are the gold standard for causal inference?
  - If we are able to randomize people into different income groups, we can then collect the `total_spending` for each individual in each `income` group.
  - We can run a linear regression to examine the impact of `income` on `total_spending`.

$$Spending = \beta_0 + \beta_1 Income + \epsilon$$

- In the above regression
  - Are there still any confounding effects?
  - Is *Income* correlated with any of the confounding effects?

## RCTs and Causal Inference (cont.)



## Section 2

# Endogeneity and Its Causes

# Endogeneity

## Endogeneity

Endogeneity refers to an econometric issue with OLS linear regression, in which an explanatory variable is correlated with the error term, such that the requirement for OLS linear regression  $E[\epsilon|X] = 0$  is violated.

## Cause I: Omitted Variable Bias

### Omitted Variable Bias (OVB)

An omitted variable is a determinant of the outcome variable  $y_i$  that is correlated with the focal explanatory variable  $x_i$ , but is not included in the regression, either due to data unavailability or ignorance of data scientists.

Two conditions for omitted variable bias

- The variable affects the dependent variable.
- The variable is correlated with the focal explanatory variable.

## Examples of OVB

- If we would like to understand the causal effect of years in education on a person's salary.

$$Salary_t = \beta_0 + \beta_1 Education_t + \epsilon_t$$

- Can we get causal effect from this regression? What would be the issue here?

## Examples of OVB

- When building Marketing Mix Modeling, the common practice in the industry is to regress the sales in each period on the price in each period.

$$Sales_t = \beta_0 + \beta_1 Price_t + \epsilon_t$$

- However, is this regression correct?
  - Very often, if we regress sales on price, we get a positive coefficient for price.

## Cause II: Reverse Causality (Simultaneity)

### Reverse Causality

Reverse causality refers to the phenomenon that the independent variable  $X_i$  affects the dependent variable  $y_i$  and the dependent variable  $y_i$  also affects the independent variable  $X_i$  at the same time.

"The Usual"



Reverse Causality



Simultaneity





## Examples of Reverse Causality (Simultaneity)

- Besides potential omitted variable biases, there may also exist reverse causality problems with marketing mix modelling.

$$Sales_t = \beta_0 + \beta_1 Price_t + \epsilon_t$$

- Price affects demand, and demand affects sellers' price setting decisions.
  - Higher price leads to lower sales. ( $X \Rightarrow Y$ )
  - If sellers expect higher demand, sellers may increase the price to increase profits. ( $Y \Rightarrow X$ )

## Examples of Reverse Causality (Simultaneity)

- UberEat interview question: If we have historical data on **number of restaurants on UberEat** in each month, and **the total number of orders in each month**, can we run an OLS regression to get the causal effect?

$$NumOrders_t = \beta_0 + \beta_1 NumRestaurants_t + \epsilon_t$$

- If not, how can we measure the causal effects for UberEat?
- This question is not just limited to UberEat; it is in fact related to any platform business with network effect!
  - Amazon; Airbnb; Uber Ridesharing; etc.

# Main Takeaway

- Common threats to causal inference from secondary data include
  - Omitted Variable Bias
  - Reverse Causality
- We can overcome the endogeneity problem using **instrumental variable method**.