LUND UNIVERSITY

# Causal Inference in Environmental & Social Science

Nils Droste

2023 ClimBEco course

# Structure of the Course


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


| | time | **Day 1:** April 24, 2023 | **Day 2:** April 25, 2023 | **Day 3:** April 26, 2023 | **Day 4:** April 27, 2023 | **Day 5:** April 28, 2023 |
|---|---|---|---|---|---|---|
| **Lectures** | 10-12h | Greetings, *Introduction to Causal inference*, and randomized controlled trials | *(Semi) Natural Experiments*: Panel data regressions, two-way fixed effects, and recent corrections for staggered treatment | *Simulated Counterfactuals*: matching methods, synthetic controls, and Bayesian Structural time series | *Instruments & Interruptions*: instrumental variables, regression discontinuity design | *Cutting edges*: Structural equation modelling for causal inference (and machine learning techniques?) |
| **Seminars** | 13-15h | *Replication*: Jayachandran et al. (2017) *Science* | *Replication*: Card & Krueger (1994) *JAERE* | *Replication*: LaLonde (1986) *PNAS* | *Replication*: Abou-Chadi & Krause (2020) *RPP* | ***Student presentations*** |
| **Consultations** | 15-16h | | | | | |

# Learning Contract

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

## My offer

- I will provide you with different *"entry points"* (words, graphs, math) to sharpen your intuition and conceptual understanding of quantitative causal inference
- We will collaboratively replicate exemplary works / causal inference strategies

## My ask price

- I want feedback what goes nice and what does not?

## Your task

- You apply one of the methods to a problem of your choice, write a short report and provide replication code

# Motivation – My answer

**Motivation**
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

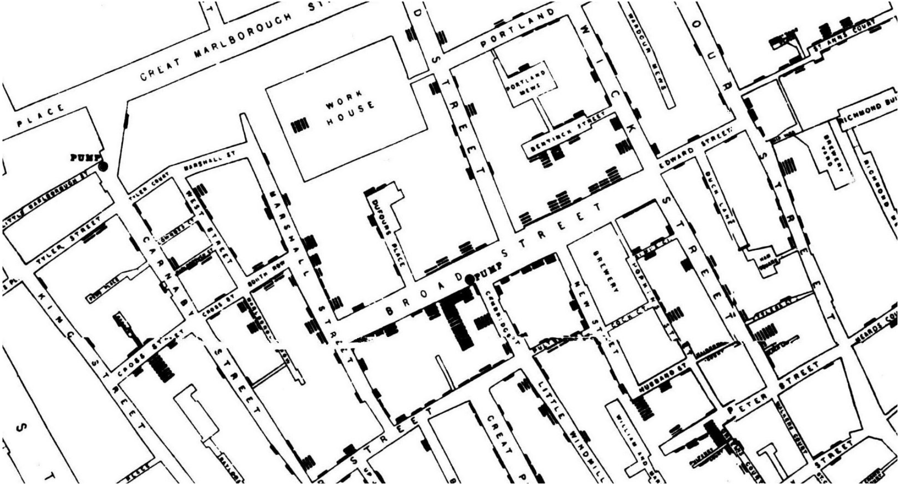
If you think about policies as if

- they were instruments / mechanisms / interventions
- with a potential to fix societal problems

***Would you not want to know which ones actually work?***

# Example I: Epidemiology






John Snow's original dot map of the 1854 Broad street cholera outbreak. Image sources & info: wikipedia

# Motivation – Greater minds' answers

**Motivation**
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

*Development of Western science is based on **two great achievements**: the invention of the formal logical system (in Euclidean geometry) by the Greek philosophers, and the discovery of the possibility to find out **causal relationships by systematic experiment** (during the Renaissance).*"

Albert Einstein (1953), as cited in Pearl (2009), my emphasis

# Motivation – Greater minds' answers

**Motivation**
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

*Development of Western science is based on* ***two great achievements****:*
*the invention of the formal logical system (in Euclidean geometry)*
*by the Greek philosophers, and the discovery of the possibility to find out*
***causal relationships by systematic experiment*** *(during the Renaissance)*."

Albert Einstein (1953), as cited in Pearl (2009), my emphasis

*My interpretation*:

→ If we want to check our theories about how the world works, we can use systematic obervations (i.e. data) to test our assumptions.

# Motivation – Greater minds' answers

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

*Development of Western science is based on* ***two great achievements****:*
*the invention of the formal logical system (in Euclidean geometry)*
*by the Greek philosophers, and the discovery of the possibility to find out*
***causal relationships by systematic experiment*** *(during the Renaissance).*"

Albert Einstein (1953), as cited in Pearl (2009), my emphasis

*My interpretation*:

→ If we want to check our theories about how the world works, we can use systematic obervations (i.e. data) to test our assumptions.
→ That does not *necessarily* entail quantitative analysis, but large number of observations have benefits for robustness (see next slide).

# A short detour into probability

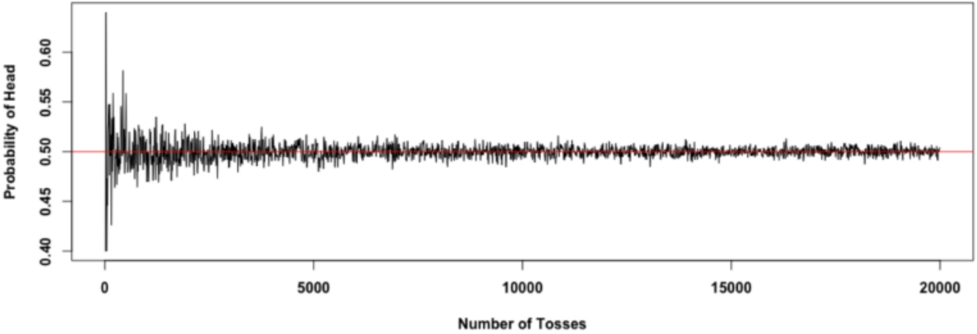
**Motivation**
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Is the coin fair?

# A short detour into probability


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


Is the coin fair?




$\rightarrow$ The law of large numbers allows to aproximate "*true*" values.

# Epistemological & Ontological Foundations


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


BLIND MASTER PO: *Close your eyes. What do you hear?*

YOUNG KWAI CHANG CAINE: *I hear the water, I hear the birds.*

MASTER PO: *Do you hear your own heartbeat?*

KWAI CHANG CAINE: *No.*

MASTER PO: *Do you hear the grasshopper that is at your feet?*

KWAI CHANG CAINE: *Old man, how is it that you hear these things?*

MASTER PO: *Young man, **how is it that you do not?***

*Kung Fu*, Pilot. Cited from Angrist and Pischke 2015, (p. xi), own emphasis

# Epistemological & Ontological Foundations

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

BLIND MASTER PO: *Close your eyes. What do you hear?*

YOUNG KWAI CHANG CAINE: *I hear the water, I hear the birds.*

MASTER PO: *Do you hear your own heartbeat?*

KWAI CHANG CAINE: *No.*

MASTER PO: *Do you hear the grasshopper that is at your feet?*

KWAI CHANG CAINE: *Old man, how is it that you hear these things?*

MASTER PO: *Young man, **how is it that you do not?***

*Kung Fu*, Pilot. Cited from Angrist and Pischke 2015, (p. xi), own emphasis

$\rightarrow$ We assume a measurable reality (positivism, empiricism).

# Epistemological & Ontological Foundations

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

To answer questions of causality we need an *epistemological framework* to

- formulate testable hypothesis
- find a suitable method to test hypothesis

# Epistemological & Ontological Foundations

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

To answer questions of causality we need an *epistemological framework* to

- formulate testable hypothesis
- find a suitable method to test hypothesis

Statistical causal inference is *one* such approach, suitable for

- both inductive and deductive reasoning
- generalizable, reproducible, falsifiable research

# Causation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

We have a population of units; for each unit $i$ we observe a variable $D$ and a variable $Y$.

# Causation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

We have a population of units; for each unit $i$ we observe a variable $D$ and a variable $Y$.

We observe that $D$ and $Y$ are correlated. Does *correlation* imply *causation*?

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

# Causation

We have a population of units; for each unit $i$ we observe a variable $D$ and a variable $Y$.

We observe that $D$ and $Y$ are correlated. Does *correlation* imply *causation*?

**In general no**, because of

- confounding factors;
- reverse causality

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

# Causation

We have a population of units; for each unit $i$ we observe a variable $D$ and a variable $Y$.

We observe that $D$ and $Y$ are correlated. Does *correlation* imply *causation*?

**In general no**, because of

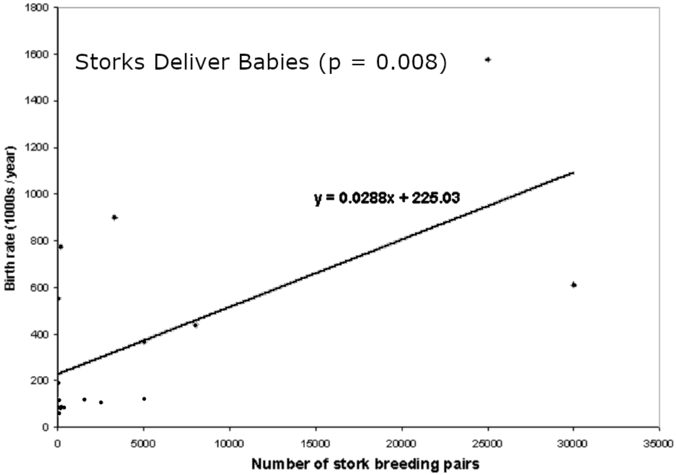
- confounding factors;
- reverse causality

We would like to understand in which circumstances one can conclude from the evidence that D causes Y.

source: lecture notes Sascha Becker 2014

# Example II: Storcks & Babies


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


Do storcks deliver babies? Image source: Matthews (2000)

# Example II: Storcks & Babies

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

What happened, why did we get it so wrong?

| Country | Area ($km^2$) | Storks (pairs) | Humans ($10^6$) | Birth rate ($10^3$/yr) |
|---|---|---|---|---|
| Albania | 28,750 | 100 | 3.2 | 83 |
| Austria | 83,860 | 300 | 7.6 | 87 |
| Belgium | 30,520 | 1 | 9.9 | 118 |
| Bulgaria | 111,000 | 5000 | 9.0 | 117 |
| Denmark | 43,100 | 9 | 5.1 | 59 |
| France | 544,000 | 140 | 56 | 774 |
| Germany | 357,000 | 3300 | 78 | 901 |

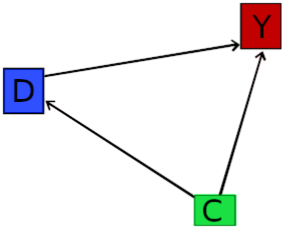
Subset of original data. Source: Matthews (2000)

Besides outcome variable and variable of interest, we forgot confounding variables.

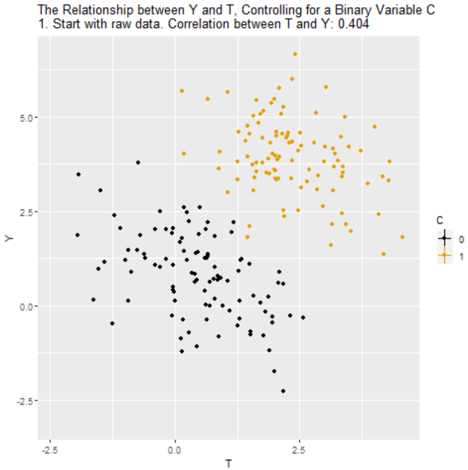
$$Y_i = \alpha + \beta_1 D_i + \beta_2 C_i + \varepsilon_i \tag{1}$$

# Problem I: Confounding variables


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


Directed acyclic graph where variable C affects both textcolorblueD and Y. Image source: Modified from Huntington-Klein 2018



# Neyman-Rubin Model I

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Recall, we let $Y$ denote our outcome variable, and $D$ our treatment or intervention which we are interested in.

Letter $i$ is an index of the individuals within our population.

# Neyman-Rubin Model I

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Recall, we let $Y$ denote our outcome variable, and $D$ our treatment or intervention which we are interested in.

Letter $i$ is an index of the individuals within our population.

For $D$ we have two possible realizations:

# Neyman-Rubin Model I

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Recall, we let $Y$ denote our outcome variable, and $D$ our treatment or intervention which we are interested in.

Letter $i$ is an index of the individuals within our population.

For $D$ we have two possible realizations:

- $D = 1$ if $i$ has received treatment;
- $D = 0$ if $i$ has *not* received treatment.

# Neyman-Rubin Model I

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Recall, we let $Y$ denote our outcome variable, and $D$ our treatment or intervention which we are interested in.

Letter $i$ is an index of the individuals within our population.

For $D$ we have two possible realizations:

- $D = 1$ if $i$ has received treatment;
- $D = 0$ if $i$ has *not* received treatment.

Thus, $Y_i(D_i)$ indicates the *potential outcome* according to treatment:

- $Y_i(1)$ is the outcome in case of treatment;
- $Y_i(0)$ is the outcome in case of *no* treatment.

# Neyman-Rubin Model II

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

The hypothetical outcome for each unit can be written as

$$\Delta Y_i = Y_i(1) - Y_i(0) \tag{2}$$

# Neyman-Rubin Model II

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

The hypothetical outcome for each unit can be written as

$$\Delta Y_i = Y_i(1) - Y_i(0) \tag{2}$$

- This approach requires to think in terms of "*counterfactuals*".

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

# Neyman-Rubin Model II

The hypothetical outcome for each unit can be written as

$$\Delta Y_i = Y_i(1) - Y_i(0) \tag{2}$$

- This approach requires to think in terms of "*counterfactuals*".
- While theoretically ideal, the identification and the measurement of a pure counterfactual is logically impossible:

# Neyman-Rubin Model II

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

The hypothetical outcome for each unit can be written as

$$\Delta Y_i = Y_i(1) - Y_i(0) \tag{2}$$

- This approach requires to think in terms of "*counterfactuals*".
- While theoretically ideal, the identification and the measurement of a pure counterfactual is logically impossible:
- We can only observe one state of the world, i.e. we cannot *directly* measure what would have happened in the counterfactual case (cf. Holland 1986).

# Neyman-Rubin Model III

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

The best we can do to infer an average treatment effect (ATE) by comparing sufficiently large subsamples from the overall population $I$: i.e. $I = \{A, B...\}$.

# Neyman-Rubin Model III

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

The best we can do to infer an average treatment effect (ATE) by comparing sufficiently large subsamples from the overall population $I$: i.e. $I = \{A, B...\}$.

Say, we expect the outcome to be

$$E\{\Delta Y_i\} = E\{Y_i(1) - Y_i(0)\} = E\{Y_i(1)\} - E\{Y_i(0)\}. \tag{3}$$

# Neyman-Rubin Model III


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


The best we can do to infer an average treatment effect (ATE) by comparing sufficiently large subsamples from the overall population $I$: i.e. $I = \{A, B...\}$.

Say, we expect the outcome to be

$$E\{\Delta Y_i\} = E\{Y_i(1) - Y_i(0)\} = E\{Y_i(1)\} - E\{Y_i(0)\}. \tag{3}$$

We can approximate this theoretical effect by treating individuals $a$ from $A$, and compare their average to the one of untreated individuals $b \in B$:

$$E\{\Delta Y_i\} \approx E\{Y_a(1)\} - E\{Y_b(0)\} \tag{4}$$

# Neyman-Rubin Model III

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

The best we can do to infer an average treatment effect (ATE) by comparing sufficiently large subsamples from the overall population $I$: i.e. $I = \{A, B...\}$.

Say, we expect the outcome to be

$$E\{\Delta Y_i\} = E\{Y_i(1) - Y_i(0)\} = E\{Y_i(1)\} - E\{Y_i(0)\}. \tag{3}$$

We can approximate this theoretical effect by treating individuals $a$ from $A$, and compare their average to the one of untreated individuals $b \in B$:

$$E\{\Delta Y_i\} \approx E\{Y_a(1)\} - E\{Y_b(0)\} \tag{4}$$

In this case we exploit *random chance* within sufficiently large samples that makes these groups comparable. Such a setting can be generated by randomized controlled experiments.

# Structural Causal Models I

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Another approach is to specify the assumed causal relation within a system by directed acyclic graphs (DAG). For example:

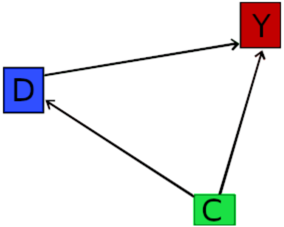

Directed acyclic graph where D affects Y. Image source: modified from Huntington-Klein 2018

# Structural Causal Models I

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Another approach is to specify the assumed causal relation within a system by directed acyclic graphs (DAG). For example:


Directed acyclic graph where D affects Y. Image source: modified from Huntington-Klein 2018



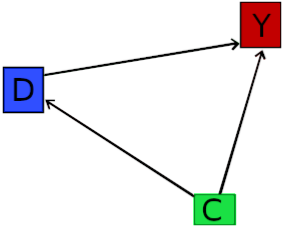

Directed acyclic graph where variable C affects both D and Y. Image source: Huntington-Klein 2018

# Structural Causal Models I

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Another approach is to specify the assumed causal relation within a system by directed acyclic graphs (DAG). For example:


Directed acyclic graph where D affects Y. Image source: modified from Huntington-Klein 2018




Directed acyclic graph where variable C affects both D and Y. Image source: Huntington-Klein 2018

In the second case we need to close the *back-door path* by controlling for *C*.

# Structural Causal Models II

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Judea Pearl et al. (2016) developed the do-calculus to express the effect of an intervention you *do*:

# Structural Causal Models II

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Judea Pearl et al. (2016) developed the do-calculus to express the effect of an intervention you *do*:

$P(Y|D)$ is the *conditional probability* of $Y$ given $D$.

# Structural Causal Models II

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Judea Pearl et al. (2016) developed the do-calculus to express the effect of an intervention you *do*:

$P(Y|D)$ is the *conditional probability* of $Y$ given $D$.

If we have a confounding variable $C$ and we want an unbiased estimate of intervention $D$'s effects on $Y$, we shall control for $C$ and assess the probability of $Y$ given both $D$ and $C$:

# Structural Causal Models II

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Judea Pearl et al. (2016) developed the do-calculus to express the effect of an intervention you *do*:

$P(Y|D)$ is the *conditional probability* of $Y$ given $D$.

If we have a confounding variable $C$ and we want an unbiased estimate of intervention $D$'s effects on $Y$, we shall control for $C$ and assess the probability of $Y$ given both $D$ and $C$:

$$P(Y|do(D)) = \sum_{C} P(Y|D,C)P(C) \tag{5}$$

# Mechanism

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Specifying a model is a necessary but not a sufficient condition to understand causality. Our model also needs to resemble reality.

# Mechanism

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Specifying a model is a necessary but not a sufficient condition to understand causality. Our model also needs to resemble reality.

We therefore need an understanding of the underlying ***mechanism***.

# Mechanism

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Specifying a model is a necessary but not a sufficient condition to understand causality. Our model also needs to resemble reality.

We therefore need an understanding of the underlying ***mechanism***.

> *"Causal processes, causal interactions, and causal laws provide the mechanisms by which the world works; to understand why certain things happen, we need to see how they are produced by these mechanisms."*
>
> Salmon 1984 as cited in Samantha Kleinberg Causal Inference, lecture 9

# Mechanism

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Specifying a model is a necessary but not a sufficient condition to understand causality. Our model also needs to resemble reality.

We therefore need an understanding of the underlying ***mechanism***.

> *"Causal processes, causal interactions, and causal laws provide the mechanisms by which the world works; to understand why certain things happen, we need to see how they are produced by these mechanisms."*
>
> Salmon 1984 as cited in Samantha Kleinberg Causal Inference, lecture 9

My take: $\rightarrow$ ***We need theory!*** Theory can be developed (and tested) through many (inductive & deductive) methods.

# Ontology - Epistemology - Theory

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Plato's allegory of the cave. Image source: Studio Binder 2020

# Intermediate lessons

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Do you have developed an intuition for the following?

# Intermediate lessons

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Do you have developed an intuition for the following?

- How large numbers of obervations allow more robust inference?

# Intermediate lessons

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Do you have developed an intuition for the following?

- How large numbers of obervations allow more robust inference?
- That correlation does not imply causation?

# Intermediate lessons

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Do you have developed an intuition for the following?

- How large numbers of obervations allow more robust inference?
- That correlation does not imply causation?
- That causal analysis require some form of framework to ...
  - formulate hypothesis
  - test hypothesis ?

# Intermediate lessons

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Do you have developed an intuition for the following?

- How large numbers of obervations allow more robust inference?
- That correlation does not imply causation?
- That causal analysis require some form of framework to ...
  - formulate hypothesis
  - test hypothesis ?
- That quantitative causal inference needs theory / an understanding of the causal mechanism to work?

# The history of randomized controlled trials (RCT)

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

# The history of randomized controlled trials (RCT)

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

- 1747 James Lind conducted a clinical trial on the treatment of scurvy

# The history of randomized controlled trials (RCT)


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


- 1747 James Lind conducted a clinical trial on the treatment of scurvy
- 19th century: experimental psychology (Wilhelm Wundt)

# The history of randomized controlled trials (RCT)


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


- 1747 James Lind conducted a clinical trial on the treatment of scurvy
- 19th century: experimental psychology (Wilhelm Wundt)
- up to early 20th century: experimental sociology (Comte vs. Hegel vs. Marx)

# The history of randomized controlled trials (RCT)


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


- 1747 James Lind conducted a clinical trial on the treatment of scurvy
- 19th century: experimental psychology (Wilhelm Wundt)
- up to early 20th century: experimental sociology (Comte vs. Hegel vs. Marx)
- Ronald Fisher's 1935 *Design of Experiments* (agricultural field experiments)

# The history of randomized controlled trials (RCT)

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

- 1747 James Lind conducted a clinical trial on the treatment of scurvy
- 19th century: experimental psychology (Wilhelm Wundt)
- up to early 20th century: experimental sociology (Comte vs. Hegel vs. Marx)
- Ronald Fisher's 1935 *Design of Experiments* (agricultural field experiments)
- since 1960's standard for approval of medicine (double blind clinical trials)

# The history of randomized controlled trials (RCT)


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


- 1747 James Lind conducted a clinical trial on the treatment of scurvy
- 19th century: experimental psychology (Wilhelm Wundt)
- up to early 20th century: experimental sociology (Comte vs. Hegel vs. Marx)
- Ronald Fisher's 1935 *Design of Experiments* (agricultural field experiments)
- since 1960's standard for approval of medicine (double blind clinical trials)
- 1970's RAND Health Insurance Experiment (cf. Angrist and Pischke 2015)

# The history of randomized controlled trials (RCT)


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


- 1747 James Lind conducted a clinical trial on the treatment of scurvy
- 19th century: experimental psychology (Wilhelm Wundt)
- up to early 20th century: experimental sociology (Comte vs. Hegel vs. Marx)
- Ronald Fisher's 1935 *Design of Experiments* (agricultural field experiments)
- since 1960's standard for approval of medicine (double blind clinical trials)
- 1970's RAND Health Insurance Experiment (cf. Angrist and Pischke 2015)
- 2019 Nobel Prize in Economics to *randomistas* (Banerjee and Duflo 2011)

# The history of randomized controlled trials (RCT)


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


- 1747 James Lind conducted a clinical trial on the treatment of scurvy
- 19th century: experimental psychology (Wilhelm Wundt)
- up to early 20th century: experimental sociology (Comte vs. Hegel vs. Marx)
- Ronald Fisher's 1935 *Design of Experiments* (agricultural field experiments)
- since 1960's standard for approval of medicine (double blind clinical trials)
- 1970's RAND Health Insurance Experiment (cf. Angrist and Pischke 2015)
- 2019 Nobel Prize in Economics to *randomistas* (Banerjee and Duflo 2011)

References and further reading

- RCTs: Pearce and Raman 2014; de Souza Leão and Eyal 2019; Jamison 2019
- Experiments in a broader sense, cf. Wikipedia, Britannica

# Experiments – the "gold" standard

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

In order to assess the effect of a "treatment" (of sorts), we can

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

# Experiments – the "gold" standard

In order to assess the effect of a "treatment" (of sorts), we can

- take two random samples from a population

# Experiments – the ”gold” standard

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

In order to assess the effect of a ”treatment” (of sorts), we can

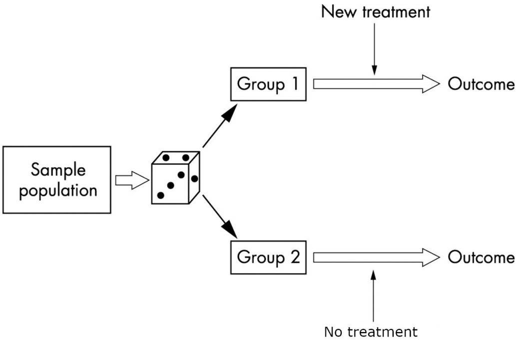
- take two random samples from a population
- treat one, and compare it to the other (as if ”counterfactual”)

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

# Experiments – the "gold" standard

In order to assess the effect of a "treatment" (of sorts), we can

- take two random samples from a population
- treat one, and compare it to the other (as if "counterfactual")




Schematic outline of a randomized controlled trial. Image source: Adapted from Kendall 2003

# Experiments – statistical approach

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Recall that we approach the average treatment effect (ATE) by comparing sufficiently large subsamples from the overall population: i.e. $I = \{A, B...\}$.

# Experiments – statistical approach

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Recall that we approach the average treatment effect (ATE) by comparing sufficiently large subsamples from the overall population: i.e. $I = \{A, B...\}$.

To approximate this treatment effect we can treat individuals $a \in A$, and compare their average to the one of untreated individuals $b \in B$.
This is called a *difference-in-means* estimator:

$$E\{\Delta Y_i\} \approx E\{Y_a(1)\} - E\{Y_b(0)\} \tag{6}$$

# Experiments – statistical approach

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
**Design**
Empirics
Conservation
Randomistas
References

Recall that we approach the average treatment effect (ATE) by comparing sufficiently large subsamples from the overall population: i.e. $I = \{A, B ...\}$.

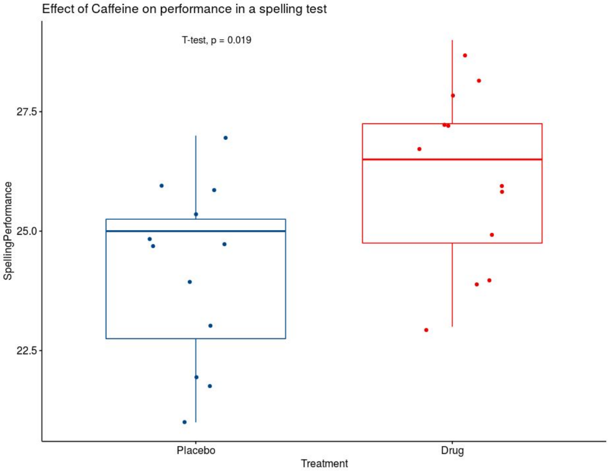
To approximate this treatment effect we can treat individuals $a \in A$, and compare their average to the one of untreated individuals $b \in B$.
This is called a *difference-in-means* estimator:

$$E\{\Delta Y_i\} \approx E\{Y_a(1)\} - E\{Y_b(0)\} \tag{6}$$

*Random chance* in sufficiently large samples makes these groups comparable (remember the law of large numbers).

# Experiments – graphical approach

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References




A hypothetical experiment. Image source: Adapted from personality-project

# Experiments – methodological note of caution

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

When designing an experiment we need a **big enough sample size**.

What is big enough can be calculated based on

- false positive probability (e.g. no more than 5%)
- minimum detectable effect (MDE)
- the power required at MDE (e.g. 80%)

Reference: cf. Coleman 2018 or Ramesh Johari MS&E 226 lecture 18

# Paying households for conservation


Motivation
Epistemes
Causation
Theory
- Neyman-Rubin Model
- Structural Causal Models
- Mechanism
Controlled Trials
Design
Empirics
- Conservation
Randomistas
References


RESEARCH ARTICLE

ECONOMICS

## Cash for carbon: A randomized trial of payments for ecosystem services to reduce deforestation


Seema Jayachandran,[1*] Joost de Laat,[2] Eric F. Lambin,[3,4] Charlotte Y. Stanton,[5] Robin Audy,[6] Nancy E. Thomas[7]



We evaluated a program of payments for ecosystem services in Uganda that offered forest-owning households annual payments of 70,000 Ugandan shillings per hectare if they conserved their forest. The program was implemented as a randomized controlled trial in 121 villages, 60 of which received the program for 2 years. The primary outcome was the change in land area covered by trees, measured by classifying high-resolution satellite imagery. We found that tree cover declined by 4.2% during the study period in treatment villages, compared to 9.1% in control villages. We found no evidence that enrollees shifted their deforestation to nearby land. We valued the delayed carbon dioxide emissions and found that this program benefit is 2.4 times as large as the program costs.

# Paying households for conservation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Deforestation contributes to climate change.

# Paying households for conservation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Deforestation contributes to climate change.

- As much land is private, paying land users for conservation (a public good) is a common approach.

# Paying households for conservation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Deforestation contributes to climate change.

- As much land is private, paying land users for conservation (a public good) is a common approach.
- Payments for ecosystem services (PES) schemes became popular (in the developing world).

# Paying households for conservation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Deforestation contributes to climate change.

- As much land is private, paying land users for conservation (a public good) is a common approach.
- Payments for ecosystem services (PES) schemes became popular (in the developing world).
- Jayachandran et al. (2017) run an experiment in Uganda (third highest deforestation rate in the world 2005-2010)

# Paying households for conservation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Deforestation contributes to climate change.

- As much land is private, paying land users for conservation (a public good) is a common approach.
- Payments for ecosystem services (PES) schemes became popular (in the developing world).
- Jayachandran et al. (2017) run an experiment in Uganda (third highest deforestation rate in the world 2005-2010)
- They
  - pay 563 private forest owners (PFO) in 60 treated villages (there are 535 PFO in 61 control villages), and
  - monitor deforestation rates by satelite imagery.

# Paying households for conservation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Deforestation contributes to climate change.

- As much land is private, paying land users for conservation (a public good) is a common approach.
- Payments for ecosystem services (PES) schemes became popular (in the developing world).
- Jayachandran et al. (2017) run an experiment in Uganda (third highest deforestation rate in the world 2005-2010)
- They
  - pay 563 private forest owners (PFO) in 60 treated villages (there are 535 PFO in 61 control villages), and
  - monitor deforestation rates by satelite imagery.
- Jayachandran et al. (2017) analyse the effect on tree cover.

# Paying households for conservation


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References


## Results

Primary outcomes

| | Village boundaries | | |
|---|---|---|---|
| | ΔTree cover (ha) | ΔTree cover (ha) | ΔLog of tree cover |
| | (1) | (2) | (3) |
| Treatment group | 5.549* | 5.478** | 0.0521** |
| | [2.888] | [2.652] | [0.021] |
| Control group | –13.371 | –13.371 | –0.095 |
| Control variables | No | Yes | Yes |
| Observations | 121 | 121 | 121 |

# Paying households for conservation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

## Results

### Secondary outcomes

| | Cut any trees in the past year | Allow others to gather firewood from own forest | Increased patrolling of the forest in last 2 years | Has any fence around land with natural forest | IHS of food expend. in past 30 days | IHS of nonfood expend. in past 30 days |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Treatment group | −0.140*** | −0.170*** | 0.109*** | 0.036 | 0.065 | 0.156** |
| | [0.034] | [0.033] | [0.039] | [0.033] | [0.074] | [0.066] |
| Lee bound (lower) | −0.161*** | −0.185*** | 0.094** | 0.007 | −0.029 | 0.053 |
| | [0.034] | [0.033] | [0.039] | [0.033] | [0.070] | [0.064] |
| Lee bound (upper) | −0.104*** | −0.148*** | 0.132*** | 0.055 | 0.144* | 0.215*** |
| | [0.033] | [0.032] | [0.039] | [0.034] | [0.075] | [0.064] |
| Control group mean | 0.453 | 0.427 | 0.378 | 0.667 | 2.524 | 4.363 |
| Control group SD | [0.498] | [0.495] | [0.485] | [0.472] | [1.177] | [1.354] |
| Observations | 1018 | 9767 | 984 | 1020 | 1020 | 1020 |
| Observations (Lee bounds) | 994 | 957 | 965 | 998 | 998 | 998 |

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

# Paying households for conservation

## Results

Paying forest owners for conservation reduces deforestation rates
$\rightarrow$ No afforestation is observable at that payment level.

# Paying households for conservation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

## Results

Paying forest owners for conservation reduces deforestation rates
$\rightarrow$ No afforestation is observable at that payment level.

”This study also adds to the literature on PES [by]”

- ”satellite images with very high resolution, which enables us to detect selective tree-cutting in addition to clear-cutting”

Jayachandran et al. 2017, p. 6

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

# Paying households for conservation

## Results

Paying forest owners for conservation reduces deforestation rates
$\rightarrow$ No afforestation is observable at that payment level.

"This study also adds to the literature on PES [by]"

- "satellite images with very high resolution, which enables us to detect selective tree-cutting in addition to clear-cutting"
- "cost-benefit analysis allows policy-makers to assess the cost-effectiveness of the PES program in comparison to other options for reducing global carbon emissions"

Jayachandran et al. 2017, p. 6

# Paying households for conservation

## A note on methods

The authors used a *stratification* strategy to ensure balanced randomization:

- number of PFOs

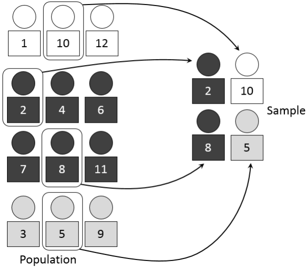



Image source: wikipedia

# Paying households for conservation

## A note on methods

The authors used a *stratification* strategy to ensure balanced randomization:

- number of PFOs
- av. household earnings / capita

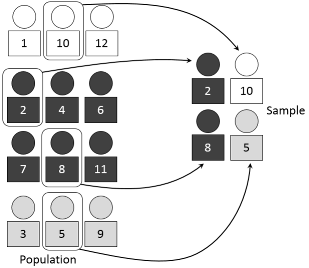



Image source: wikipedia

# Paying households for conservation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

## A note on methods

The authors used a *stratification* strategy to ensure balanced randomization:

- number of PFOs
- av. household earnings / capita
- distance to a road, and

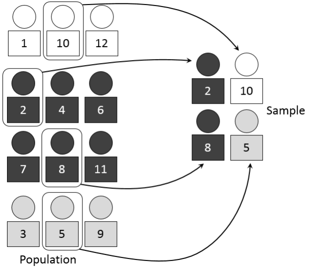



Image source: wikipedia

# Paying households for conservation

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

## A note on methods

The authors used a *stratification* strategy to ensure balanced randomization:

- number of PFOs
- av. household earnings / capita
- distance to a road, and
- average landsize

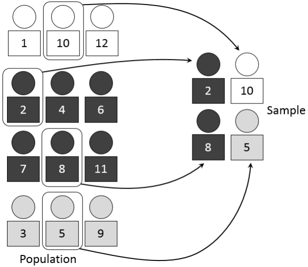



Image source: wikipedia

# Paying households for conservation

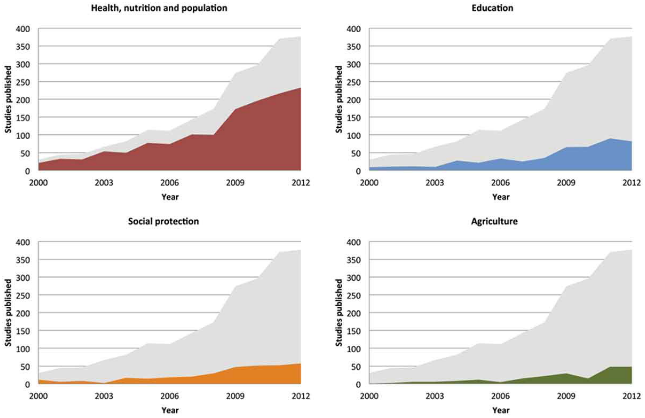
Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

## Discussion questions

- Do you think it is a good idea to pay private land owners for the provision of public goods  ecosystem services?
- Do you think it is a market-based approach if the government pays it? If so why?
- What could be alternative approaches to ensure provision of public (environmental) goods?

# Randomistas on a roll

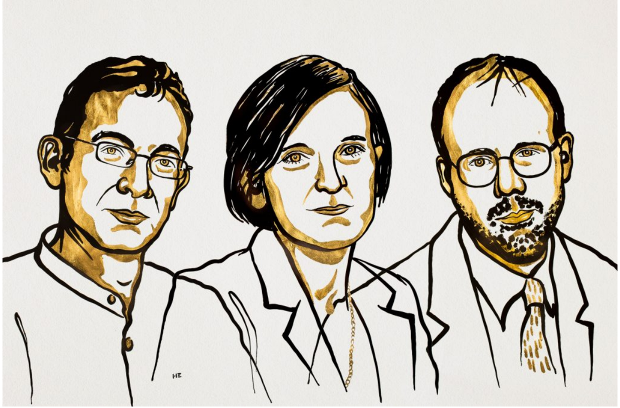
Increased use of development policy evaluation studies (or RCTs)




Share of quasi-experimental studies in color. Image source: Cameron et al. 2016, cf. Tollefson 2015

# Randomistas on a roll

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
**Randomistas**
References




Banerjee, Duflo & Kremer win the 2019 Nobel Prize in Economics.
Image source: Sverige Riksbank

# Not all that glitters is gold

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
**Randomistas**
References

- Some treatments cause ethical concern.

# Not all that glitters is gold

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
**Randomistas**
References

- Some treatments cause ethical concern.
- RCTs target individuals not structural causes.

# Not all that glitters is gold


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
**Randomistas**
References


- Some treatments cause ethical concern.
- RCTs target individuals not structural causes.
- A solid design is needed for internal and external validity.

# Not all that glitters is gold

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
**Randomistas**
References

- Some treatments cause ethical concern.
- RCTs target individuals not structural causes.
- A solid design is needed for internal and external validity.
- There is / was a replication crisis and p-hacking.

# Not all that glitters is gold


Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
**Randomistas**
References


- Some treatments cause ethical concern.
- RCTs target individuals not structural causes.
- A solid design is needed for internal and external validity.
- There is / was a replication crisis and p-hacking.
- There can be secondary, unintended outcomes.

# Not all that glitters is gold

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

- Some treatments cause ethical concern.
- RCTs target individuals not structural causes.
- A solid design is needed for internal and external validity.
- There is / was a replication crisis and p-hacking.
- There can be secondary, unintended outcomes.
- Experiments can be costly.

# A rejoinder

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
**Randomistas**
References

- Experiments do not deliver all answers (cf. Howe 2004)

# A rejoinder

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

- Experiments do not deliver all answers (cf. Howe 2004)
- A fuller picture may be provided by mixed method research (cf. Imai et al. 2011; Latour et al. 2012; Blok and Pedersen 2014)

# A rejoinder

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

- Experiments do not deliver all answers (cf. Howe 2004)
- A fuller picture may be provided by mixed method research (cf. Imai et al. 2011; Latour et al. 2012; Blok and Pedersen 2014)
- Observational data and identification strategies provide alternative quantitative approaches for causal inference (cf. Gelman 2014)

# A rejoinder

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
**Randomistas**
References

- Experiments do not deliver all answers (cf. Howe 2004)
- A fuller picture may be provided by mixed method research (cf. Imai et al. 2011; Latour et al. 2012; Blok and Pedersen 2014)
- Observational data and identification strategies provide alternative quantitative approaches for causal inference (cf. Gelman 2014)

$\rightarrow$ *My own take*: I believe more systematical experiments in the implementation of policies can increase effectiveness (compared to trial-and-error)

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

# Econometricians

MASTER JOSHWAY: *In a nutshell, please, Grasshopper.*

GRASSHOPPER: *Causal inference compares potential outcomes, descriptions of the world when alternative roads are taken.*

MASTER JOSHWAY: *Do we compare those who took one road with those who took another?*

GRASSHOPPER: *Such comparisons are often contaminated by selection bias, that is, differences between treated and control subjects that exist even in the absence of a treatment effect.*

MASTER JOSHWAY: *Can selection bias be eliminated?*

GRASSHOPPER: *Random assignment to treatment and control conditions eliminates selection bias. Yet even in randomized trials, we check for balance.*

MASTER JOSHWAY: *Is there a* ***single causal truth****, which all randomized investigations are sure to reveal?*

GRASSHOPPER: *I see now that there can be* ***many truths****, Master, some compatible, some in contradiction. We therefore take special note when findings from two or more experiments are similar.*

Angrist and Pischke 2015, (p. 30), own emphasis

# Experiment lessons

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

- The design of the experiments matter for it's
  - (internal and external) validity
  - ethical implications
- Interpretation of the results is a big part of the story / political recommendation.

# Further readings

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
**Randomistas**
References


- Behaghel, L., Macours, K., & Subervie, J. (2019). How can randomised controlled trials help improve the design of the common agricultural policy? *European Review of Agricultural Economics*, 46(3), 473-493. doi: 10.1093/erae/jbz021
- Beaman, L., Duflo, E., Pande, R., & Topalova, P. (2012). Female leadership raises aspirations and educational attainment for girls: A policy experiment in India. *Science, 335*(6068), 582-586. doi: 10.1126/science.1212382
- Braga, A. A., & Bond, B. J. (2008). Policing crime and disorder hot spots: A randomized controlled trial. *Criminology*, 46(3), 577-607. doi: 10.1111/j.1745-9125.2008.00124.x

# References I

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Angrist, Joshua D and Jörn-Steffen Pischke (2015). *Mastering 'Metrics*. Princeton: Princeton University Press.

Banerjee, Abhijit and Esther Duflo (2011). *Poor economics: A radical rethinking of the way to fight global poverty*. PublicAffairs.

Blok, Anders and Morten Axel Pedersen (2014). 'Complementary social science? Quali-quantitative experiments in a Big Data world'. In: *Big Data and Society* 1.2, pp. 1–6. DOI: 10.1177/2053951714543908.

Cameron, Drew B, Anjini Mishra and Annette N Brown (2016). 'The growth of impact evaluation for international development: how much have we learned?' In: *Journal of Development Effectiveness* 8.1, pp. 1–21. DOI: 10.1080/19439342.2015.1034156.

Coleman, Renita (2018). *Designing Experiments for the Social Sciences: How to Plan, Create, and Execute Research Using Experiments*. Sage.

de Souza Leão, Luciana and Gil Eyal (2019). 'The rise of randomized controlled trials (RCTs) in international development in historical perspective'. In: *Theory and Society* 48.3, pp. 383–418. DOI: 10.1007/s11186-019-09352-6.

Gelman, Andrew (2014). 'Experimental Reasoning in Social Science'. In: *Field Experiments and Their Critics: Essays on the Uses and Abuses of Experimentation in the Social Sciences*, p. 185.

Holland, Paul W (1986). 'Statistics and causal inference'. In: *Journal of the American Statistical Association* 81.396, pp. 945–960. DOI: 10.1080/01621459.1986.10478354.

# References II

Motivation
Epistemes
Causation
Theory
Neyman-Rubin Model
Structural Causal Models
Mechanism
Controlled Trials
Design
Empirics
Conservation
Randomistas
References

Howe, Kenneth R (2004). 'A critique of experimentalism'. In: *Qualitative Inquiry* 10.1, pp. 42–61. DOI: 10.1177/1077800403259491.

Imai, Kosuke et al. (2011). 'Unpacking the black box of causality: Learning about causal mechanisms from experimental and observational studies'. In: *American Political Science Review* 105.4, pp. 765–789. DOI: 10.1017/S0003055411000414.

Jamison, Julian C (2019). 'The Entry of Randomized Assignment into the Social Sciences'. In: *Journal of Causal Inference* 7.1. DOI: 10.1515/jci-2017-0025.

Jayachandran, Seema et al. (2017). 'Cash for carbon: A randomized trial of payments for ecosystem services to reduce deforestation'. In: *Science* 357.6348, pp. 267–273. DOI: 10.1126/science.aan0568.

Kendall, J M (2003). 'Designing a research project: randomised controlled trials and their principles'. In: *Emergency Medicine Journal* 20.2, pp. 164–168. DOI: 10.1136/emj.20.2.164.

Latour, Bruno et al. (2012). ''The whole is always smaller than its parts' - a digital test of Gabriel Tardes' monads'. In: *British Journal of Sociology* 63.4, pp. 590–615. DOI: 10.1111/j.1468-4446.2012.01428.x.

Matthews, Robert (2000). 'Storks deliver babies (p= 0.008)'. In: *Teaching Statistics* 22.2, pp. 36–38. DOI: 10.1111/1467-9639.00013.

# References III



Pearce, Warren and Sujatha Raman (2014). 'The new randomised controlled trials (RCT) movement in public policy: challenges of epistemic governance'. In: *Policy Sciences* 47.4, pp. 387–402. DOI: 10.1007/s11077-014-9208-3.

Pearl, Judea (2009). *Causality - Models, Reasoning, and Inference*. 2nd editio. Cambridge University Press.

Pearl, Judea, Madelyn Glymour and Nicholas P Jewell (2016). *Causal inference in statistics: A primer*. Wiley. URL: http://bayes.cs.ucla.edu/PRIMER/.

Salmon, Wesley C (1984). *Scientific explanation and the causal structure of the world*. Princeton University Press.

Tollefson, Jeff (2015). 'Revolt of the Randomistas: a new generation of economists is trying to transform global development policy through the power of randomized controlled trials'. In: *Nature* 524.7564, pp. 150–154. DOI: 10.1038/524150a.