Inference & Causality
Week 3
Session 6

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Course Overview

Reminder: Check the course hub on Notion for up-to-date information:

https://tinyurl.com/mrcjp79s

Feedback

Before we start the lecture today, please help me adjust the remaining sessions of the course with your feedback (it's anonymous and very appreciated):

Outline of Week 3
Session 6

- Counterfactuals
- Randomized Controlled Trials

Counterfactuals

- "Counterfactual" = what-if world where we imagine a different action or treatment.

- They ask: What would have happened to the same individual if X had been different?

- Formal symbol: Y_x = outcome that would occur if X were set to x.

The Need for Counterfactual Thinking

- Observation tells us what did happen, but policy questions require what would have happened otherwise.

- Example:

- Alice took a job-training course and now earns €45k.
    - Would she have earned less if she hadn't taken it?
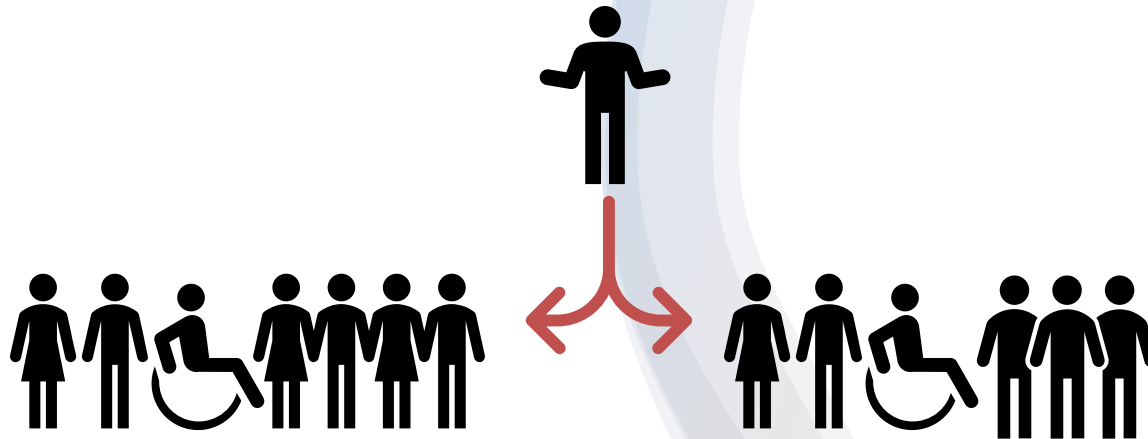
The Fundamental Problem of Causal Inference

- For each unit i, two potential outcomes exist: $Y_i(1)$ = outcome if treated; $Y_i(0)$ = outcome if not.
- We only ever observe one of them → the other is counterfactual.
- Hence, causality needs modeling or randomization to estimate $E[Y(1) - Y(0)]$.

Individual vs. Average Effects

- Individual causal effect: $Y_i(1) - Y_i(0)$ (unobservable).

- Average Treatment Effect (ATE): $E[Y(1)] - E[Y(0)]$ (estimable with randomization).

- **Randomized Controlled Trials (RCTs)** approximate this by balancing counterfactual worlds across groups.

Randomized Controlled Trials (RCTs)

- An RCT is an experimental study design in which participants are randomly assigned to different groups (treatment vs. control) to test the causal effect of an intervention.

- It is considered one of the highest quality sources of evidence.

Why? Randomization breaks the link between confounders and treatment, making groups statistically equivalent except for the intervention.

A Brief History of RCTs

1648 – The idea of an RCT:
Jan Baptist van Helmont proposed comparing two fever treatments (bloodletting vs. his own method) — likely never executed (van Helmont, Ortus Medicinae).

1747 – First clinical trial:
James Lind tested six scurvy remedies on sailors, identifying citrus fruit as effective.

1784 – First blind experiment:
French Royal Commission on Animal Magnetism tested Mesmer's claims with blinding to reduce bias.

1880s – Randomization in psychology:
Charles Sanders Peirce and Joseph Jastrow introduced random assignment in perception studies.

Early 1900s – Controlled trials in education and psychology:
Edward Thorndike, John E. Coover, and others used treatment vs. control designs.

1920s–30s – Modern experimental design:
Jerzy Neyman and Ronald A. Fisher developed statistical theory and popularized randomization in agricultural experiments.

1948 – First modern medical RCT:
Medical Research Council (UK) published "Streptomycin treatment of pulmonary tuberculosis" (BMJ), led by Austin Bradford Hill.

1980s – Large-scale trials:
ISIS studies (International Study of Infarct Survival) shaped modern cardiac treatment testing.

1990s–2010s – Global standardization:
RCTs became the benchmark for "rational therapeutics"; the CONSORT Statements (1996, 2001, 2010) set reporting standards.

RCT Standards

Features of good RCTs:

- Random assignment

- Blinding (participants/researchers unaware of assignment)

- Pre-registration and reproducibility

- Ethical approval and informed consent

Advantages & Limitations

Advantages

•Causal clarity:
Randomization removes confounding and differences in outcomes can be attributed to the intervention.

•Internal validity:
Well-designed RCTs provide the strongest evidence for cause–effect relationships.

•Transparency:
Design and procedures are explicit, replicable, and auditable.

•Benchmark for causal inference:
Forms the "gold standard" against which observational and quasi-experimental studies are compared.

Limitations

•Ethical constraints:
Some interventions (e.g., smoking, withholding treatment) cannot be randomized.

•Cost and logistics:
Large sample sizes, follow-up, and compliance monitoring can be expensive.

•External validity:
Findings may not generalize beyond the specific population or context.

•Attrition & noncompliance:
Dropouts or participants switching groups can bias results.

•Hawthorne effect:
Participants may change behavior simply because they know they're being studied.

Major Categories of RCT

- Parallel-group
- Crossover
- Stepped-wedge trial
- Cluster
- Factorial

Class exercise:
- What are these types?
  Each row of students should explain one of these types in maximum 3 lines.

Session Summary

- Introduced the concept of counterfactuals as imagined "what-if" scenarios used to define causal effects.

- Explained the fundamental problem of causal inference — only one potential outcome is ever observed.

- Explored how Randomized Controlled Trials (RCTs) simulate counterfactual worlds through random assignment.

- Discussed the strengths and limits of RCTs and their role as the benchmark for causal inference.

Exercise

Finad and briefly report one published or publicly documented Randomized Controlled Trial (RCT) example.

- Your report should include at least:

- Topic / Research Question – What causal question does the study address?
- Type of RCT – For example: medical, educational, behavioral, policy, or field experiment.
- Number of Participants / Units – How large was the study sample?
- Intervention and Control Description – What was tested, and against what?
- Key Finding / Outcome – What was the causal effect or main result?
- (Optional) Notes on Ethics or External Validity – Any limitations, replication attempts, or generalizability concerns.

- Format:
- One presentation slide or a short written summary (about 5 minutes presentation or discussion time).
- Include a proper citation or source link for the study.

- Goal:

To recognize how RCTs apply counterfactual reasoning in different disciplines and compare how experimental designs are implemented in practice.

Congratulations!
We finished <u>unit 3</u> of this course.

Don't forget to read unit 3 of your course book for more detailed understanding of this unit.

Let's check out our pre-set unit 3 quiz!
You have 15min.