Session I
Survey Experiments in Context

Thomas J. Leeper

Government Department
London School of Economics and Political Science
1 Introductions

2 Course Outline

3 History and Logic
Activity!
Activity!

1. Ask you to guess a number
Activity!

1. Ask you to guess a number
2. Number off 1 and 2 across the room
Activity!

1. Ask you to guess a number
2. Number off 1 and 2 across the room
3. Group 2, close your eyes
Activity!

Group 1
Think about whether the population of Chicago is more or less than 500,000 people. What do you think the population of Chicago is?
Activity!

1. Ask you to guess a number
2. Number off 1 and 2 across the room
3. Group 2, close your eyes
4. Group 1, close your eyes
Activity!

Group 2
Think about whether the population of Chicago is more or less than 10,000,000 people. What do you think the population of Chicago is?
Enter your data

- Enter your guess and your group number
Results

- True population: 2.79 million
Results

- True population: 2.79 million
- What did you guess? (See Responses)
Results

- True population: 2.79 million
- What did you guess? (See Responses)
- What’s going on here?
  - An experiment!
  - Demonstrates “anchoring” heuristic
Results

- True population: 2.79 million

- What did you guess? (See Responses)

- What’s going on here?
  - An experiment!
  - Demonstrates “anchoring” heuristic

- Experiments are easy to analyze, but only if designed and implemented well
1 Introductions

2 Course Outline

3 History and Logic
Who am I?

Thomas Leeper

Associate Professor in Political Behaviour at London School of Economics

- 2013–15: Aarhus University (Denmark)
- 2008–12: PhD from Northwestern University (Chicago, USA)
- Birth–2008: Minnesota, USA

Interested in public opinion and political psychology

Email: t.leeper@lse.ac.uk
Who are you?

- Introduce yourself to a neighbour
- Where are you from?
- What do you hope to learn from the course?
Quick Survey

1. How many of you have worked with survey data before?
2. Of those, how many of you have performed a survey before?
3. How many of you have worked with experimental data before?
4. Of those, how many of you have performed an experiment before?
Quick Survey

1. How many of you have worked with survey data before?
Quick Survey

1. How many of you have worked with survey data before?

2. Of those, how many of you have *performed* a survey before?
Quick Survey

1. How many of you have worked with survey data before?

2. Of those, how many of you have performed a survey before?

3. How many of you have worked with experimental data before?
Quick Survey

1. How many of you have worked with survey data before?
2. Of those, how many of you have performed a survey before?
3. How many of you have worked with experimental data before?
4. Of those, how many of you have performed an experiment before?
1 Introductions

2 Course Outline

3 History and Logic
Course Materials

All material for the course is available at:

http://www.thomasleeper.com/surveyexpcourse/
By the end of the week, you should be able to...

1. Explain how to analyze experiments quantitatively.
2. Explain how to design experiments that speak to relevant research questions and theories.
3. Evaluate the uses and limitations of several common survey experimental paradigms.
4. Identify practical issues that arise in the implementation of experiments and evaluate how to anticipate and respond to them.
Learning Outcomes

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Schedule of Four Sessions

1. Survey Experiments in Context
2. Examples and Paradigms
3. Hands-on Session
4. Practical Issues
Questions?
1 Introductions

2 Course Outline

3 History and Logic
Experiments: History I

Oxford English Dictionary defines “experiment” as:

1. A scientific procedure undertaken to make a discovery, test a hypothesis, or demonstrate a known fact
2. A course of action tentatively adopted without being sure of the outcome
"Experiments" have a very long history.

Major advances in design and analysis of experiments based on agricultural and later biostatistical research in the 19th century (Fisher, Neyman, Pearson, etc.)
Experiments: History II

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- Multiple origins in the social sciences
Experiments: History II

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- Major advances in design and analysis of experiments based on agricultural and later biostatistical research in the 19th century (Fisher, Neyman, Pearson, etc.)

- Multiple origins in the social sciences
  - First randomized experiment by Peirce and Jastrow (1884)
  - Gosnell (1924)
  - LaLonde (1986)
  - Gerber and Green (2000)
Experiments: History III

- “Question testing” split ballots (e.g., Cantril)
- Rise of surveys in the behavioral revolution
  - Split ballots (e.g., Schuman & Presser; Bishop)
“Question testing” split ballots (e.g., Cantril)

Rise of surveys in the behavioral revolution

Split ballots (e.g., Schuman & Presser; Bishop)

1983: Merrill Shanks and the Berkeley Survey Research Center develop CATI
Experiments: History III

- “Question testing” split ballots (e.g., Cantril)
- Rise of surveys in the behavioral revolution
  - Split ballots (e.g., Schuman & Presser; Bishop)
- 1983: Merrill Shanks and the Berkeley Survey Research Center develop CATI
- Mid-1980s: Paul Sniderman & Tom Piazza performed the first modern survey experiment
  - Then: the “first multi-investigator”
  - Later: Skip Lupia and Diana Mutz created TESS

---

TESS

- Time-Sharing Experiments for the Social Sciences
- Multi-disciplinary initiative that provides infrastructure for survey experiments on nationally representative samples of the United States population
- Great resource for survey experimental materials, designs, and data
- Funded by the U.S. National Science Foundation
- Anyone anywhere in the world can apply

See also: LISS, Bergen’s Citizen Panel, Gothenburg’s Citizen Panel
The First Survey Experiment?

Hadley Cantril (1940) asks 3000 Americans either:
The First Survey Experiment?

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Do you think the U.S. should do more than it is now doing to help England and France?

- Yes
- No

The "Hitler effect" was 22% - 13% = 9%
The First Survey Experiment?

Hadley Cantril (1940) asks 3000 Americans either:

Do you think the U.S. should do more than it is now doing to help England and France?

- Yes
- No

Do you think the U.S. should do more than it is now doing to help England and France in their fight against Hitler?

- Yes
- No

Yes: 13%
No: 22%

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A randomized experiment is:

*The observation of units after, and possibly before, a randomly assigned intervention in a controlled setting, which tests one or more precise causal expectations*
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The observation of units after, and possibly before, a randomly assigned intervention in a controlled setting, which tests one or more precise causal expectations

If we manipulate the thing we want to know the effect of ($X$), and control (i.e., hold constant) everything we do not want to know the effect of ($Z$), the only thing that can affect the outcome ($Y$) is $X$. 
Definitions II

A survey experiment is just an experiment that occurs in a survey context as opposed to in the field or in a laboratory. It can be in any mode (face-to-face, CATI, IVR, CASI, etc.) and may or may not involve a representative population. Mutz (2011): "population-based survey experiments."
Definitions II

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Definitions II
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**Unit**: A physical object at a particular point in time
Definitions II

**Treatment**: An intervention, whose effect(s) we wish to assess relative to some other (non-)intervention

Synonyms: manipulation, intervention, factor, condition, cell
Definitions II

**Outcome:** The variable we are trying to explain
Potential outcomes: The outcome value for each unit that we *would observe* if that unit received each treatment.

Multiple potential outcomes for each unit, but we only observe one of them.
Definitions II

**Causal effect**: The comparisons between the unit-level potential outcomes under each intervention

*This is what we want to know!*
Definitions II

Average causal effect: Difference in mean outcomes between treatment groups

This is almost what we want to know!
Example

- Unit: Americans in 1940
- Outcome: Support for military intervention
- Treatment: Mentioning Hitler versus not
- Potential outcomes:
  1. Support in "Hitler" condition
  2. Support in control condition
- Causal effect: Difference in support between the two question wordings for each respondent

Individual treatment effect not observable! Average effect (ATE) is the mean-difference
Example

Unit: Americans in 1940
Example

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**Unit**: Americans in 1940

**Outcome**: Support for military intervention

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- Average effect (ATE) is the mean-difference
Questions?
Why are experiments useful?
Why are experiments useful?

Causal inference!
Addressing Confounding

In observational research…
Addressing Confounding

In observational research...

1. Correlate a “putative” cause \((X)\) and an outcome \((Y)\), where \(X\) temporally precedes \(Y\)
Addressing Confounding

In observational research...

1. Correlate a “putative” cause ($X$) and an outcome ($Y$), where $X$ temporally precedes $Y$

2. Identify all possible confounds ($Z$)
Addressing Confounding

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1. Correlate a “putative” cause ($X$) and an outcome ($Y$), where $X$ temporally precedes $Y$

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3. “Condition” on all confounds
   - Calculate correlation between $X$ and $Y$ at each combination of levels of $Z$
Addressing Confounding

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   - Calculate correlation between $X$ and $Y$ at each combination of levels of $Z$

4. Basically: $Y = \beta_0 + \beta_1 X + \beta_2 Z + \epsilon$
Course Outline

Introductions

History/Logic

- Media Coverage
- Salience of Hitler
- Support for Military Intervention
- Demographics
- Political Sophistication
- Ideology

Demographics

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- Salience of Hitler
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Introductions

History/Logic
Experiments are different

1. Causal inferences from design, not analysis.
   Solves both temporal ordering and confounding.
   Treatment (X) applied by researcher before outcome (Y).
   Randomization eliminates confounding (Z).
   We don't need to "control" for anything.

2. Basically:
   \[ Y = \beta_0 + \beta_1 X + \epsilon \]

3. Thus experiments are a "gold standard".
Experiments are different

1 Causal inferences from *design* not *analysis*
Experiments are different

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3. Basically: $Y = \beta_0 + \beta_1 X + \epsilon$

4. Thus experiments are a “gold standard”
If an instance in which the phenomenon under investigation occurs, and an instance in which it does not occur, have every circumstance save one in common, that one occurring only in the former; the circumstance in which alone the two instances differ, is the effect, or cause, or an necessary part of the cause, of the phenomenon.
Mill’s Method of Difference

If an instance in which the phenomenon under investigation occurs, and an instance in which it does not occur, have every circumstance save one in common, that one occurring only in the former; the circumstance in which alone the two instances differ, is the effect, or cause, or an necessary part of the cause, of the phenomenon.
Questions?
Neyman-Rubin Potential Outcomes Framework

If we are interested in some outcome $Y$, then for every unit $i$, there are numerous “potential outcomes” $Y^*$ only one of which is visible in a given reality. Comparisons of (partially unobservable) potential outcomes indicate causality.
Neyman-Rubin Potential Outcomes Framework

Concisely, we typically discuss two potential outcomes:

- $Y_{0i}$, the *potential* outcome realized if $X_i = 0$ (b/c $D_i = 0$, assigned to control)
- $Y_{1i}$, the *potential* outcome realized if $X_i = 1$ (b/c $D_i = 1$, assigned to treatment)
Experimental Inference I

- Each unit has multiple *potential* outcomes, but we only observe one of them, randomly.
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In this sense, we are sampling potential outcomes from each unit’s population of potential outcomes.

<table>
<thead>
<tr>
<th>unit</th>
<th>low</th>
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<tbody>
<tr>
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<tr>
<td>4</td>
<td>?</td>
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<td>?</td>
<td>…</td>
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</tbody>
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We cannot see individual-level causal effects

Ex.: Average difference in military support among those thinking of Hitler versus not

We want to know:

$$TE_i = Y_1 - Y_0$$
We cannot see individual-level causal effects

We can see *average causal effects*

Ex.: Average difference in military support among those thinking of Hitler versus not
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We can see *average causal effects*

Ex.: Average difference in military support among those thinking of Hitler versus not

We want to know: $TE_i = Y_{1i} - Y_{0i}$
We want to know: $TE_i = Y_{1i} - Y_{0i}$ for every $i$ in the population.
Experimental Inference III

- We want to know: $TE_i = Y_{1i} - Y_{0i}$ for every $i$ in the population
- We can average: $E[TE] = E[Y_1 - Y_0] = E[Y_1] - E[Y_0]$
Experimental Inference III

- We want to know: $TE_i = Y_{1i} - Y_{0i}$ for every $i$ in the population
- We can average: $E[TE] = E[Y_1 - Y_0] = E[Y_1] - E[Y_0]$
- But we still only see one potential outcome for each unit:

$$ATE_{naive} = E[Y_1|X = 1] - E[Y_0|X = 0]$$
We want to know: $TE_i = Y_{1i} - Y_{0i}$ for every $i$ in the population

We can average: $E[TE] = E[Y_1 - Y_0] = E[Y_1] - E[Y_0]$

But we still only see one potential outcome for each unit:

$ATE_{naive} = E[Y_1|X = 1] - E[Y_0|X = 0]$

Is this what we want to know?
What we want and what we have:

\[
ATE = E[Y_1] - E[Y_0] \tag{1}
\]

\[
ATE_{\text{naive}} = E[Y_1|X = 1] - E[Y_0|X = 0] \tag{2}
\]

Are the following statements true?

\[
E[Y_1] = E[Y_1|X = 1] \quad E[Y_0] = E[Y_0|X = 0]
\]

Not in general!
What we want and what we have:

\[ ATE = E[Y_1] - E[Y_0] \]  \hspace{1cm} (1)

\[ ATE_{naive} = E[Y_1|X = 1] - E[Y_0|X = 0] \]  \hspace{1cm} (2)

Are the following statements true?

- \[ E[Y_1] = E[Y_1|X = 1] \]
- \[ E[Y_0] = E[Y_0|X = 0] \]
Experimental Inference IV

- What we want and what we have:

\[
ATE = E[Y_1] - E[Y_0] \tag{1}
\]

\[
ATE_{naive} = E[Y_1 | X = 1] - E[Y_0 | X = 0] \tag{2}
\]

- Are the following statements true?

\[E[Y_1] = E[Y_1 | X = 1]\]
\[E[Y_0] = E[Y_0 | X = 0]\]

- Not in general!
Experimental Inference V

- Only true when both of the following hold:

\[
E[Y_1] = E[Y_1|X = 1] = E[Y_1|X = 0] \tag{3}
\]
\[
E[Y_0] = E[Y_0|X = 1] = E[Y_0|X = 0] \tag{4}
\]

- In that case, potential outcomes are independent of treatment assignment

- If true (e.g., due to randomization of \( X \)), then:

\[
ATE_{naive} = E[Y_1|X = 1] - E[Y_0|X = 0] = E[Y_1] - E[Y_0] = ATE \tag{5}
\]
This holds in experiments because of a physical process of randomization\textsuperscript{2}

\textsuperscript{2}Random means “known probability of treatment” not “haphazard”.
Experimental Inference VI

- This holds in experiments because of a *physical process of randomization*\(^2\)

- Units differ only in side of coin that was up
  - \(X_i = 1\) only because \(D_i = 1\)

---

\(^2\)Random means “known probability of treatment” not “haphazard”.
Experimental Inference VI

- This holds in experiments because of a *physical process of randomization*\(^2\)

- Units differ only in side of coin that was up
  - \(X_i = 1\) only because \(D_i = 1\)

**Implications:**
- Covariate balance
- Potential outcomes balanced and independent of treatment assignment
- No confounding (selection bias)

\(^2\)Random means “known probability of treatment” not “haphazard”.
Introductions

Course Outline

History/Logic

- Media Coverage
- Salience of Hitler
- Support for Military Intervention
- Demographics
- Ideology
- Political Sophistication
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Introductions
Course Outline
History/Logic

Media Coverage

Salience of Hitler

Randomly Assigned Prime

Demographics

Support for Military Intervention

Ideology

Political Sophistication
Questions?
The statistic of interest in an experiment is the \textit{sample average treatment effect} (SATE).

If our sample is \textit{representative}, then this provides an estimate of the population average treatment (PATE).

- Design-based random sampling
- Model-based re-weighting
The statistic of interest in an experiment is the *sample average treatment effect* (SATE)

- If our sample is *representative*, then this provides an estimate of the population average treatment (PATE)
  - Design-based random sampling
  - Model-based re-weighting

This boils down to being a mean-difference between two groups:

\[
SATE = \frac{1}{n_1} \sum Y_{1i} - \frac{1}{n_0} \sum Y_{0i}
\]  
(5)
An experimental data structure looks like:

<table>
<thead>
<tr>
<th>unit</th>
<th>treatment</th>
<th>outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
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<td>6</td>
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<td>10</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>9</td>
</tr>
</tbody>
</table>
**Tidy Experimental Data**

Sometimes it looks like this instead, which is bad:

<table>
<thead>
<tr>
<th>unit</th>
<th>treatment</th>
<th>outcome0</th>
<th>outcome1</th>
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</thead>
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<tr>
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<table>
<thead>
<tr>
<th>unit</th>
<th>treatment</th>
<th>outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>13</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>9</td>
</tr>
</tbody>
</table>
Computation of Effects I

- In practice we often estimate SATE using t-tests, ANOVA, or OLS regression
- These are all basically equivalent
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- Disciplinary norms
Computation of Effects I

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  - Ease of interpretation
Computation of Effects I

- In practice we often estimate SATE using t-tests, ANOVA, or OLS regression
- These are all basically equivalent
- Reasons to choose one procedure over another:
  - Disciplinary norms
  - Ease of interpretation
  - Flexibility for >2 treatment conditions
Computation of Effects II

R:

t.test(outcome ~ treatment, data = data)
lm(outcome ~ factor(treatment), data = data)

Stata:

ttest outcome, by(treatment)
reg outcome i.treatment
Questions?
Experimental Analysis II

- We don’t just care about the size of the SATE. We also want to know whether it is significantly different from zero (i.e., different from no effect/difference)

- Thus we need to estimate the *variance* of the SATE

- The variance is influenced by:
  - Total sample size
  - Element variance of the outcome, $Y$
  - Relative size of each treatment group
  - (Some other factors)
Experimental Analysis III

- Formula for the variance of the SATE is:
  \[ \widehat{\text{Var}}(SATE) = \widehat{\text{Var}}(\bar{Y}_0) + \widehat{\text{Var}}(\bar{Y}_1) \]

  - \( \widehat{\text{Var}}(\bar{Y}_0) \) is control group variance
  - \( \widehat{\text{Var}}(\bar{Y}_1) \) is treatment group variance

- We often express this as the standard error of the estimate:
  \[ \widehat{SE}_{SATE} = \sqrt{\widehat{\text{Var}}(\bar{Y}_0) + \widehat{\text{Var}}(\bar{Y}_1)} \]
Intuition about Variance

- Bigger sample $\rightarrow$ smaller SEs
- Smaller variance $\rightarrow$ smaller SEs

Efficient use of sample size:
- When treatment group variances equal, equal sample sizes are most efficient
- When variances differ, sample units are better allocated to the group with higher variance in $Y$
Statistical Power

- Power analysis is used to determine sample size before conducting an experiment
- Type I and Type II Errors

|                | $H_0$ False ($|ATE| > 0$) | $H_0$ True ($ATE = 0$) |
|----------------|--------------------------|------------------------|
| Reject $H_0$   | **True positive**        | Type I Error           |
| Accept $H_0$   | Type II Error            | True zero              |

- True positive rate ($1 - \kappa$) is power
- False positive rate is the significance threshold ($\alpha$)
Doing a Power Analysis

- $\mu$, Treatment group mean outcomes
- $N$, Sample size
- $\sigma$, Outcome variance
- $\alpha$, Statistical significance threshold
- $\phi$, a sampling distribution

$\text{Power} = \phi \left( \frac{|\mu_1 - \mu_0|}{2\sigma} \sqrt{N} - \phi^{-1} \left( 1 - \frac{\alpha}{2} \right) \right)$
Intuitions about Power

Minimum detectable effect is the smallest effect we could detect given sample size, “true” ATE, variance of outcome measure, power \((1 - \kappa)\), and \(\alpha\).
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In essence: some non-zero effect sizes are not detectable by a study of a given sample size.
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In essence: some non-zero effect sizes are not detectable by a study of a given sample size.

In underpowered study, we will be unlikely to detect true small effects. And most effects are small!  

---

Intuition about Power

- It can help to think in terms of “standardized effect sizes”
- Intuition: How large is the effect in standard deviations of the outcome?
  - Know if effects are large or small
  - Compare effects across studies
Intuition about Power

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- Cohen’s $d$: $d = \frac{\bar{x}_1 - \bar{x}_0}{s}$, where $s = \sqrt{\frac{(n_1-1)s_1^2+(n_0-1)s_0^2}{n_1+n_0-2}}$

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- Cohen’s $d$: $d = \frac{\bar{x}_1 - \bar{x}_0}{s}$, where $s = \sqrt{\frac{(n_1-1)s_1^2 + (n_0-1)s_0^2}{n_1 + n_0 - 2}}$
- Small: 0.2; Medium: 0.5; Large: 0.8
Intuition about Power

The diagram illustrates the relationship between sample size (per group) and Cohen's $d$ for different levels of power (0.99, 0.95, 0.90, 0.80, 0.50). As power increases, the sample size required to achieve a given Cohen's $d$ decreases.
Power analysis in R

```r
power.t.test(
    # sample size (leave blank!)
    n = ,

    # minimum detectable effect size
delta = 0.4, sd = 1,

    # alpha and power (1-kappa)
sig.level = 0.05, power = 0.8,

    # two-tailed vs. one-tailed test
    alternative = "two.sided"
)
```
Power analysis in Stata

```
power twomeans 0, diff(0.2)

// for multiple values of
forvalues i = 0.1 (0.1) 1.0 {
    power twomeans 0, diff('i')
}

// using raw effect sizes and standard deviations
power twomeans 0 0.5, sd1(.5) sd2(.7)

// adjusting alpha or power
power twomeans 0, diff(0.2) alpha(0.10) power(0.7)
```
## Increasing/Decreasing Power

<table>
<thead>
<tr>
<th>Increases Power</th>
<th>Decreases Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bigger sample</td>
<td>Attrition</td>
</tr>
<tr>
<td>Precise measures</td>
<td>Noncompliance</td>
</tr>
<tr>
<td>Covariates?</td>
<td>Clustering</td>
</tr>
</tbody>
</table>
Factorial Designs

- The two-condition experiment is a stylized ideal

- An experiment can have any number of conditions
  - Up to the limits of sample size
  - More than 8–10 conditions is typically unwieldy

- Three “flavors”:
  - Multiple conditions in a single factor
  - Multiple fully *crossed* factors
  - Partially crossed (“fractional factorial”) designs

- Regression methods provide a generalizable tool for causal inference in such designs
Example\textsuperscript{4}

- How close do you feel to your ethnic or racial group?

- Some people have said that taxes need to be raised to take care of pressing national needs. How willing would you be to have your taxes raised to improve education in public schools?

Example

How close do you feel to other Americans?

Some people have said that taxes need to be raised to take care of pressing national needs. How willing would you be to have your taxes raised to improve education in public schools?

---

Example$^4$

- How close do you feel to your ethnic or racial group?

- Some people have said that taxes need to be raised to take care of pressing national needs. How willing would you be to have your taxes raised to improve educational opportunities for minorities?

---

Example$^4$

- How close do you feel to other Americans?
- Some people have said that taxes need to be raised to take care of pressing national needs. How willing would you be to have your taxes raised to improve educational opportunities for minorities?

### 2x2 Factorial Design

<table>
<thead>
<tr>
<th>Condition</th>
<th>$Y_1$</th>
<th>$Y_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educ. for Minorities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schools</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# 2x2 Factorial Design

<table>
<thead>
<tr>
<th>Condition</th>
<th>Americans</th>
<th>Own Race</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educ. for Minorities</td>
<td>$Y_{1,0}$</td>
<td>$Y_{1,1}$</td>
</tr>
<tr>
<td>Schools</td>
<td>$Y_{0,0}$</td>
<td>$Y_{0,1}$</td>
</tr>
</tbody>
</table>
Two ways to parameterize this

Dummy variable regression (i.e., treatment–control CATEs):
\[ Y = \beta_0 + \beta_1 X_{0,1} + \beta_2 X_{1,0} + \beta_3 X_{1,1} + \epsilon \]

Interaction effects (i.e., treatment–treatment CATEs):
\[ Y = \beta_0 + \beta_1 X_{1_1} + \beta_2 X_{2_1} + \beta_3 X_{1_1} \times X_{2_1} + \epsilon \]

Use margins to extract marginal effects
Factorial designs can quickly become unwieldy and expensive. Need to consider what CATEs are of theoretical interest:

- Treatment–control, pairwise
- Treatment–treatment, pairwise
- Marginal effects, averaging across other factors
- Comparison of merged conditions
### Probably obvious, but...

<table>
<thead>
<tr>
<th>Factors</th>
<th>Conditions per factor</th>
<th>Total Conditions</th>
<th>$n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
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</tr>
<tr>
<td>4</td>
<td>4</td>
<td>16</td>
<td>3200</td>
</tr>
</tbody>
</table>

Assumes power to detect a relatively small effect, but no consideration of multiple comparisons.
Considerations

- Factorial designs can quickly become unwieldy and expensive
Considerations

- Factorial designs can quickly become unwieldy and expensive
- Need to consider what CATEs are of theoretical interest
  - Treatment–control, pairwise
  - Treatment–treatment, pairwise
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Questions?