Estimating Patient-Centered and Community-Centered Treatment Effects: Examples from Medical Care and Public Health

Glen P. Mays, *University of Kentucky*
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Examples from Medical Care and Public Health

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Acknowledgement

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Funding for this research was provided by the Robert Wood Johnson Foundation.
Questions of interest

- Do the effects of interventions vary across patient and community subgroups based on health needs, vulnerabilities and risks?

- How can we estimate treatment heterogeneity at the level of the individual patient or community?

- Can we achieve larger and more equitable impacts with this knowledge, e.g. through enhanced targeting and tailoring of interventions?
  - Precision medicine
  - Precision public health
Instrumental variables: a review

- IVs influence treatment choices/exposures but are independent of factors that determine outcomes.
- IVs serve as natural randomizers: they approximate RCTs with observational studies.
- IVs can be used to estimate causal treatment effects while accounting for both observed and hidden confounding and selection bias.
IVs: a classic example

**Unobserved confounder:** Treatment selection of lower-risk patients.

**Treatment**
Invasive cardiac treatment

Relative Rate = 0.84
95% CI: 0.79-0.90

**Outcome**
Long-term AMI Mortality rate

**Observed confounders:**
Age, sex, race, socio-economic status, comorbidities, inpatient treatments

**Instrumental Variable**
Regional catheterization rate

Differential distance to hospitals with cath labs
Treatment effect heterogeneity: fundamental empirical questions

- Which programs, interventions, policies, strategies (*mechanisms*)…
- Work best (*outcomes*)…
- In which institutional & community settings (*contexts*)…
- For whom (*populations and subgroups*)?

Pawson and Tilley 1997
Treatment effect heterogeneity

- Biological, behavioral, or structural mechanisms

- Average treatment effect from an RCT may not match the causal treatment effect found in observational data

- Average treatment effect may have little clinical utility and policy significance

- IV estimates may be difficult to interpret in the presence of treatment effect heterogeneity
Variations in policy design, implementation, enforcement

Estimated Effects of Smoke-free Policies on AMI admissions

<table>
<thead>
<tr>
<th>Study ID</th>
<th>ES (95% CI)</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Helena Montana</td>
<td>0.60 (0.21, 0.99)</td>
<td>1.76</td>
</tr>
<tr>
<td>Pueblo Colorado</td>
<td>0.73 (0.63, 0.85)</td>
<td>10.13</td>
</tr>
<tr>
<td>Piedmont Italy</td>
<td>0.89 (0.81, 0.98)</td>
<td>12.14</td>
</tr>
<tr>
<td>Bowling Green Ohio</td>
<td>0.61 (0.55, 0.67)</td>
<td>14.24</td>
</tr>
<tr>
<td>New York State</td>
<td>0.80 (0.80, 0.80)</td>
<td>17.20</td>
</tr>
<tr>
<td>Ireland</td>
<td>0.89 (0.81, 0.97)</td>
<td>12.56</td>
</tr>
<tr>
<td>Saskatoon Canada</td>
<td>0.87 (0.84, 0.90)</td>
<td>16.35</td>
</tr>
<tr>
<td>Rome Italy</td>
<td>0.89 (0.85, 0.93)</td>
<td>15.61</td>
</tr>
<tr>
<td>Overall</td>
<td>0.81 (0.76, 0.86)</td>
<td>100.00</td>
</tr>
</tbody>
</table>

NOTE: Weights are from random effects analysis

Glantz 2008
Treatment effect heterogeneity: estimation problems

- Treatment effects may vary over unobserved confounders

- "Essential heterogeneity"

- IV estimates may vary with specific IVs used

**Solution:** local IV methods to estimate marginal treatment effects (Heckman 1999, 2006)
Person-centered treatment effect estimation

- Treatment effects vary across patients based on factors observed by decision-makers
- Treatment is “sorted” across patients based in part on differential potential benefit
  - No single treatment effect
  - Average treatment effects vary across patient subgroups based on chosen treatment levels

Heckman et al. 2006; Basu et al 2007
Person-centered treatment effect estimation

- PCTE is a conditional treatment effect that conditions on observed risk factors AND averages over the conditional distribution of unobserved risk factors, conditional on treatment choices
- Identifies individual-level treatment effect heterogeneity better than other methods
- Superior at identifying/controlling for self-selection
- Requires IVs to isolate distribution of unobserved risk factors

Heckman et al. 2006; Basu et al. 2007
Person-centered treatment effect estimation

Revisiting the CATIE Trial Results

PeT Effects of Generic Group vs Branded Group of AADs

On # of Schizophrenia-related hospitalizations in Year 1

Received Generic AADs

Received Branded AADs

Basu et al. 2013
## Person-centered treatment effect estimation

Revisiting the CATIE Trial Results

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Average annual number of hospitalizations (95% CI)</th>
<th>% change from Status-quo</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status-quo</td>
<td>1.83 (1.81 – 1.85)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>All patients started on branded group of AADs</td>
<td>1.73 (1.59 – 1.87)</td>
<td>-5.5</td>
<td>0.15</td>
</tr>
<tr>
<td>All patients started on generic group of AADs</td>
<td>2.07 (1.91 – 2.23)</td>
<td>13.1</td>
<td>0.001</td>
</tr>
<tr>
<td>All patients started on optimal predicted therapy</td>
<td>1.32 (1.26 – 1.40)</td>
<td>-27.9</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Notes: P-values reflect comparisons of average annual number of hospitalizations under various scenarios to status quo.

Basu et al. 2013
Does treatment heterogeneity extend to public health services at the community-level?
Research questions of interest

- Which organizations contribute to the implementation of public health activities in local communities?

- How do these contributions change over time? Recession, recovery, ACA implementation?

- What are the health and economic effects of these activities?
  - Heterogeneity by population and delivery system characteristics?
Data: public health production

National Longitudinal Survey of Public Health Systems

- Cohort of 360 communities with at least 100,000 residents
- Local public health officials report:
  - **Scope**: availability of 20 recommended public health activities
  - **Network**: types of organizations contributing to each activity
  - **Effort**: contributed by designated local public health agency
  - **Quality**: perceived effectiveness of each activity

** Stratified sample of 500 communities<100,000 added in 2014 wave
Cluster and network analysis to identify “system capital”

Cluster analysis is used to classify communities into one of 7 categories of public health system capital based on:

- **Scope of activities** contributed by each type of organization
- **Density of connections** among organizations jointly producing public health activities
- **Degree centrality** of the local public health agency

Estimating network effects

**Dependent variables:**

- **Quantity**: Percent of recommended public health activities performed in the community
- **Quality**: Perceived effectiveness of activities
- **Resource use**: Local governmental expenditures for public health activities
- **Health outcomes**: premature mortality (<75), infant mortality, death rates for heart disease, diabetes, cancer, influenza

**Independent variables:**

- **Contribution scores**: percent of activities contributed by each type of organization
- **Network characteristics**: network density, organizational degree centrality, betweenness centrality
Estimating network effects

Estimation:

- Log-transformed Generalized Linear Latent and Mixed Models
- Account for repeated measures and clustering of public health jurisdictions within states
- Instrumental variables address endogeneity of network structures

\[
\ln(\text{Network}_{z,ijt}) = \sum \alpha_z \ln(\text{Governance}_{ijt}) + \beta_1 \text{Agency}_{ijt} + \beta_2 \text{Community}_{ijt} + \mu_j + \phi_t + \epsilon_{ijt}
\]

\[
\ln(\text{Quantity/Quality/Cost}_{ijt}) = \sum \alpha_z \ln(\hat{\text{Network}}_{z,ijt}) + \beta_1 \text{Agency}_{ijt} + \beta_2 \text{Community}_{ijt} + \mu_j + \phi_t + \epsilon_{ijt}
\]

All models control for type of jurisdiction, population size and density, metropolitan area designation, income per capita, unemployment, racial composition, age distribution, educational attainment, and physician availability.
### Delivery of recommended public health activities, 1998-2014

<table>
<thead>
<tr>
<th>Public Health Activity</th>
<th>1998</th>
<th>2014</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Community health needs assessment</td>
<td>71.5%</td>
<td>86.0%</td>
<td>20.2%**</td>
</tr>
<tr>
<td>2 Behavioral risk factor surveillance</td>
<td>45.8%</td>
<td>70.2%</td>
<td>53.2%**</td>
</tr>
<tr>
<td>3 Adverse health events investigation</td>
<td>98.6%</td>
<td>100.0%</td>
<td>1.4%</td>
</tr>
<tr>
<td>4 Public health laboratory testing services</td>
<td>96.3%</td>
<td>96.5%</td>
<td>0.2%</td>
</tr>
<tr>
<td>5 Analysis of health status and health determinants</td>
<td>61.3%</td>
<td>72.8%</td>
<td>18.7%**</td>
</tr>
<tr>
<td>6 Analysis of preventive services utilization</td>
<td>28.4%</td>
<td>39.4%</td>
<td>38.8%**</td>
</tr>
<tr>
<td>7 Health information provision to elected officials</td>
<td>80.9%</td>
<td>84.8%</td>
<td>4.8%</td>
</tr>
<tr>
<td>8 Health information provision to the public</td>
<td>75.4%</td>
<td>83.8%</td>
<td>11.1%*</td>
</tr>
<tr>
<td>9 Health information provision to the media</td>
<td>75.2%</td>
<td>87.5%</td>
<td>16.3%**</td>
</tr>
<tr>
<td>10 Prioritization of community health needs</td>
<td>66.1%</td>
<td>82.3%</td>
<td>24.6%**</td>
</tr>
<tr>
<td>11 Community participation in health improvement planning</td>
<td>41.5%</td>
<td>67.7%</td>
<td>63.0%**</td>
</tr>
<tr>
<td>12 Development of community health improvement plan</td>
<td>81.9%</td>
<td>86.2%</td>
<td>5.2%</td>
</tr>
<tr>
<td>13 Resource allocation to implement community health plan</td>
<td>26.2%</td>
<td>43.2%</td>
<td>64.9%**</td>
</tr>
<tr>
<td>14 Policy development to implement community health plan</td>
<td>48.6%</td>
<td>57.5%</td>
<td>18.4%*</td>
</tr>
<tr>
<td>15 Communication network of health-related organizations</td>
<td>78.8%</td>
<td>84.8%</td>
<td>7.6%</td>
</tr>
<tr>
<td>16 Strategies to enhance access to needed health services</td>
<td>75.6%</td>
<td>50.2%</td>
<td>-33.6%**</td>
</tr>
<tr>
<td>17 Implementation of legally mandated public health activities</td>
<td>91.4%</td>
<td>92.4%</td>
<td>1.0%</td>
</tr>
<tr>
<td>18 Evaluation of public health programs and services</td>
<td>34.7%</td>
<td>38.4%</td>
<td>10.8%**</td>
</tr>
<tr>
<td>19 Evaluation of local public health agency capacity/performance</td>
<td>56.3%</td>
<td>55.0%</td>
<td>-2.4%</td>
</tr>
<tr>
<td>20 Implementation of quality improvement processes</td>
<td>47.3%</td>
<td>49.6%</td>
<td>5.0%</td>
</tr>
<tr>
<td>Composite availability of assessment activities (1-6)</td>
<td>66.7%</td>
<td>77.6%</td>
<td>16.4%**</td>
</tr>
<tr>
<td>Composite availability of policy development activities (7-15)</td>
<td>60.2%</td>
<td>72.5%</td>
<td>20.4%</td>
</tr>
<tr>
<td>Composite availability of assurance activities (16-20)</td>
<td>64.4%</td>
<td>52.8%</td>
<td>-18.0%*</td>
</tr>
<tr>
<td>Composite availability of all activities (1-20)</td>
<td>63.8%</td>
<td>67.6%</td>
<td>6.0%*</td>
</tr>
</tbody>
</table>
Variation and Change in Delivery
Delivery of recommended public health activities, 2006-14

Quintiles of communities

National Longitudinal Survey of Public Health Systems, 2014
Node size = centrality
Line size = % activities jointly contributed (tie strength)
Prevalence of Public Health System Configurations, 1998-2014

<table>
<thead>
<tr>
<th>Scope</th>
<th>Centrality</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Mod</td>
<td>High</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>Mod</td>
</tr>
<tr>
<td>Mod</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Mod</td>
<td>Low</td>
<td>Mod</td>
</tr>
<tr>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Mod</td>
</tr>
</tbody>
</table>

Comprehensive (High System Capital)

Conventional

Limited
Prior Research: Mortality reductions attributable to local public health spending, 1993-2008

Hierarchical regression estimates with instrumental variables to correct for selection and unmeasured confounding

Mays et al. 2011
Prior Research: Medical cost offsets attributable to local public health spending 1993-2008

Offset elasticity = -0.088

Mays et al. 2013
Value of an additional dollar in public health

Health

Public Health Spending

A. Under-spending
B. Equipoise spending
C. Over-spending
Analytic Approach

- Use the technique of local instrumental variables (LIV) estimation to estimate **community-specific effects** of public health spending.

- Compare the health & economic impact of increases public health spending between:
  - Low-income vs. higher-income communities
  - Agencies that deliver broad vs. narrow scope of public health activities


Local IV Approach

- Estimate predicted spending (P) as a function of all measured covariates (X) and instruments (Z)
- Model outcome (O) as nonlinear function of P(X,Z) and X
- Estimate $\frac{\partial O}{\partial P}$ the effect of a change in predicted spending on the outcome
- Find the distribution of P(X,Z) for the subset of communities of interest
- Estimate the average treatment effect for each subset as the average weighted value of $\frac{\partial O}{\partial P}$ across the subset


Analytical approach: IV estimation

- Identify exogenous sources of variation in spending that are unrelated to outcomes
  - Governance structures: local boards of health
  - Decision-making authority: agency, board, local, state

- Controls for unmeasured factors that jointly influence spending and outcomes

![Diagram showing relationships between Governance/Decision-making, PH spending, Unmeasured economic conditions, Unmeasured disease burden, risk, Mortality/Medical $]
## Determinants of Local Public Health Spending Levels: Local IVs

<table>
<thead>
<tr>
<th>Governance/Decision Authority</th>
<th>Coefficient</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Governed by local board of health</td>
<td>0.131**</td>
<td>(0.061, 0.201)</td>
</tr>
<tr>
<td>State hires local PH agency head†</td>
<td>-0.151*</td>
<td>(-0.318, 0.018)</td>
</tr>
<tr>
<td>Local board approves local PH budget</td>
<td>0.388***</td>
<td>(0.576, 0.200)</td>
</tr>
<tr>
<td>State approves local PH budget†</td>
<td>-0.308**</td>
<td>(-0.162, -0.454)</td>
</tr>
<tr>
<td>Local govt sets local PH fees</td>
<td>0.217**</td>
<td>(0.101, 0.334)</td>
</tr>
<tr>
<td>Local govt imposes local PH taxes</td>
<td>0.190**</td>
<td>(0.044, 0.337)</td>
</tr>
<tr>
<td>Local board can request local PH levy</td>
<td>0.120**</td>
<td>(0.246, 0.007)</td>
</tr>
</tbody>
</table>

\[
F = 16.4 \quad p < 0.001
\]

log regression estimates controlling for community-level and state-level characteristics.  
*p<0.10  \quad **p<0.05  \quad ***p<0.01

†As compared to the local board of health having the authority.

Mays et al. HSR 2009
Community-specific estimates of public health spending on heart disease mortality

Impact of 10% Increase in Public Health Spending/Capita Based on Income Per Capita in Communities

Log IV regression estimates controlling for community-level and state-level characteristics

Mays et al. forthcoming 2013
Community-specific estimates of public health spending on heart disease mortality

Impact of 10% Increase in Public Health Spending/Capita Based on Delivery System Comprehensiveness

Log IV regression estimates controlling for community-level and state-level characteristics

Mays et al. forthcoming 2013
Comprehensive systems do more with less

![Bar chart showing expenditures per capita and recommended activities performed across different types of delivery systems.](chart.png)
Conclusions

- Sizable health & economic gains are attributable to local public health expenditures
- Gains are 21-44% larger in low-income communities
- Gains are 17-38% larger for communities with comprehensive delivery systems
- No evidence of over-spending
Implications for policy & practice

Increase the value of public health investments through:

- **Enhanced targeting**: low-resource, high-need communities

- **Enhanced infrastructure**: broad scope of core public health activities
  - Accreditation standards
  - Minimum package of services
Can Patient-Centered Treatment Estimation Help to Evaluate Community-level Programs?
Estimating Program ROI
Arkansas Community Connector Program

- Use community health workers & public health infrastructure to identify people with unmet social support needs
- Connect people to home and community-based services & supports
- Link to hospitals and nursing homes for transition planning
- Use Medicaid and SIM financing, savings reinvestment
- Costing with electronic time logs

Felix, Mays et al. 2011
http://content.healthaffairs.org/content/30/7/1366.abstract
The Community Connector Program (CCP)

- Quasi-experimental research design
- Measured expenditures one year before participation and up to 3 years after participation
- Statistically-matched comparison group of Medicaid recipients not served by CCP
- Difference-in-difference estimates of impact, controlling for time-varying covariates

Source: RWJF University of Wisconsin County Health Rankings 2014
# Estimates of Program Impact

## Regression-Adjusted, Difference-in-Difference Estimates

<table>
<thead>
<tr>
<th>Time Period*</th>
<th>Average Spending Change from Baseline</th>
<th>PET Spending Change for Multi-morbidity patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>-6.0%**</td>
<td>-9.6%**</td>
</tr>
<tr>
<td>Year 2</td>
<td>-13.4%**</td>
<td>18.2%**</td>
</tr>
<tr>
<td>Year 3</td>
<td>-15.3%**</td>
<td>21.4%**</td>
</tr>
</tbody>
</table>

After adjusting for baseline and time-varying differences between groups

*Reference year is one year prior to CCP participation

**p<0.05
Estimated Program ROI

Three Year Aggregate Estimates

- Combined Medicaid spending reductions: $3.515 M
- Program implementation costs: $0.896 M
- Net savings: $2.629 M
- ROI: $2.92
- ROI for multi-morbidity: $5.17

Felix, Mays et al. 2011
http://content.healthaffairs.org/content/30/7/1366.abstract
PCT References


Heckman JJ, Vytlacil EJ. Local instrumental variables and latent variable models for identifying and bounding treatment effects. Proc Nat Acad Sci 1999; 96(8): 4730-34


Funded by Robert Wood Johnson Foundation: $10.5M to UK from 2011-2015

Intramural research activities
- Public Health Value: Cost estimation, economic evaluation
- Delivery System Reform: ACA effects on public health delivery, population health measurement, aligning public health & health care delivery

Extramural research programs (funded separately ≈ $30M)
- Practice-based Research Networks (PBRNs) across U.S.
- Investigator-initiated research awards
- Predoctoral/Postdoctoral & career development awards
- Quick Strike rapid-cycle studies