The Essential Role of Pair Matching in Cluster-Randomized Experiments, with Application to the Mexican Universal Health Insurance Evaluation

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Joint work with Gary King (Harvard) & Clayton Nall (Stanford)

September 6, 2012

Published in *Statistical Science* (2009) with discussions
Problem of many field experiments:
- unit of randomization = clusters of individuals
- unit of interest = individuals

Public health and medicine:
CREs have “risen exponentially since 1997” (Campbell, 2004)

Political science:
About 2/3 of field experiments are CREs

Education:
Randomization of classrooms and schools
Advantages of CRE

- Feasibility
- Cluster-level treatment
- Interference between units
  - Standard potential outcomes framework: $Y_i(T_i = 1)$ and $Y_i(T_i = 0)$
  - Potential outcomes of one unit may depend on treatment status of other units: many potential outcomes for each unit
  - Examples: peer effects, contagion, spill-over effects
  - Causal inference with such interference is notoriously difficult
  - Cluster randomization limits the number of potential outcomes: all units in the same cluster receives the treatment vs. no unit does
  - Avoids the interference problem rather than “solving” it
Main Disadvantage of CREs and Possible Solution

- Problem: Loss of efficiency

\[
\text{CRE variance} = \text{usual variance} \times \{1 + (n - 1)\rho\}
\]

where \(n\) is the cluster size and \(\rho\) is the intracluster correlation coefficient

- Number of clusters is often small

- Matched-Pair Designs (MPDs) to improve efficiency:
  1. Pair clusters based on background characteristics
  2. Within each pair, randomly assign one cluster to the treatment group and the other to the control group

- Idea: Eliminate as much difference between treated and control groups as possible before randomization of treatment assignment
"Analytical limitations" of MPDs (Klar and Donner, 1997):
1. inability to test for homogeneity of causal effects across clusters
2. difficulties in estimating the intracluster correlation coefficient
3. Concerns about losing both clusters in a pair in event of randomization failure (Donner and Klar, 2000)

- In 10 or fewer pairs, MPDs can lose power (Martin et al. 1993)
- Our paper shows that these concerns are unfounded
Conclusion: pair-matching should be used whenever feasible
- MPDs improve bias, efficiency, and power
- Not pairing = throwing away data!

Existing estimator is based on a highly restrictive model
Propose new simple design-based estimators and s.e.’s
Demonstrate advantages using data from the Mexico study
Present quantities of interest for CREs
Design-based Analysis of CREs under MPDs

- Existing **Model-based** approach: assume DGP for observed data
- The standard estimator assumes homogeneity across clusters
  \[ \implies \text{no point of matching to begin with!} \]

- Our **Design-based** approach avoids modeling assumptions (Neyman, 1923)
- Randomness comes from:
  1. *randomization* of treatment assignment
  2. *random sampling* of clusters and units within clusters

- Recommendation: match on **cluster sizes and prognostic covariates**
Motivating Study: Seguro Popular de Salud (SPS)

- Article 4 of the Mexican constitution:
  
  \textit{all persons have a right to the protection of their health}

- SPS provides medical services, preventive care, pharmaceuticals, and financial health protection
- Voluntary and available for everyone but free to the poor
- Beneficiaries: intended to cover (by 2012) all 50M Mexicans who otherwise have no access to the healthcare system
- A key goal: reduce out-of-pocket health expenditures

- Randomized evaluation commissioned by the Fox administration
- One of the largest policy experiments to date
1. Define 12,284 “health clusters” that tile Mexico’s 31 states; each includes a health clinic and catchment area.
2. Persuaded 13 of 31 states to participate (7,078 clusters).
3. Match clusters in pairs on background characteristics.
4. Select 74 pairs (based on necessary political criteria, closeness of the match, likelihood of compliance).
5. Randomly assign one in each pair to receive encouragement to affiliate, better health facilities, drugs, and doctors.
6. Conduct baseline survey of each cluster’s health facility.
7. Survey $\approx 32,000$ random households in 50 of the 74 treated and control unit pairs (chosen based on likelihood of compliance with encouragement and similarity of the clusters within pair).
8. Repeat surveys in 10 months and subsequently to see effects.
Clustering is Representative on Measured Variables

- **Prop earning <2 min wages**
- **Mean Years Education**
- **Prop aged 0–4 years old**
- **Prop Employed**
- **Prop Female−headed HH**
- **Prop w/o Soc Sec Rights**

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Matched-Pair Cluster-Randomized Design

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<table>
<thead>
<tr>
<th>Quantities</th>
<th>Clusters</th>
<th>Units within Clusters</th>
<th>Inferential Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>SATE</td>
<td>Observed</td>
<td>Observed</td>
<td>Observed sample</td>
</tr>
<tr>
<td>CATE</td>
<td>Observed</td>
<td>Sampled</td>
<td>Population within observed clusters</td>
</tr>
<tr>
<td>UATE</td>
<td>Sampled</td>
<td>Observed</td>
<td>Observable units within pop. of clusters</td>
</tr>
<tr>
<td>PATE</td>
<td>Sampled</td>
<td>Sampled</td>
<td>Population</td>
</tr>
</tbody>
</table>
**Main Finding: Effect of SPS on % of Households with Catastrophic Expenditures**

<table>
<thead>
<tr>
<th></th>
<th>All Study Participants</th>
<th>Experimental Compliers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average (Control)</td>
<td>ITT</td>
</tr>
<tr>
<td>All</td>
<td>8.4</td>
<td>1.9*</td>
</tr>
<tr>
<td>Low Asset</td>
<td>9.9</td>
<td>3.0*</td>
</tr>
<tr>
<td>High Asset</td>
<td>7.1</td>
<td>0.9</td>
</tr>
<tr>
<td>Female-Headed</td>
<td>8.5</td>
<td>1.4</td>
</tr>
</tbody>
</table>

“Catastrophic expenditures”: out-of-pocket health expenses > 30% of post-subsistence income

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Efficiency Gains: MPD vs. Complete Randomization

- Unit ATE: MPDs 1.1 to 2.9 times more efficient
- Population ATE: MPDs 1.8 to 38.3 times more efficient!
Bias and Inefficiency of Existing Approach

Simulations Based on Mexico Data

- Coverage Probability of 90% CIs
- Ratio of Existing (Biased) SE to New (Unbiased) SE
- Average Cluster-Size Ratio Across Pairs

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Other Findings of SPS Evaluation

- **Positive effects detected:**
  - Catastrophic expenditures slashed
  - In-patient out-of-pocket expenditures drastically reduced
  - Out-patient out-of-pocket expenditures drastically reduced
  - Citizen satisfaction is high

- **Positive effects not yet seen:**
  - Expenditures on medicines
  - Utilization (preventative and procedures)
  - Risk factors
Concluding Remarks

- Field experiments often require cluster randomization
- Problem: Loss of statistical efficiency

Our recommendation: **MPDs for CREs**

1. Select quantities of interest
2. Identify pre-treatment covariates for matching
3. Pair clusters based on the covariates and cluster sizes
4. Randomize treatment within each pair
5. Use design-based methods to analyze the data

Our design-based estimators avoid modeling assumptions

- MPDs are preferred from perspectives of bias, efficiency, & power
- May affect CONSORT, Cochrane Collaboration, Council guidelines, etc.