Causal Inference

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Enhancing Implementation Science: Program Planning, Scale-up, and Evaluation
Program → ? → Outcome
Social, economic, cultural, political and biological milieu

HIV Incidence

Source: Stefano Bertozzi, BMGF
Learning Objectives

Understand the concept of counterfactuals and how selection bias affects impact evaluations

1. Impact evaluation and counterfactuals
2. Importance of a valid counterfactual
3. Selection bias
4. Study designs and threats to validity
5. Quality Assessment
Monitoring and Evaluation Results Pyramid

- **MONITORING**
  - **INPUTS**
    - Resources (fixed or mobile)
    - Staff
    - Funds
    - Supplies
    - Training

  - **OUTPUTS**
    - No. of procedures
    - Condom availability
    - Trained staff
    - Service quality

- **EVALUATION**
  - **OUTCOMES**
    - Short-term and intermediate effects:
      - Behavior change
      - STIs

  - **IMPACT**
    - Long-term effects:
      - HIV/AIDS
      - Mortality
      - Economic impact

Impact Evaluation Answers:

- What was the effect of the program on outcomes? (*causal attribution*)
- How much better off are the beneficiaries as a result of the program?
- What happened compared to what would have happened without the program?
- Is the program cost-effective?
Example: What is the Impact of...
giving Robert additional pocket money on Robert’s consumption of candies?
The Perfect **Clone**

Robert

Robert’s Clone

IMPACT: $6 - 4 = 2$ Candies
Solving the Evaluation Problem

• Problem: we never observe the same individual with and without program at same point in time

• Need to estimate what would have happened to the beneficiary if he or she had not received benefits; i.e. causal attribution
In reality, use statistics

Average \( Y = 6 \) candies

Average \( Y = 4 \) Candies

IMPACT = \( 6 - 4 = 2 \) Candies
Our Objective:

Estimate the *CAUSAL* effect (*impact*) of:

*intervention* \( P \) *(male circumcision)*

on

*outcome* \( Y \) *(HIV incidence)*
Solution:

- Estimate what *would* have happened to $Y$ in the absence of $P$
- We call this the..............

COUNTERFACTUAL
Solution:

- Estimate what *would* have happened to $Y$ in the absence of $P$
- We call this the…

**COUNTERFACTUAL**

The key to a good impact evaluation is a valid counterfactual!
Why Do We Need a Counterfactual?

At this stage of the epidemic...?

- Prevention failure or treatment success?
- Balanced success?
- Treatment failure or prevention success?
Good Counterfactuals

• Since we can never actually know what \textit{would have happened}, \textit{comparison groups} allow us to \textit{estimate} the counterfactual

• A good counterfactual can help you estimate the “true” (hypothetical) causal effect

\textbf{Hint:} With a good counterfactual, the \textbf{only reason} for different outcomes between treatments and controls is the \textit{intervention} (P)
Finding a Good Counterfactual

The treated group and the counterfactual group:

• Have identical factors/characteristics, except for benefiting from the intervention

• The only reason for the difference in outcomes is due to the intervention
Population 1 + Intervention Vs. Population 2
Poor Counterfactuals Can Threaten Validity

1. Selection Bias
   • Volunteer participants or those not receiving program are different than those without

2. Confounding

3. Endogenous Change
   • Secular changes or drift (long term trends in community, region or country)
   • Maturational trends (Individual change)
   • Interfering events
• Measurement error
• Hawthorne/ cohort effects

All studies!
Study Designs & Threats to Validity

1. Enrolled vs. Not Enrolled (Selection Bias)
Consider a school-based pregnancy prevention program.

10 schools in the district are asked if they would like to participate.
<table>
<thead>
<tr>
<th>Design</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No intervention</strong></td>
<td>5 schools decline participation</td>
</tr>
<tr>
<td><strong>Pregnancy Prevention Program</strong></td>
<td>5 schools elect to participate in the program</td>
</tr>
<tr>
<td>Design</td>
<td>Pregnancy Rate</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>------------------------</td>
</tr>
<tr>
<td>No intervention</td>
<td>3 per 100 student years</td>
</tr>
<tr>
<td>Pregnancy Prevention Program</td>
<td>2 per 100 student years</td>
</tr>
</tbody>
</table>
Designs Leading to Biased Results: “Enrolled versus Not Enrolled”

Schools in the program had fewer adolescent pregnancies...

Can we attribute this difference to the program?
<table>
<thead>
<tr>
<th>No intervention</th>
<th>Pregnancy prevention program</th>
<th>Pregnancy rate</th>
<th>Factor X (more conservative)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2 per 100 student years</td>
<td>Less conservative</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 per 100 student years</td>
<td>Factor X (more conservative)</td>
</tr>
</tbody>
</table>
Observed effect might be due to differences in “Factor X” which led to differential self-selection into the program (“selection bias”).
Designs Leading to Biased Results: “Enrolled versus Not Enrolled”

- This design compares “apples to oranges”
- The reason for not enrolling in the program might be correlated with the outcome
  - You can statistically “control” for observed factors
  - But you cannot control for factors that are “unobserved”

- Estimated impact erroneously mixes the effect of different factors
Study Designs & Threats to Validity

2. Confounding (Correlation or Causation?)
Confounding Example: Male Circumcision (pre-2005)

- Frequently observed that male circumcision status associated with lower HIV prevalence (since 1986)
  - Difficult to disentangle from religion

```
Religion

MC  ?  HIV
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- Was this association **correlation** or **causation**?
RCTs confirmed the observational data

The RCTs addressed this problem by randomizing men to get circumcised immediately or after a waiting period, eliminating selection bias & confounding

<table>
<thead>
<tr>
<th>Study</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auvert, 2005, South Africa</td>
<td>$\text{IRR}_A = 0.39 \ (0.23, 0.66)$</td>
</tr>
<tr>
<td>Bailey, 2007, Kenya</td>
<td>$\text{RR} = 0.47 \ (0.28, 0.78)$</td>
</tr>
<tr>
<td>Gray, 2007, Uganda</td>
<td>$\text{IRR}_A = 0.49 \ (0.29, 0.81)$</td>
</tr>
<tr>
<td><strong>Combined Effect</strong></td>
<td>↓58% (95% CI: 43–69%)</td>
</tr>
</tbody>
</table>
Study Designs & Threats to Validity

3. Before-After or Pre-Post (endogenous changes)
Designs Leading to Biased Results: “Before-After” or “Pre-Post” Designs

• Data on the same individuals before and after an intervention
Designs Leading to Biased Results: “Before-After” or “Pre-Post” Designs
Designs Leading to Biased Results: “Before-After” or “Pre-Post” Designs

Measure HIV/AIDS knowledge at baseline

Knowledge score = 5/10
Designs Leading to Biased Results: “Before-After” or “Pre-Post” Designs

Knowledge score = 5/10

HIV Educational Intervention

Time
Designs Leading to Biased Results: “Before-After” or “Pre-Post” Designs

Knowledge score = 5/10
Designs Leading to Biased Results: “Before-After” or “Pre-Post” Designs

Knowledge score = 5/10

HIV Educational Intervention

Knowledge score = 9/10

Time
Designs Leading to Biased Results: “Before-After” or “Pre-Post” Designs

4 point improvement in score after the intervention...

Can we attribute this improvement to the program?

Knowledge score = 5/10  Time  Knowledge score = 9/10

HIV Educational Intervention
Designs Leading to Biased Results: “Before-After” or “Pre-Post” Designs

Simultaneous Informational Media Campaign

HIV Educational Intervention

Knowledge score = 5/10

Time

Knowledge score = 9/10
Problem: Can’t account for time varying factors that impact the outcome, such as:

• changes in the economy
• natural changes in the epidemic
• simultaneous interventions
Study Designs & Threats to Validity

4. Historical Controls
Designs Leading to Biased Results: “Historical Controls”

Students tested annually, but no intervention
Designs Leading to Biased Results: “Historical Controls”

Knowledge score = 4/10

Students tested annually, but no intervention
Designs Leading to Biased Results: “Historical Controls”

Students tested annually, but no intervention

Knowledge score = 4/10

Knowledge score = 5/10
Designs Leading to Biased Results: “Historical Controls”

- **Knowledge score = 4/10**
- **Knowledge score = 5/10**
- **Knowledge score = 5/10**
- **Knowledge score = 9/10**
The controls improved by 1 point whereas the intervention group improved by 4 points...

Can we attribute this improvement to the program?
Designs Leading to Biased Results: “Historical Controls”

Problem: Control group may not be comparable

Factors (other than the intervention) may differ:

- teachers
- teacher: student ratio
- funding
- textbooks
Study Designs & Threats to Validity

5. Matched Designs
Designs Leading to Biased Results: “Matched Designs”

Individuals, groups, or communities are matched based on known characteristics to improve comparability:

- Age, race, sex
- Region, poverty
Designs Leading to Biased Results: “Matched Designs”

From each pair, one receives the intervention.

Differences in outcomes are compared within the pair.
Does this design ensure that the matched pairs are comparable on all factors except the intervention?
Does this design ensure that the matched pairs are comparable on all factors except the intervention?

No: Only **observed** factors are used for matching

**Unobserved** factors may differ
Counterfactuals & Ethical Conduct of Research

• Often our choice of counterfactuals is limited by ethics

• Lack of naive comparison groups

• When we might want to compare “something” to “nothing” we have to instead compare to “something” to “something else”
Prevention Services in Control Arm

**Intervention**
- New technology
- Effective prevention

**Control**
- Effective prevention

VS.
Hypothetical results of measuring new HIV infections in four groups of villages receiving four prevention options

Universal ethical guidelines prohibit observing the two groups of villages which do not receive "exceptional" prevention interventions
Impact Evaluation Quality Assessment

What is the question of interest?

• “What is the impact of $P$ on $Y$ among population $X$?”
• What is the program, intervention, or treatment, $P$?
• What is the outcome, $Y$, of interest?

What is the unit of analysis?

• Is impact being measured in individuals or clusters (e.g., facilities, schools)?
• Was clustering accounted for in the analysis?
Impact Evaluation Quality Assessment

What is the counterfactual?

• Is there an observed comparison group?

• If not, what are observed data being compared to (e.g., historical controls, pre-intervention baseline, modeled counterfactual)?

• How is membership in the treatment and comparison group determined?
Impact Evaluation Quality Assessment

**Quality of the counterfactual**

- Does the treatment and comparison groups differ only with respect to the program?  
  If randomized assignment ➔ Yes  
  If non-randomized assignment ➔ No

- What are potential sources of bias?

- What are strengths and weaknesses of this counterfactual?
During IAS sessions....

<table>
<thead>
<tr>
<th>Session Title</th>
<th>Research Question</th>
<th>Exposure/Treatment</th>
<th>Outcome</th>
<th>Unit of Analysis (community, individual, district etc.)</th>
<th>If cluster, did they account for clustering in analysis?</th>
<th>Comparison/Counterfactual</th>
<th>Strengths</th>
<th>Weaknesses</th>
</tr>
</thead>
</table>
Questions?

Many thanks to those whose slides I’ve borrowed: Nancy Padian, Stefano Bertozzi, Sebastian Martinez, Paul Gertler, Mead Over

Several slides adapted from:

*Impact Evaluation in Practice*

by Paul J. Gertler, Sebastian Martinez, Patrick Premand, Laura B. Rawlings, Christel M. J. Vermeersch