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Technical Appendix: Estimating the Effects of Public Health Spending on Preventable Mortality

Study Population

A longitudinal, retrospective cohort design was used to analyze changes in spending patterns and population health within service areas of the nation's nearly 3000 local public health agencies between 1993 and 2005. The study population included all organizations operating during this time period that met the National Association of County and City Health Officials' (NACCHO) definition of a local health department: an administrative or service unit of a local or state government that has responsibility for performing public health functions for a geopolitical jurisdiction smaller than a state.[1] NACCHO maintains an active list of these organizations through public records reviews and ongoing contacts with government officials. During the study period, all U.S. states except Rhode Island contained agencies that met this definition. In 2005, approximately 73 percent of these agencies served county jurisdictions or combined city-county jurisdictions, with the remaining agencies serving city or township jurisdictions (16%) or multi-county or regional jurisdictions (11%).

Data Sources

NACCHO collected expenditure data along with organizational and operational characteristics of local public health agencies through census surveys fielded in 1993, 1997, and 2005. A total of 2888 agencies meeting the NACCHO definition were identified in 1993, of which 72 percent responded to the survey. During the 1997 survey, 88 percent of the 2834 identified agencies provided usable responses, and in 2005 80 percent of 2864 agencies responded. While the content of the survey changed considerably from year to year, a core set of variables reflecting annual agency expenditures, jurisdiction size, service offerings and staffing levels were collected in each year of the survey. Observations were linked across the three years of the survey using identifying information on each public health agency.

Using identifying information about each local public health agency’s jurisdiction and the county or counties in which it operates, we linked the NACCHO survey data with contemporaneous information from several other data sources. County-level data on population characteristics and health resources were obtained from the Area Resource File, a collection of more than 50 data sources including the American Medical Association Physician

Masterfile, the American Hospital Association Annual Hospital Survey, and U.S. Census Bureau data sources. County-level variables reflecting direct federal public health expenditures were constructed from the Census Bureau's Consolidated Federal Funds Report. State-level data on public health expenditures were obtained from the U.S. Census Bureau's 1993, 1997, and 2005 Census of Governments using expenditure function category 32 that excludes hospital care and most other medical care expenditures.

We also linked the NACCHO data with county-level mortality data obtained from the CDC Compressed Mortality File. Each county-specific mortality rate was constructed using two calendar years of data in order to increase statistical precision in small counties. Mortality data for calendar years 1992 and 1993 were linked with the 1993 NACCHO survey data, while mortality data for 1996-97 were linked with the 1997 NACCHO data, and mortality data for 2004-05 were linked with the 2005 NACCHO survey data. All county-level data were linked with the NACCHO data using county identifiers. For public health agencies serving jurisdictions of more than one county, we aggregated county-level data to the jurisdiction level.

Measures and Model Specification

Health Outcome Measures. For the dependent variables used in this analysis, we selected health outcome measures that were routinely collected from public health surveillance systems, available at the local (county) level, and that were expected to be sensitive to public health interventions over the 13-year period of study.[2, 3] Based on these criteria, we selected the all-cause mortality rate, the infant mortality rate, and the cause-specific mortality rates for heart disease, cancer, diabetes, and influenza. All mortality rates used in the analysis were age-adjusted based on the national age distribution from the 2000 U.S. Census. Two additional mortality measures were selected as control conditions based on the hypothesis that they would not be influenced by public health resources and interventions over the period of study. These measures included mortality from Alzheimer's disease and a measure of residual mortality indicating deaths not attributable to heart disease, chronic obstructive pulmonary disease, cancer, diabetes, influenza, cerebrovascular diseases, or unintentional injuries.

Public Health Spending Measures. The primary independent variable of interest in this analysis is the measure of per-capita local public health spending. This variable was measured as the total annual expenditures of the local public health agency, divided by the total population residing within the jurisdiction of the agency. The 1997 and 2005 NACCHO surveys collected jurisdiction population estimates, so these data were used construct the estimates of spending per capita in those years. The 1993 survey did not collect detailed population estimates, so we constructed measures of the jurisdiction population size for that year using Census data.

Each spending measure was adjusted to represent 2005 constant dollars using a weighted average of the general Consumer Price Index (CPI) and the medical care CPI as proposed by NACCHO.[1] Because public health agencies often provide a mix of personal medical services and population-based public health activities, using a blend of the medical care price index and the general price index is likely to provide the most accurate approximation of price trends faced by public health agencies. Ideally, the weights for this adjustment would reflect the proportion of each agency's expenditures that were devoted to the production of medical care services (e.g. immunizations, prenatal care, communicable disease treatment) vs. population-based public health activities (e.g. surveillance, epidemiological investigation, health code inspections and enforcement). Because detailed expenditure data of this nature were not collected by the NACCHO surveys, we constructed CPI weights that reflected the proportion of each agency's revenue obtained from medical care payment sources (Medicaid, Medicare, and private health insurance).

In addition to the measure of total public health spending, we constructed a separate measure designed to approximate local public health agency spending on population-based public health activities specifically. This measure excludes each agency's expenditures on personal medical care services in order to isolate the impact of population-based public health spending. We constructed this measure by multiplying the total public health expenditure measure by one minus the proportion of each agency's revenue obtained from medical care payment sources. This measure is only an approximation and may understate spending for population-based activities because revenues from medical care services may be used by agencies to cross-subsidize their population-based activities. Consequently, we used this measure only as a robustness check on estimates obtained when using the total spending measure.

Two additional measures of public health spending were used in this analysis to control for state and federal expenditures that are not passed through to local public health agencies. State governments are important sources of funding for public health activities. Some of the funds that state governments allocate to public health activities are passed through to local public health agencies, where they contribute to local public health spending. Other state funds, however, are retained and expended directly by state public health agencies to perform statewide health promotion and disease prevention activities, or allocated to other grantees that are not local public health agencies. To control for the portion of state public health spending that is not reflected in local spending measures, we constructed a measure of residual state public health spending per capita using annual data from the U.S. Census of Governments. This measure was calculated for each state and each year as the total amount expended by the state for public health activities net of all intergovernmental transfers to local governments for public health activities.

We also constructed a measure of residual federal spending on public health activities using data from the U.S. Census Bureau's Consolidated Federal Funds Report. Much of the federal government's public health expenditures are passed through to state and/or local public health agencies and are therefore reflected either in the local public health agency spending measure or in the residual state public health spending measure. However, some federal public health funds are provided directly to nongovernmental grantees and are therefore not included in the local or state spending measures. To capture these federal resources, we constructed a county-level measure of residual federal public health spending by taking the total amount of federal public health spending in each county and subtracting the total amount of federal revenue received by the local public health agency. For simplicity we defined federal public health spending to include all federal grant-in-aid programs administered by the U.S. Centers for Disease Control and Prevention (CDC).

We tested the use of these residual spending measures in the multivariate models, and also the use of a combined spending measure that summed agency spending and residual spending together into a single measure of spending at the local level. Results obtained when using these residual spending measures were qualitatively similar to results obtained when using only the local public health agency spending measure, except that considerably larger standard errors were obtained. These results suggest that the residual spending measures are subject to considerable measurement error and therefore do not add explanatory power to the estimation strategy; therefore, our final estimates exclude these residual spending variables from the models.

Other Explanatory Variables. To isolate the relationship between local public health spending and health outcomes, we controlled for an array of other characteristics likely to influence population health. Prior studies have examined the association between local medical care resources and community-level mortality rates using similar data and methods to those employed in this analysis.[4-7] Informed by Andersen’s behavioral model of health care utilization, these studies controlled for demographic and socioeconomic characteristics of the community that are likely to reflect underlying health needs and care-seeking behavior, along with medical resource characteristics that influence the ability to obtain needed care.[8] We control for these same characteristics in order to examine whether public health spending is independently associated with health outcomes after accounting for local medical care resources and other known correlates of population health. The demographic and socioeconomic characteristics used as explanatory variables in this analysis include the community's population size and density, racial and ethnic composition, age distribution, educational attainment, poverty level, and personal income per capita. The measures of medical resources within the community include the number of active nonfederal physicians per 100,000 residents, the number of hospital beds per 10,000 residents, and the number of federally-qualified health centers per 10,000 low-income residents. Descriptive statistics for all of the variables used in the analysis are summarized in Table 1.

Empirical Model

Multivariate regression models for panel data are used to estimate the association between local public health spending and each health outcome measure while controlling for the effects of other characteristics likely to influence population health. Because we use longitudinal data, it is important to account for the autocorrelation that exists between the multiple observations taken on the same community over time. We used a fixed-effects model that allows the community-specific correlation coefficients to be correlated with other observed characteristics of the communities, as would be the case if communities with high historical rates of mortality also have socioeconomic characteristics associated with disadvantage, such as persistently high rates of poverty and low educational attainment. Hausman specification tests confirmed the appropriateness of the fixed-effects model. An important consequence of the fixed-effects model specification is that the effect of each independent variable is identified by changes within each community over time. This specification allows us to estimate what happens to mortality in an individual community as local public health spending changes over time.

We estimate each model using a logarithmic specification in order to reduce skewness and the influence of outlier observations in both the public health spending variables and the mortality variables. A separate model is estimated for each mortality variable using a specification that expresses the outcome for community *i* in state *j* at time *t* as:

[1] $$[Ln(Outcome_{ijt}) = Ln(Spending]_{ijt})\delta + Community_{ijt}\beta + State_{jt}\gamma + Year_{t}\omega + \mu_{i} + \varepsilon_{ijt}$$

where $Spending_{ijt}$ indicates local public health agency spending per capita, $Community_{ijt}$ represents a matrix of other community characteristics including residual federal spending within the community, $State_{jt}$ represents residual state public health spending, $Year_t$ reflects general temporal trends across the study period, μ_i indicates the community-specific fixed effects, and ϵ_{ijt} is a random error term. The coefficient δ to be estimated by the model indicates the relative change in the outcome measure that is associated with a 1 percent increase in local public health spending.

An important methodological complication arises in this analysis due to the possibility that local public health spending levels are endogenously determined based on unobserved community characteristics that also influence population health. To address this possible source of bias, we use instrumental variables (IV) methods to model the relationship between local public health spending and mortality while controlling for the effects of unmeasured characteristics that may simultaneously influence spending and health [9, 10]. To implement the IV analysis, an ancillary multivariate model is estimated that expresses the public health spending level in community i and state j at time t as:

[2] $$Ln(Spending_{ijt}) = Agency_{ijt}\theta + Community_{ijt}\beta + State_{jt}\gamma + Year_t\omega + \mu_i + \varepsilon_{ijt}$$

where public health agency characteristics are included as explanatory variables in the model along with other characteristics used in the mortality equation [1] above. Estimates from equation [2] are used to generate predicted values of local public health spending that are then used in place of the actual spending values to estimate the mortality equation [1]. This two-stage method effectively removes the influence of unobservable characteristics on local public health spending levels, thereby allowing an unbiased estimate of the association between spending and population health.

Identification of this two-equation IV model requires the use of one or more variables that are correlated with local public health spending and therefore included in equation [2], but uncorrelated with community mortality rates and therefore excluded from equation [1]. We use measures of local public health decision-making structures for this purpose, including (1) whether the agency is governed by a local board of health with policy-making authority, and (2) whether the agency operates under the centralized administrative control of state government. Theory and prior studies indicate that these characteristics influence the ability and inclination of local public health agencies to secure external funding sources for their work. [11-13],[14] Local governing boards of health are hypothesized to generate enhanced public and political support for local public health agencies, because their membership frequently includes individuals who have political access, professional credibility, and/or technical expertise that can be used to attract and maintain resources. Several prior studies have found evidence of higher levels of spending and performance among local public health agencies that are governed by local boards of health.[12, 13] Conversely, spending is expected to be lower among local public health agencies that operate as centralized units of state government. These agencies are hypothesized to have less autonomy and administrative flexibility to seek outside sources of support, and less ability to tap local sources of funding, than their counterparts that operate as decentralized units of local government.[14] Specification tests[15] indicate that the governance and centralization variables are strongly associated with local public health spending levels (F=28.6).

Using a two-step process, we first estimate the impact of the instrumental variables on spending levels, and then use the natural variation in spending produced by these variables to estimate how spending affects mortality. One important limitation of the two-equation IV model is that it produces estimates with considerably larger standard errors than those produced by a standard, single-equation regression model that ignores the endogenous relationship between spending and health outcomes. These standard errors are particularly large when the IV model is estimated with a fixed-effects specification, because there is relatively little change in the two instrumental variables within communities over time. To address this problem, we estimated the IV model using a random-effects specification that assumes the community-specific correlation coefficients are randomly distributed and uncorrelated with other characteristics included in the model. Specification tests confirm that when the mortality equation is estimated using the IV methodology, the random effects assumption is plausible and produces estimates similar to the fixed-effects estimator but with smaller standard errors. To enhance this study's power to detect statistically significant associations between spending and outcomes, we report estimates from the IV model using the random-effects specification, and compare these results with estimates from the single-equation model using a fixed-effects specification.

RESULTS

Estimates from fixed-effects models indicated that mortality declined more rapidly in communities that experienced larger increases in local public health spending, after adjusting for demographic, socioeconomic, and health resources characteristics of the communities (Table A1). In the fixed-effects models, this relationship between mortality and spending was statistically significant for four of the six mortality measures examined, including heart disease, diabetes, influenza, and all-cause mortality. However, these associations were modest in magnitude, indicating that mortality rates fell by 0.2 to 0.4 percent for each 10 percent increase in public health spending after controlling for other characteristics ($p<0.05$).

Estimates from instrumental-variables models revealed that the associations between spending and mortality were consistently larger in magnitude after accounting for unmeasured characteristics that jointly influence spending and health. These associations reached statistical significance for four of the six mortality rates examined, despite the much larger standard errors produced by the IV models. The strongest associations were observed for infant mortality and cardiovascular disease mortality, indicating that mortality rates fell by 6.9 percent and 3.8 percent for each 10 percent increase in spending ($p<0.05$), after controlling for other characteristics in the model. Diabetes mortality fell by 1.4 percent while cancer mortality fell by 1.1 percent for each 10 percent increase in spending ($p<0.05$). Influenza mortality and total mortality changed in the expected direction but did not reach statistical significance. Public health spending showed no association with the two control conditions, Alzheimer's mortality and residual mortality, helping us to rule out the possibility of spurious associations between spending and mortality.

Overall, public health spending emerged as one of the strongest and most consistent correlates of mortality in the IV models. Most of the other variables that were consistently associated with reductions in mortality reflected social determinants of health, including educational attainment, percent of population above the poverty level, and percent of population of white race (Table A2). Medical resource variables were not consistently associated with mortality after controlling for other variables in the model.

When models were re-estimated using the measure of spending on population-based services as the dependent variable, the estimates of association were qualitatively similar to those shown in Table A1 but most estimates failed to achieve statistical significance. We found no evidence that population-based spending, as measured in this analysis, had a stronger association with mortality than did total public health spending.

The variables measuring residual state and federal public health spending were not independently associated with mortality after accounting for local spending and other variables included in the models. The coefficient estimates for these explanatory variables were small and non-significant in both the fixed-effects and IV models. However, these variables were positively associated with local public health spending levels, suggesting an indirect, negative relationship with mortality.

Table A1: Association between Local Public Health Spending and Mortality Rates

	Fixed Effects Estimates			IV Estimates		
Dependent Variable	Coefficient	Std. Err		Coefficient	Std. Err	
Infant mortality	0.0234	0.0192		-0.6854	0.2668	***
Heart disease mortality	-0.0103	0.0040	**	-0.3216	0.1600	**
Diabetes mortality	-0.0487	0.0174	***	-0.1439	0.0605	**
Cancer mortality	-0.0007	0.0024		-0.1131	0.0566	**
Influenza mortality	-0.0275	0.0107	**	-0.0252	0.0362	
All-cause mortality	-0.0051	0.0024	**	-0.0288	0.0451	
Alzheimer's mortality	0.0183	0.0741		0.0249	0.1146	
Residual mortality	0.0086	0.0151		0.0184	0.0462	

***p<0.01 **p<0.05 *p<0.10

Note: Column 1 displays coefficient estimates from fixed-effects semi-logarithmic regression models that control for characteristics shown in Table 1. Column 2 displays coefficient estimates from instrumental variables estimation using semi-logarithmic regression models with a random effects specification, also controlling for the characteristics shown in Table 1.

Table A2: Instrumental Variables Estimates of Factors Associated with Mortality

Independent Variable	Infant Mortality Coef.	SE		Heart Disease Mortality Coef.	SE		Diabetes Mortality Coef.	SE		Cancer Mortality Coef.	SE	
Local public health spending/capita	-0.6854	0.2668	***	-0.3216	0.1600	**	-0.1439	0.0605	**	-0.1131	0.0566	**
Population size (log)	-0.4237	0.1965	**	-0.1747	0.1050	*	-0.1392	0.0500	***	-0.0869	0.0372	**
Population per sq mile (1000s)	-0.0201	0.1000		-0.0270	0.0408		0.0000	0.0000		0.0125	0.0146	
Percent population nonwhite	0.0155	0.0062	***	0.0057	0.0027	**	-0.0020	0.0016		0.0013	0.0010	
Percent with college degree	-0.0045	0.0102		-0.0280	0.0038	***	-0.0116	0.0029	***	-0.0109	0.0014	***
Percent 65+ years old	0.0365	0.0195	*	0.0689	0.0072	***	0.0308	0.0059	***	0.0410	0.0026	***
Percent non-English speaking	-0.0304	0.0284		-0.0169	0.0108		-0.0158	0.0080	**	-0.0178	0.0039	***
Percent below poverty	-0.0244	0.0105	**	-0.0054	0.0040		0.0062	0.0031	**	0.0042	0.0014	***
Income per capita (log)	-0.8108	0.2374	***	0.0788	0.0871		-0.0881	0.0718		0.1099	0.0313	***
Active physicians per 10,000	0.0627	0.0560		0.0498	0.0230	**	0.0001	0.0002		0.0029	0.0081	
Hospital beds per 10,000	-0.0160	0.0120		-0.0073	0.0051		0.0000	0.0000		0.0030	0.0018	*
FQHC in community (yes=1)	-0.0492	0.2438		-0.0601	0.0928		0.0937	0.0709		0.0128	0.0333	
Metropolitan area designation												
Metropolitan area	-0.2185	0.3907		-0.0385	0.1464		-0.3259	0.1436	**	-0.0752	0.0525	
Micropolitan area	-0.0681	0.3691		-0.0529	0.1307		-0.1261	0.1174		-0.0125	0.0469	
(reference: nonmetropolitan area)												
Year												
1997	0.0631	0.0652		0.0118	0.0263		0.0557	0.0176	***	0.0685	0.0094	***
2005	0.1648	0.1274		-0.0683	0.0497		0.3764	0.0362	***	0.0636	0.0179	***
(reference: 1993)												
Constant	16.3274	3.5984	***	6.9281	1.7387	***	5.6395	0.8493	***	5.0715	0.6178	***
sigma_u	1.4094			0.5566			0.4607			0.2278		
sigma_e	0.8380			0.3171			0.2250			0.1138		
Rho	0.7388			0.7549			0.8074			0.8002		

***p<0.01 **p<0.05 *p<0.10

Note: coefficients are from logarithmic regression models

ExhibitA1: IV Estimates of Factors Associated with Mortality (Continued)

	Influenza Mortality			Total Mortality		
Independent Variable	Coef.	Std. Err.		Coef.	Std. Err.	
Local public health spending/capita	-0.0252	0.0362		-0.0288	0.0451	
Population size (log)	0.0779	0.0130	***	-0.0348	0.0296	
Population per square mile (1000s)	0.0034	0.0099		0.0051	0.0115	
Percent population nonwhite	-0.0049	0.0013	***	-0.0009	0.0008	
Percent with college degree	-0.0169	0.0030	***	-0.0078	0.0011	***
Percent 65+ years old	0.0760	0.0048	***	0.0412	0.0020	***
Percent non-English speaking	-0.0020	0.0092		-0.0076	0.0031	**
Percent population below poverty	0.0168	0.0042	***	0.0068	0.0011	***
Income per capita (log)	0.2339	0.1177	**	0.0588	0.0245	**
Active physicians per 10,000	0.0837	0.0156	***	0.0140	0.0065	**
Hospital beds per 10,000	-0.0158	0.0043	***	0.0040	0.0014	***
FQHC in community (yes=1)	0.0497	0.0336		0.0127	0.0262	
Metropolitan area designation						
Metropolitan area	0.1274	0.0495	***	-0.0774	0.0413	*
Micropolitan area	0.0926	0.0456	**	-0.0224	0.0369	
(reference: nonmetropolitan area)						
Year						
1997	0.0209	0.0311		0.0138	0.0074	*
2005	-0.3308	0.0557	***	0.0145	0.0140	
(reference: 1993)						
Constant	-0.7462	1.1567		6.2252	0.4903	***
sigma_u	0.5686			0.1413		
sigma_e	0.7228			0.0894		
Rho	0.3823			0.7140		

***p<0.01 **p<0.05 *p<0.10

Note: coefficients are from semi-logarithmic regression models

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