**Spatiotemporal variations in primary care physician density and population mortality across U.S. counties, 2005-2015**

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Keywords: primary care, life expectancy, health disparities**Abstract**

Objectives: To assess recent spatiotemporal variations in primary care physician density, and identify whether those variations relate to variations in life expectancy and cause-specific mortality among U.S. counties.

Methods: Repeated cross-sectional fixed effects and first-differences regressions of primary care physician density against age-standardized life-expectancy and cause-specific mortality over the period 2005 to 2015 at the level of US counties (N = 3,142), adjusted for demographic, socioeconomic, behavioral, and healthcare system covariates.

Results: Primary care physician density decreased from 4.1 per 10,000 population in 2005 to 3.6 per 10,000 in 2015, with rural and lower-income counties experiencing disproportionate losses. Primary care physician density was not consistently related to overall age-standardized life expectancy, but a one standard deviation increase in primary care physician density (2.8 physician/10,000 population) was associated with a 5.6 per 1 million (0.2%) reduction in cardiovascular mortality (95% CI: 0.3, 10.9; P = 0.038) and a 1.5 per 1 million (0.5%) reduction in substance use and injury mortality (95% CI: 0.1, 2.8; P = 0.035), net of covariates.

Conclusions: Primary care physician density has decreased in vulnerable areas, and while not consistently related to overall life expectancy, was related to cardiovascular and substance use/injury mortality.

**Introduction**

Whether and to what degree primary care physicians can influence population-wide health outcomes remains heavily debated. Traditionally, assessments from the field of social epidemiology suggested that there is little or no measurable influence of medical care, including preventive and curative services delivered through primary care, on population health metrics such as life expectancy.1 Thomas McKweon’s 1976 assessment of death in England and Wales suggested that while life expectancy had increased by 23 years over the prior half century, little of the advance could be attributed to medical care;2 the previous year, Ivan Illich claimed more radically that medical care did more harm than good to population health.3 In the three decades that followed, improvements in life expectancy were more consistently attributed to advances in biomedicine including the treatment of hypertension,4,5 but contradictions also appeared, such as the increase in mortality rates from diseases amenable to medicine in areas with the most medical care resources.6

While many debates concerning medical care and population health focused on analysis of rich data from the United Kingdom, within the United States, debates during the early 21st century often compared aggregate U.S. medical care characteristics and population health statistics to that of international peers. Starfield and colleagues prominently argued that by comparing the United States to other countries with high average income, the availability of primary care services—that is, services provided by a generalist physician in an accessible manner across a broad range of illnesses and with longitudinal continuity between patient and provider—could be associated with lower all-cause and cause-specific mortality, when analyses were aggregated at the level of entire nations.7 State-level and metro-area assessments in the 1990’s also showed that large areas with more primary care physicians tended to have better birth outcomes and lower overall and cause-specific mortality,8–12 although whether these associations were independent of other types of medical care, overall healthcare infrastructure, and unaccounted-for community factors remains unclear.

Recent assessments of smaller area-level inequalities in the United States during the early 2000’s suggested increasing variations in life expectancy and cause-specific mortality across the nation, including stagnating or decreasing life expectancy in some counties, and increasing mortality from substance use and self-harm.13–15 Simultaneously, since the early 2000’s, healthcare reforms at the state and national level dramatically expanded financial support for primary care and increased the financial responsibility of medical care providers for population-health outcomes. Primary care providers and their associated healthcare ownership companies in many states, for example, have received increased funding to support proactive treatment of hypertension, diabetes, depression, substance abuse, and other chronic conditions, and conversely received financial penalties if they failed to meet population health metrics for their catchment population.16–21 Some authors called for large population-level metrics derived from mortality statistics to be incorporated into such outcome assessments.22 Large state and national initiatives are now expanding support for population health measures to be integrated into primary care clinics, and directing an increasing supply of primary care physicians to underserved regions through financial incentives.22–24

How primary care physician supply has changed over the last decade in the United States remains unclear. It also remains unclear to what extent changes in primary care physician supply can help to explain recent temporal and geographic variations in mortality across the United States. Addressing these uncertainties is critical to identify whether existing primary care initiatives are related to population health, and whether further efforts to expand primary care physician supply have the potential to produce measurable population health improvements. Here, we sought to assess temporal and geospatial variations in primary care physician density, and test the *a priori* null hypothesis that those variations do not significantly relate to variations in life expectancy and cause-specific mortality among U.S. counties from 2005 through 2015.

**Methods**

*Independent variable of interest*

Primary care physician density was defined, consistent with prior work,25 as non-federally-employed doctors of medicine less than 75 years of age who self-reported their specialty as general practice, general family medicine, or general internal medicine, with their principal activity as office-based patient care, per 10,000 population in each US county within the 50 contiguous states, Alaska, Hawaii, or the District of Columbia (*N* = 3,142 counties). Primary care physician numbers were obtained from the American Medical Association Physician Masterfile for the years 2005, 2010, and 2015,26 and population counts from the US Census Bureau.26 As some counties changed boundaries over the study period, Health Resource and Service Administration guidelines were used to identify carry-overs from one designated county to newly-defined counties over the study period.27

*Dependent outcome variables*

Life-expectancy (the primary pre-specified outcome) and cause-specific mortality (secondary pre-specified outcomes) were obtained from the Institute for Health Metrics and Evaluation (IHME),27 whose estimates were derived from de-identified death records from the National Center for Health Statistics (NCHS) and population counts from the US Census Bureau, NCHS, and the Human Mortality Database to estimate age-adjusted life expectancy at birth and cause-specific mortality for the years 2005, 2010, and 2014. The estimates are based on a Bayesian spatially explicit mixed-effects regression model incorporating fixed covariate effects (for the proportion of the adult population who graduated from high school, are Hispanic, are Black, are a race other than Black or White, and are contained within a state or federal Native American reservation; the median household income; and population density); random age-time effects; random spatial effects; random space-time effects; and random space-age effects with conditional autoregressive distributions, updated from 2014 to 2015 with linear interpolation at the county level.15 Five major categories of cause of death were considered: cancer, cardiovascular disease, infectious disease, respiratory disease, and substance use/injury (which includes deaths from alcohol use, drug use, self-harm and interpersonal violence).

*Covariates*

Additional covariates for the years 2005, 2010, and 2015 included control variables itemized in **Table 1**: urban/rural designation by the NCHS Urban-Rural Classification Scheme for Counties, which classifies counties as large central metropolitan areas, fringe metro areas, medium metro, small metro, micropolitan, or non-core areas, with the latter two labelled “non-metro”;26 percent of people under the federal poverty threshold and median household income in 2015 U.S. Dollars per the Census Small Area Income and Poverty Estimates Program;26 percent of people aged 25 years and older with at least a high school diploma, per the Census American Community Survey;26 percent of people aged 65 years and older, of Black race, and of Hispanic ethnicity, per the Census County Characteristics File;26 the unemployment rate for people aged 16 years and older, per the Bureau of Labor Statistics;28 the percent of people less than 65 years old without health insurance from the Census Small Area Health Insurance Estimates;28 the number of hospital beds per 10,000 population from the American Hospital Association Survey Database;28 the percent of people enrolled in Medicare from the Centers for Medicare and Medicaid Services Enrollment Dashboard;28 standardized, risk-adjusted per capita medical care costs from the Medicare Geographic Variation Public Use Files;28 age-adjusted percent of adults who currently smoke tobacco and percent of adults currently obese from the CDC Behavioral Risk Factor Surveillance System;28 number of days with maximum 8-hour average ozone concentration over the National Ambient Air Quality Standard from the CDC National Environmental Public Health Tracking Program;28 and the number of non-primary-care medical doctors with their principal activity as patient care, per 10,000 population, from the American Medical Association Physician Masterfile.29

*Statistical analysis methods*

Variables were centered and scaled into Z scores, so that regression coefficients could be interpreted as the change in the dependent outcome variable associated with a one standard deviation increase in each independent variable. Missing data were not imputed, as <5% of counties had any missing variable. The primary pre-specified model was a dynamic fixed effects panel regression model:

[Eq. 1] ,

where *yit* is the dependent outcome variable observed for county *i* at time *t*, *Xit* is the time-varying 1 x *k* matrix of the *k* independent variables, ** is the *k* x1 matrix of coefficients to be estimated, *i* is the county fixed effect to adjust for time-invariant unobserved differences among counties, *t* is the time fixed effect to adjust for time-invariant unobserved differences among time periods, and *it* is the error term. Clustered standard errors were computed at the county level to correct for serial correlation. A Hausman test rejected the null hypothesis that the preferred model would be a random effects specification, in favor of the above fixed effects specification. The model was also subject to calculation of variance inflation factors (VIFs) and the Farrar-Glauber test to identify the potential for estimates to be influenced by multi-collinearity;30 the tests indicated that the factors with problematic levels of collinearity (having VIFs>4) were: elderly and Medicare population, uninsured <65 years old and unemployed, and income and poverty. Hence, the covariates with the highest VIFs (elderly, uninsured, and income) were removed to leave their collinear variables with lower VIFs (Medicare, unemployed, and poverty) in the final specification, which enabled the model to have all covariates with VIF<3 in the final specification.

*Robustness and falsification tests*

To assess robustness, a secondary pre-specific model was a dynamic first differences panel regression model:

[Eq. 2] ,

The first differences model regresses between-period changes in each variable within a county. In the absence of bias due to endogeneity, the point estimates of the coefficients from the fixed effects and the first differences regressions should not significantly differ, as each regression is attempting to remove unobserved time-invariant confounding effects within counties over time. An additional of specification applied a single period (5-year) lag between the independent variables and the dependent outcome variables.

Finally, two falsification tests were performed by regressing the independent variables against two dependent outcome variables that would not be expected to have significant relationships to primary care physician density: mortality rates from interpersonal violence (e.g., murder) that are classified within the larger group of injury deaths, and mortality rates from age-adjusted motor vehicle transport accident mortality rates obtained from the CDC Wonder Database.30 These falsification tests help to test whether unobserved factors, such as the propensity for physicians to move to desirable areas that may have populations or neighborhood features correlated to lower mortality rates, would produce false associations between primary care physician density and the outcome variables.

Analyses were performed in *R* v. 3.4.3 (*R* Foundation for Statistical Computing, Vienna), using the statistical code deposited at https://sdr.stanford.edu.

**Results**

*Changes in primary care physician density over time and space*

Primary care physician density decreased from 4.1 (95% CI: 0, 9.7, median 3.8) per 10,000 population in 2005 to 3.8 (95% CI: 0, 9.7, median 3.5) per 10,000 to 3.6 (95% CI: 0, 9.4, median 3.2) per 10,000 in 2015, with rural and lower-income counties experiencing disproportionate losses (**Figures 1 and 2**). Primary care physician density decreased by on average 0.5 physicians per 10,000 population within counties in the U.S. overall during the period 2005 to 2015 (95% CI: 4.2 decrease, 2.7 increase), but decreased by 0.2 physicians per 10,000 population for metro counties (95% CI: 2.3 decrease, 1.8 increase), versus 0.7 among non-metro counties (95% CI: 4.9 decrease, 3.2 increase). Primary care physician density decreased on average by 0.4 physicians per 10,000 population within counties with less than the median of 16% poverty (95% CI: 4.0 decrease, 2.1 increase), versus 0.6 within counties with higher than the median of 16% poverty (95% CI: 4.9 decrease, 3.2 increase). Density did not disproportionately change among counties with lower versus higher rates of Black or Hispanic minorities (**Figure 2**).

*Associations between primary care physician density and life expectancy and cause-specific mortality outcomes*

A one standard deviation (2.8 physicians) increase in primary care physicians per 10,000 population was associated with a 5.5 day (95% CI: 0.01, 11.0; P = 0.049) increase in life expectancy, or about 2.0 days per physician, after adjusting for county-level distributions of age, sex, race/ethnicity, poverty, education, employment, tobacco smoking, obesity, air pollution, urban/rural residence, standardized healthcare costs, hospital beds, density of non-primary care physicians, and county and time fixed effects (**Table 2**). Notably, the effect was smaller than a one standard deviation (11.9 physician) increase in all other types of physician per 10,000, which produced a 31.1 day (95% CI: 21.1, 41.1, P<0.001) increase in life expectancy, or 2.6 days/physician.

Changes in other social and economic covariates at the county level had larger associations in absolute magnitude to the outcome of life expectancy than did primary care physician density. For example, as shown in **Table 2**, a 1 standard deviation increase in the proportion of people graduating from high school (7.7 percentage points) improved life expectancy by 41.7 days (95% CI: 29.7, 51.5; P<0.001), while a 1 standard deviation increase in tobacco smoking (4.3 percentage points) reduced life expectancy by 20.3 days (95% CI: 15.0, 25.6; P<0.001). Consistent with prior studies,8,31 a higher Black population was associated with reduced life expectancy, a larger Hispanic population was associated with increased life expectancy (e.g., the “Hispanic paradox”; **Table 2**), and hospital beds tended to be more prevalent in areas with lower life expectancy.

Increased primary care physician density was related to decreased mortality from cardiovascular disease and from substance use/injury, but not other specific causes of death (**Figure 3**). A one standard deviation (2.8 physicians) increase in primary care physicians per 10,000 population was associated with a 5.6 per 1 million (0.2%) reduction in cardiovascular mortality (95% CI: 0.3, 10.9, P = 0.038), which was equivalent to a reduction of 2.0 deaths per million per primary care physician. A one standard deviation (11.9 physicians) increase in all other types of physicians per 10,000 population was associated with a 11.7 per 1 million (0.5%) reduction in cardiovascular mortality (95% CI: 1.7, 21.7, P = 0.022), which was equivalent to a reduction of 1.0 deaths per million per non-primary care physician. A one standard deviation (2.8 physicians) increase in primary care physicians per 10,000 population was associated with a 1.5 per 1 million (0.5%) reduction in substance use/injury mortality (95% CI: 0.1, 2.8, P = 0.035). A one standard deviation (11.9 physicians) increase in all other types of physicians per 10,000 population was not significantly associated with a reduction in substance use/injury mortality (**Figure 3**). Among the subtypes of substance use/injury mortality, primary care physician density related to reduced alcohol mortality (-0.2 per million for a 1 standard deviation increase in supply; 95% CI: -0.01, -0.4; P = 0.042; a 0.7% decrease) and reduced self-harm mortality (-0.5 per million, 95% CI: -0.01, -1.5; P = 0.044; a 0.3% decrease), but not significantly to reduced drug use (-0.6 per million, 95% CI: -1.7, +0.5; P = 0.274).

*Robustness and falsification testing*

Point estimates of the coefficients for primary care physician density were not significantly different between the fixed effects and a first differences regression model, but had a reduced effect size in the first differences regression (**Appendix Figure 1**). The effect of life expectancy was no longer statistically significant, but the effects on cardiovascular mortality and substance use/injury mortality remained significant at the P<0.05 level. Point estimates were smaller when applying lags between the independent variables and the dependent outcome variables, with no significant relations between lagged primary care physician density and any of the outcomes (**Appendix Figure 2**).

Increased primary care physician density was not—in falsification tests— significantly related to reductions in transport accident deaths or to deaths due to interpersonal violence (**Figure 3**).

**Discussion**

We were unable to robustly or consistently reject the null hypothesis that changes in primary care physician density were not related to overall life expectancy over the period 2005-2015 among U.S. counties, but we did find consistent relations between increased primary care physician density and cause-specific mortality from cardiovascular diseases and substance use/injury. Unfortunately, we observed that efforts to expand the supply of primary care physicians do not seem to have been effective at the national level in the period studied, at least when evaluating by county-level density; primary care physician supply decreased overall, and disproportionately in rural and lower-income areas. Our findings also indicate, however, that increases in primary care supply do not appear to be consistently associated with population-level improvements to life expectancy or most sources of cause-specific mortality, net of confounding factors. While initiatives that seek to evaluate primary care supply have proposed large population-level metrics based on area-level mortality as appropriate indicators of effective supply,22 our findings suggest that such indicators may not be consistently or measurably influenced by primary care physician supply, except in the cardiovascular and substance use/injury domains.

Primary care physician supply may be vital and desirable for many individual-level reasons, such as to provide humane, accessible, timely care and improve individual patient medical and psychosocial outcomes. Yet our assessment differs from prior studies that associated state-level primary care physician density with overall life-expectancy, while being similar to prior studies finding that primary care supply is related to lower cardiovascular disease deaths.8–10,12 Our results may be different with regard to overall life expectancy because of the increased number of control variables considered in our assessment, including other non-primary-care physician density and numerous socio-economic and demographic features. Our model specifications also attempted to control for time-invariant unobserved factors such as local cultural factors that are unmeasured and may both attract physicians to an area and be related to lower mortality. Our results are also concordant with the idea that healthcare reforms may need to be directly address the larger social determinants of health, which overwhelm primary care supply as influencers of county-level mortality. Nevertheless, our finding that primary care supply may be beneficial in reducing substance use/injury deaths is important in the context of ongoing increases in “diseases of desperation” nationwide, particularly in the rural and lower-income counties that have disproportionately lost primary care providers.

Our study conclusions must be accompanied by acknowledgement of important limitations. First, to avoid ecological fallacies, we do not make conclusions about individual-level effects of population-level associations, and we are limited in being unable to provide guidance to individuals or households based on the aggregate county-level data studied here. Second, county-level analyses can be limited by the possibility that individuals cross county borders to reach healthcare services. Conversely, summary statistics at the county level may mask inequalities experienced among smaller populations.32 Finally, our analysis focuses on supply, whereas future investigations should acquire data on the quality and comprehensiveness of primary care, or on effective access rather than just density of physicians.

Nevertheless, our results here suggest that primary care physician density has decreased in vulnerable areas, and while not consistently related to overall life expectancy, primary care density was related to cardiovascular and substance use/injury mortality over the period 2005-2015.

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**Tables and Figures**

Table 1: Characteristics of the study sample (N=3,142 U.S. counties), 2005-2015.

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| --- | --- | --- | --- |
| **Characteristic** | **Value in 2005** | **Value in 2015** | **Within-county change, 2005 to 2015** |
| Primary care physicians per 10,000 population, mean (SD) | 4.1 (2.8) | 3.6 (2.6) | -0.5 (2.0) |
| Non-metro area, % (SD) | 20.6 (0.7) | 18.9 (0.7) | -0.1 (0.1) |
| Population in poverty, % (SD) | 15.3 (6.5) | 16.3 (6.5) | 1.0 (2.4) |
| Median household income, $US 2015 (SD) | $54,038 (13,917) | $48,600 (12,255) | -$5,448 (5,386) |
| Population with less than high school education, % (SD) | 17.8 (8.2) | 13.0 (7.1) | -0.6 (0.7) |
| Population 65 years or older, % (SD) | 14.8 (4.1) | 18.0 (4.5) | 3.2 (2.4) |
| Population Black, % (SD) | 9.0 (14.6) | 9.3 (14.4) | 0.3 (1.4) |
| Population Hispanic, % (SD) | 7.1 (12.5) | 9.2 (13.6) | 2.1 (2.1) |
| Unemployment rate, % (SD) | 5.6 (2.2) | 5.8 (2.5) | 0.1 (1.4) |
| Uninsured among <65 yr olds, % (SD) | 25.0 (7.2) | 12.0 (5.1) | -13.0 (5.5) |
| Hospital beds per 10,000 population, mean (SD) | 35.9 (53.6) | 29.5 (38.4) | -6.3 (41.2) |
| Medicare enrollment, % (SD) | 16.3 (5.2) | 20.6 (6.0) | 4.3 (3.1) |
| Per capita medical costs, $US 2015 (SD) | $8,946 (1,868) | $9,843 (1,226) | $898 (1,864) |
| Adult tobacco smoking, % (SD) | 17.9 (3.5) | 21.1 (5.9) | 3.3 (4.5) |
| Adult obesity, % (SD) | 27.5 (3.6) | 32.1 (5.5) | 4.5 (4.1) |
| High ozone days, % (SD) | 4.7 (8.3) | 6.2 (10.7) | 1.5 (9.7) |
| Non-primary-care physicians per 10,000 population, mean (SD) | 7.4 (11.0) | 7.7 (12.7) | 0.3 (3.8) |
| Life expectancy at birth, age adjusted, mean (SD) | 76.8 (2.2) | 77.8 (2.4) | 1.0 (0.4) |
| Cancer mortality, age-adjusted deaths/100,000, mean (SD) | 214.1 (28.6) | 206.9 (32.4) | -7.2 (7.6) |
| Cardiovascular mortality, age-adjusted deaths/100,000, mean (SD) | 317.22 (59.0) | 277.6 (59.7) | -39.6 (13.7) |
| Infectious mortality, age-adjusted deaths/100,000, mean (SD) | 38.8 (10.9) | 34.8 (11.6) | -4.0 (3.4) |
| Respiratory mortality, age-adjusted deaths/100,000, mean (SD) | 62.4 (14.0) | 64.2 (17.4) | 1.8 (5.3) |
| Substance/injury mortality, age-adjusted deaths/100,000, mean (SD) | 30.4 (10.7) | 35.5 (12.9) | 5.1 (4.2) |
| Motor transport deaths, age-adjusted deaths/100,000, mean (SD) | 19.6 (13.9) | 20.3 (10.8) | 4.2 (6.8) |
| Interpersonal violence deaths, age-adjusted deaths/100,000, mean (SD) | 5.3 (3.8) | 5.0 (3.5) | -0.3 (0.8) |

Table 2: Results of fixed-effects regressions relating primary care physician density and county-level covariates to age-standardized life expectancy at birth and cause-specific mortality (N=3,142 U.S. counties), 2005-2015. SD: standard deviation.

|  |  |
| --- | --- |
| **Covariate** | **Change in age-adjusted life expectancy (days) given a 1 SD increase in covariate, mean (SE)** |
| Primary care physicians per 10,000 population | 5.5 (2.8)\* |
| Non-metro area, change to metro area | -10.2 (11.7) |
| Population in poverty | -6.0 (5.3) |
| Population with less than high school education | -41.7 (6.1)\*\* |
| Population Black | -57.4 (48.6) |
| Population Hispanic | 108.6 (26.7)\*\* |
| Unemployment rate | 3.9 (2.5) |
| Hospital beds per 10,000 population | -8.1 (2.5)\*\* |
| Medicare enrollment | 38.3 (6.5)\*\* |
| Per capita medical costs | 4.7 (2.8) |
| Adult tobacco smoking | -20.3 (2.7)\*\* |
| Adult obesity | -14.3 (2.2)\*\* |
| High ozone days | -8.6 (2.2)\*\* |
| Non-primary-care specialized physicians per 10,000 population | 41.7 (10.3)\*\* |

\*P<0.05; \*\*P<0.01

Figure 1: Changes in primary care physician density among US counties (N=3,142 U.S. counties), 2005-2015.

Figure 2: Changes in primary care physician density by county-level features (N=3,142 U.S. counties), 2005-2015.

[forest plot]

Figure 3: Changes in cause-specific mortality associated with an increase of 1 primary care physician per 10,000 population and 1 non-primary-care physician per 10,000 population among N=3,142 U.S. counties, 2005-2015.

[forest plot:

Cause

PC

Non-PC

Falsification tests

]

**Appendix**

Appendix Figure 1: Robustness checks. Results of first-differences regressions relating primary care physician density and county-level covariates to county-level life expectancy at birth and cause-specific mortality (N=3,142 U.S. counties), 2005-2015.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Covariate, change in:** | **Change in outcome given a 1 SD increase in covariate, mean (SE)** | | | | | | | |
| Life expectancy (days) | Cancer mortality (deaths/mil.) | Cardiovascular mortality (deaths/mil.) | Infectious mortality (deaths/mil.) | Respiratory mortality (deaths/mil.) | Substance/injury mortality (deaths/mil.) | Preventable hospitalizations (stays/10,000) | Premature deaths (years lost/100,000) |
| Primary care physicians per 10,000 population | 2.7 (1.5) | -0.3 (0.8) | -4.3 (1.6)\*\* | 0.5 (0.4) | -0.6 (0.5) | -1.1 (0.3)\*\* | 16.0 (5.0)\*\* | -85.9 (58.4) |
| Non-metro area, change to metro area | -3.8 (4.5) | 3.9 (1.9)\* | 1.9 (6.4) | 5.0 (1.1)\*\* | 1.1 (1.7) | -0.6 (1.6) | -14.4 (10.6) | 43.5 (77.4) |
| Population in poverty | -7.8 (2.2)\*\* | -95.4 (10.1)\*\* | -4.9 (2.7) | 3.8 (0.7)\*\* | 6.6 (0.7)\*\* | -0.3 (0.9) | 4.4 (9.7) | 48.6 (56.1) |
| Population with less than high school education | 43.1 (3.9)\*\* | -24.7 (2.0)\*\* | 7.1 (3.4)\* | -1.3 (0.8) | -21.0 (1.3)\*\* | -5.2 (1.2)\*\* | 38.7 (7.6)\*\* | 56.4 (50.2) |
| Population Black | -67.8 (29.0)\* | -17.8 (15.7) | 62.7 (26.5)\* | 44.4 (6.9)\*\* | -23.1 (8.9)\*\* | 38.8 (8.0)\*\* | 152.8 (42.7)\*\* | 799.5 (279.4)\*\* |
| Population Hispanic | 108.5 (15.3)\*\* | -49.4 (7.1)\*\* | 74.7 (15.7)\*\* | -37.4 (3.5)\*\* | -50.8 (5.1)\*\* | -42.6 (3.4) | 131.0 (22.3)\*\* | -1.306.1 (174.1)\*\* |
| Unemployment rate | 5.4 (1.1)\*\* | -2.8 (0.6)\*\* | -5.5 (1.4)\*\* | 0.2 (0.3) | -1.9 (0.3)\*\* | 1.9 (0.4)\*\* | 10.2 (3.7)\*\* | -132.2 (34.8)\*\* |
| Hospital beds per 10,000 population | -6.2 (1.3)\*\* | 3.4 (0.6)\*\* | -0.2 (1.3) | 2.3 (0.3)\*\* | 2.5 (0.4)\*\* | 2.6 (0.3)\*\* | -1.3 (3.8) | 98.3 (45.9)\* |
| Medicare enrollment | 33.1 (3.7)\*\* | -8.0 (1.9-5.8 (3.4))\*\* | 0.6 (0.7) | -3.6 (0.7)\*\* | -15.0 (1.2)\*\* | 6.9 (1.0)\*\* | 50.0 (7.0)\*\* | 40.9 (62.8) |
| Per capita medical costs | 4.6 (1.7)\*\* | -3.8 (0.8)\*\* | 0.3 (1.0) | -0.9 (0.4)\* | -0.6 (0.6) | -1.4 (0.4)\*\* | 12.0 (3.7)\*\* | -93.6 (20.1)\*\* |
| Adult tobacco smoking | -12.7 (1.2)\*\* | 2.5 (0.6)\*\* | -4.8 (1.6) | 0.7 (0.3)\* | 4.5 (0.4)\*\* | 6.4 (0.5)\*\* | 6.0 (3.4) | 79.3 (26.9)\*\* |
| Adult obesity | -7.2 (0.9)\*\* | 3.2 (0.5)\*\* | 0.3 (1.0) | -0.4 (0.3) | 2.5 (0.3)\*\* | 1.5 (0.3)\*\* | -1.9 (2.7) | 2.1 (21.2) |
| High ozone days | -5.4 (1.0)\*\* | 1.8 (0.5)\*\* | 6.2 (1.0)\*\* | -0.2 (0.3) | 0.7 (0.3)\* | 2.0 (0.3)\*\* | -0.5 (1.6) | -24.2 (14.0) |
| Non-primary-care specialized physicians per 10,000 population | 31.1 (5.1)\*\* | -1.1 (0.5)\* | -7.0 (3.5)\* | -2.4 (1.7) | -8.9 (1.5)\* | -3.0 (1.5)\* | 24.9 (10.9)\* | 76.6 (88.0) |

\*P<0.05; \*\*P<0.01

Appendix Figure 2: Lagged regressions. Results of fixed effects regressions with single period lags, relating primary care physician density and county-level covariates to county-level life expectancy at birth and cause-specific mortality (N=3,142 U.S. counties), 2005-2015.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Lagged Covariate** | **Change in outcome given a 1 SD increase in lagged covariate, mean (SE)** | | | | | | | |
| Life expectancy (days) | Cancer mortality (deaths/mil.) | Cardiovascular mortality (deaths/mil.) | Infectious mortality (deaths/mil.) | Respiratory mortality (deaths/mil.) | Substance/injury mortality (deaths/mil.) | Preventable hospitalizations (stays/10,000) | Premature deaths (years lost/100,000) |
| Primary care physicians per 10,000 population | 2.0 (2.8) | -1.3 (2.1) | -2.3 (3.4) | 0.3 (0.7) | 0.08 (1.0) | 0.3 (0.7) | -6.6 (11.7) | 77.3 (127.1) |
| Non-metro area, change to metro area | 1.7 (9.6) | 1.0 (5.7) | -16.8 (9.9) | 7.2 (3.5)\* | -0.2 (3.5) | 1.1 (2.8) | 31.0 (21.0) | 148.6 (177.5) |
| Population in poverty | 16.5 (6.0)\*\* | -99.0 (24.7)\*\* | -24.3 (6.3)\*\* | -6.8 (1.6)\*\* | 0.5 (2.2) | -8.1 (1.7)\*\* | 45.7 (15.2)\*\* | -16.0 (125.9) |
| Population with less than high school education | 37.8 (6.9)\*\* | -28.4 (4.5)\*\* | -2.0 (7.5) | -1.0 (1.6) | -22.1 (2.5)\*\* | 0.3 (2.1) | 61.8 (18.6)\*\* | -33.4 (187.4) |
| Population Black | 26.2 (53.7) | -45.9 (28.6) | -10.3 (56.0) | 25.3 (15.0) | -34.1 (15.9)\* | 38.2 (12.8)\*\* | 49.1 (82.4) | 1,147.9 (799.7) |
| Population Hispanic | 75.4 (29.2)\*\* | -49.4 (16.9)\*\* | -6.2 (33.6) | -31.9 (8.0)\*\* | -43.9 (10.1))\*\* | -33.9 (7.6)\*\* | 114.4 (54.9)\* | -331.5 (642.8) |
| Unemployment rate | -8.1 (3.2)\* | 6.9 (1.6)\*\* | 2.7 (3.6) | 2.2 (0.9)\*\* | 2.5 (1.1)\* | 2.9 (0.8)\*\* | -19.3 (7.5)\* | 9.7 (78.3) |
| Hospital beds per 10,000 population | -9.0 (2.9)\*\* | 2.4 (1.6) | 4.8 (3.1) | 3.1 (0.9)\*\* | 2.2 (1.0)\* | 1.2 (0.7) | -9.0 (9.3) | 17.8 (147.0) |
| Medicare enrollment | 53.0 (7.8)\*\* | -14.3 (4.2)\*\* | -8.9 (8.0) | -6.8 (1.8)\*\* | -19.5 (2.6)\*\* | 1.8 (1.8) | 75.8 (18.3)\*\* | 135.3 (183.8) |
| Per capita medical costs | 39 (3.0) | -1.8 (1.9) | -0.2 (3.9) | -0.5 (0.9) | 0.3 (1.1) | -1.7 (0.8)\* | 54.2 (9.5)\*\* | -179.1 (104.8) |
| Adult tobacco smoking | -15.7 (2.1)\*\* | 5.7 (1.2)\*\* | 4.3 (2.5) | 1.1 (0.6)\* | 5.0 (0.7)\*\* | 6.5 (0.6)\*\* | -9.6 (5.7) | 40.1 (54.0) |
| Adult obesity | -19.0 (3.5)\*\* | 7.7 (2.1)\*\* | 12.6 (3.8)\*\* | 2.7 (0.9)\*\* | 6.1 (1.2)\*\* | 0.9 (0.9) | -18.1 (7.9)\* | -78.1 (75.2) |
| High ozone days | 11.1 (3.8)\*\* | -0.7 (1.7) | -6.0 (3.9) | -1.4 (1.0) | -4.2 (1.4)\*\* | -0.9 (1.1) | 9.7 (5.7) | 42.9 (44.5) |
| Non-primary-care specialized physicians per 10,000 population | 16.3 (9.1) | -2.3 (1.2) | -9.2 (10.0) | -5.4 (3.9) | -8.0 (3.1)\* | 3.7 (2.7) | 2.5 (22.5) | -259.8 (243.5) |

\*P<0.05; \*\*P<0.01