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Using Network Analysis to Understand Public Health Delivery Systems & Community Health Initiatives

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Using Network Analysis to Understand Public Health Delivery Systems & Community Health Initiatives

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Acknowledgements

- Funded by the Robert Wood Johnson Foundation through the **Public Health Services & Systems Research National Coordinating Center**
- Collaborators include Cezar Mamaril, Lava Timsina, Rachel Hogg, David Bardach
Using networks for population health improvement strategies

- Designed to achieve large-scale health improvement: neighborhood, city/county, region
- Target fundamental and often multiple determinants of health
- Mobilize the collective actions of multiple stakeholders in government & private sector
  - Usual and unusual suspects
  - Infrastructure requirements

Using networks to overcome collective action problems

- Incentive compatibility → public goods
- Concentrated costs & diffuse benefits
- Time lags: costs vs. improvements
- Uncertainties about what works
- Asymmetry in information
- Difficulties measuring progress
- Weak and variable institutions & infrastructure
- Imbalance: resources vs. needs
- Stability & sustainability of funding

Ostrom E. 1994
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?

- How do patterns of interaction in public health production influence quantity, quality, cost & population health?
  - Complementarities/Synergies
  - Substitutions/Cannibalization
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
Data: community & market characteristics

- **Area Health Resource File**: physician, hospital and CHC supply; population size and demographics, socioeconomic status, racial/ethnic composition, health insurance coverage

- **NACCHO Profile data**: public health agency institutional and financial characteristics

- **Medicare Cost Report**: hospital ownership, market share, uncompensated care

- **CDC Compressed Mortality File**: Cause-specific death rates by county
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

Network analytic approach

Two-mode networks (organization types X activities) transformed to one-mode networks with tie strength indicated by number of activities jointly produced

<table>
<thead>
<tr>
<th>Organization Type</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Local public health agency</td>
<td>X</td>
</tr>
<tr>
<td>State public health agency</td>
<td>X</td>
</tr>
<tr>
<td>Hospitals</td>
<td>X</td>
</tr>
<tr>
<td>Physician practices</td>
<td></td>
</tr>
<tr>
<td>CHCs</td>
<td>X</td>
</tr>
<tr>
<td>Insurers</td>
<td></td>
</tr>
<tr>
<td>Employers</td>
<td></td>
</tr>
<tr>
<td>Social service organizations</td>
<td>X</td>
</tr>
<tr>
<td>Schools</td>
<td></td>
</tr>
</tbody>
</table>
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

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

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

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

- Assessment (+5.6%)
- Policy/Planning (+15.8%)
- Total (+1.1%)
- Assurance (-18.4%)

% of recommended activities performed:

- 1998: 60%
- 2006: 70%
- 2012: 75%
- 2014: 70%

Graph shows a trend in the delivery of recommended public health activities from 1998 to 2014, with specific percentages and changes noted for assessment, policy/planning, and total activities.
## 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, 2006-12

% of recommended activities performed

Q1  Q2  Q3  Q4  Q5

2012

Δ 2006-12

Δ 2014:  -4.5%  -1.2%  +0.5%  +2.6%  +5.1%

Quintiles of communities
<table>
<thead>
<tr>
<th>Type of Organization</th>
<th>1998</th>
<th>2006</th>
<th>2012</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local public health agency</td>
<td>60.7%</td>
<td>66.5%</td>
<td>62.0%</td>
<td>67.4%</td>
</tr>
<tr>
<td>Other local govt agencies</td>
<td>31.8%</td>
<td>50.8%</td>
<td>26.3%</td>
<td>32.7%</td>
</tr>
<tr>
<td>State public health</td>
<td>46.0%</td>
<td>45.3%</td>
<td>36.4%</td>
<td>34.0%</td>
</tr>
<tr>
<td>Other state govt agencies</td>
<td>17.2%</td>
<td>16.4%</td>
<td>13.0%</td>
<td>12.7%</td>
</tr>
<tr>
<td>Federal agencies</td>
<td>7.0%</td>
<td>12.0%</td>
<td>8.7%</td>
<td>7.1%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>37.3%</td>
<td>41.1%</td>
<td>39.3%</td>
<td>47.2%</td>
</tr>
<tr>
<td>Physician practices</td>
<td>20.2%</td>
<td>24.1%</td>
<td>19.5%</td>
<td>18.0%</td>
</tr>
<tr>
<td>Community health centers</td>
<td>12.4%</td>
<td>28.6%</td>
<td>26.9%</td>
<td>28.3%</td>
</tr>
<tr>
<td>Health insurers</td>
<td>8.6%</td>
<td>10.0%</td>
<td>9.8%</td>
<td>11.1%</td>
</tr>
<tr>
<td>Employers/business</td>
<td>25.5%</td>
<td>16.9%</td>
<td>13.4%</td>
<td>15.0%</td>
</tr>
<tr>
<td>Schools</td>
<td>30.7%</td>
<td>27.6%</td>
<td>24.9%</td>
<td>24.7%</td>
</tr>
<tr>
<td>Universities/colleges</td>
<td>15.6%</td>
<td>21.6%</td>
<td>21.2%</td>
<td>22.2%</td>
</tr>
<tr>
<td>Faith-based organizations</td>
<td>24.0%</td>
<td>19.2%</td>
<td>15.7%</td>
<td>16.8%</td>
</tr>
<tr>
<td>Other nonprofits</td>
<td>31.9%</td>
<td>34.2%</td>
<td>31.6%</td>
<td>33.6%</td>
</tr>
<tr>
<td>Other organizations</td>
<td>8.5%</td>
<td>8.8%</td>
<td>5.4%</td>
<td>5.4%</td>
</tr>
</tbody>
</table>
Average public health network structure in 2014

Node size = degree centrality
Line size = % activities jointly contributed (tie strength)
## Changes in network structure 1998-2014

<table>
<thead>
<tr>
<th>Network Structure</th>
<th>1998</th>
<th>2006</th>
<th>2012</th>
<th>2014</th>
<th>&lt;100k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network density</td>
<td>11.3%</td>
<td>16.3%</td>
<td>13.0%</td>
<td>13.6%</td>
<td>7.8%</td>
</tr>
<tr>
<td>Network centralization</td>
<td>14.4%</td>
<td>15.0%</td>
<td>13.3%</td>
<td>14.2%</td>
<td>11.7%</td>
</tr>
<tr>
<td>Betweenness centrality: Public health agencies</td>
<td>21.7%</td>
<td>19.1%</td>
<td>39.8%</td>
<td>31.5%</td>
<td>24.5%</td>
</tr>
<tr>
<td>Hospitals</td>
<td>6.9%</td>
<td>9.7%</td>
<td>13.1%</td>
<td>13.2%</td>
<td>9.4%</td>
</tr>
</tbody>
</table>
Bridging capital in public health delivery systems
Trends in betweenness centrality

* Change from prior years is statistically significant at p<0.05
Prevalence of Public Health System Configurations, 1998-2014

<table>
<thead>
<tr>
<th>Scope</th>
<th>Centrality</th>
<th>Density</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>Mod</td>
<td>High</td>
<td>1998</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>2006</td>
</tr>
<tr>
<td>High</td>
<td>High</td>
<td>Mod</td>
<td>2012</td>
</tr>
<tr>
<td>Mod</td>
<td>High</td>
<td>Low</td>
<td>2014</td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>Low</td>
<td>Mod</td>
<td></td>
</tr>
</tbody>
</table>

- **Comprehensive (High System Capital)**
- **Conventional**
- **Limited**
Changes in system capital prevalence and coverage

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Comprehensive systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of communities</td>
<td>24.2%</td>
<td>36.9%</td>
<td>31.1%</td>
<td>32.7%</td>
<td>25.7%</td>
</tr>
<tr>
<td>% of population</td>
<td>25.0%</td>
<td>50.8%</td>
<td>47.7%</td>
<td>47.2%</td>
<td>36.6%</td>
</tr>
<tr>
<td><strong>Conventional systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of communities</td>
<td>50.1%</td>
<td>33.9%</td>
<td>49.0%</td>
<td>40.1%</td>
<td>57.6%</td>
</tr>
<tr>
<td>% of population</td>
<td>46.9%</td>
<td>25.8%</td>
<td>36.3%</td>
<td>32.5%</td>
<td>47.3%</td>
</tr>
<tr>
<td><strong>Limited systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of communities</td>
<td>25.6%</td>
<td>29.2%</td>
<td>19.9%</td>
<td>20.6%</td>
<td>16.7%</td>
</tr>
<tr>
<td>% of population</td>
<td>28.1%</td>
<td>23.4%</td>
<td>16.0%</td>
<td>19.6%</td>
<td>16.1%</td>
</tr>
</tbody>
</table>
### Determinants of public health system structure

Probit Estimates of Factors Influencing the Probability of Comprehensive System Capital

<table>
<thead>
<tr>
<th>Variable</th>
<th>Marginal Effect on Probability of System Capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local board of health with decentralized governance</td>
<td>14.2%**</td>
</tr>
<tr>
<td>Local board of health with centralized governance</td>
<td>9.7%**</td>
</tr>
<tr>
<td>Centralized governance without local board of health</td>
<td>-4.5%**</td>
</tr>
<tr>
<td>Decentralized governance without local board of health</td>
<td>Reference</td>
</tr>
<tr>
<td>Population size (100,000s)</td>
<td>4.2%**</td>
</tr>
<tr>
<td>Population density (1000s)</td>
<td>4.9%*</td>
</tr>
<tr>
<td>Household income per capita (1000s)</td>
<td>2.5%**</td>
</tr>
</tbody>
</table>

Models also control for racial composition, unemployment, health insurance coverage, educational attainment, age composition, and state and year fixed effects. 
N=779 community-years  **p<0.05   *p<0.10
Health and economic impact of system structures

Fixed Effects and IV Estimates: Effects of Comprehensive System Capital on Mortality and Spending

Models also control for racial composition, unemployment, health insurance coverage, educational attainment, age composition, and state and year fixed effects. N=779 community-years **p<0.05    *p<0.10
Comprehensive systems do more with less

![Chart showing expenditures per capita and percentage of recommended activities performed by type of delivery system]
Do other organizations complement or substitute for local public health agency centrality?

Results from Multivariate GLLAMM Models
How does organizational centrality affect the total supply of public health activities?

Results from Multivariate GLLAMM Models

- Hospitals
- Insurers
- Employers
- Physicians
- CHCs
Conclusions

- Comprehensive and highly-integrated public health systems appear to offer considerable health and economic benefits over time.
  - 10-40% larger reductions in preventable mortality rates
  - 15% lower public health resource use

- Low-income communities are less likely to achieve comprehensive public health system capital, as are communities without local governance structures.

- Failure to account for endogenous network structure can lead to biased estimates of impact
Policy and Practice Implications

- Strategies to improve population health and health system efficiency should include initiatives to build public health system capital.

- Public health delivery has become increasingly reliant on nongovernmental & health care contributions.

- Increased resiliency during economic shocks.

- Heightened need for coordination, monitoring, and accountability.

- Vulnerability to instability in contributions over time.
Limitations and Next Steps

- Organization types – lacking institutional granularity
- Single perspective – local health officials
- Future possible comparisons:
  - ACA effects
  - Hospital community benefit activities
  - PHAB accreditation
For More Information

Supported by The Robert Wood Johnson Foundation

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Blog: publichealththeconomics.org

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Lexington, KY
Thank You for Attending Today’s Methods Workshop.

Please take a moment to fill out a three (3) question evaluation on the 2015 ARM Methods Workshop(s) you attended at: