Associations Between Physician Supply Levels and Amenable Mortality Rates: An Analysis of Taiwan Over Nearly 4 Decades

Health Services Insights
Volume 13: 1–11

DOI: 10.1177/1178632920954878

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ABSTRACT: Access to health care is an important determinant of health, but it remains unclear whether having more physicians reduces mortality. In this study, we used Taiwan's population-level National Death Certification Registry data to investigate whether a greater supply of physicians is associated with lower rates of amenable mortality, defined as deaths that can be delayed with appropriate and timely medical treatment. Our baseline regression analysis adjusting only for age and sex shows that an increase in the number of physicians per 1000 is associated with a reduction of 1.7 ($P < .01$) and 0.97 ($P < .01$) age-standardized deaths per 100 000 for men and women, respectively. However, in our full analyses that control for socioeconomic factors and Taiwan's health insurance expansion, we find that physician supply is no longer statistically associated with amenable mortality rates. Nevertheless, we found that greater physician supply levels are associated with a reduction in deaths from ischemic heart disease (−0.13 ($P < .05$) for men, and −0.066 ($P < .05$) for women). These findings suggest that overall, physician supply is not associated with amenable mortality rates after controlling for socioeconomic factors but may help reduce amenable mortality rates in specific causes of death.

KEYWORDS: Taiwan, amenable mortality, physician supply, health disparities, socioeconomic status

RECEIVED: March 20, 2020. **ACCEPTED:** August 6, 2020.

TYPE: Original Research

FUNDING: The author(s) received no financial support for the research, authorship, and/or publication of this article.

DECLARATION OF CONFLICTING INTERESTS: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Introduction

Is greater physician supply associated with better health and lower mortality? Evidence shows that timely and appropriate primary care can help prevent disease.[1] More physicians, ceteris paribus, should *theoretically* increase access to timely primary care, prevent disease, and ultimately lower mortality rates, particularly from causes of death amenable to medical care.[2] Yet debate still remains whether *empirically*, having more physicians improves health and reduces amenable deaths. Some argue that, with advances in medical technology, health care is making an increasingly important contribution to overall health.[3] Others, however, believe that the marginal return from medical care is eclipsed by broader social policies such as education, housing, and transportation.[4]

Existing literature, derived primarily from Western nations, is inconclusive. While many studies report a negative correlation between physician supply and mortality generally,[5-9] other studies show that the relationship is sensitive to context,[10-12] or find no association.[13] This lack of a definitive conclusion is likely due to study differences among multiple dimensions, including causes of death investigated, definition of physicians (eg, primary care versus specialist, headcount versus Full-Time Equivalent availability), methodological approaches, geographic regions, and healthcare and cultural contexts. For example, a study in England found that a greater supply of general practitioners is associated with lower premature mortality, even in a health system with strong primary care.[5] In the United States, for every 10 additional primary care physicians per 100 000 population, cardiovascular, respiratory, and cancer mortality was lower by 0.9% to 1.4%.[6] In the U.S. elderly Medicare population as well, it was shown that areas in the highest quintile of physician supply (as measured by available FTE) had lower mortality and fewer hospitalizations for ambulatory care sensitive conditions.[7] In East Asia, Liang and colleagues[9] and Sakai and colleagues[8] found that greater numbers of healthcare professionals and pediatricians reduced child mortality in China and Japan, respectively.

On the other hand, several studies explored the healthcare and sociodemographic context of the mortality benefits of physician supply and have found inconsistent relationships. Ricketts and colleagues showed that the physician supply–mortality associations are regionally focused in the United States, with clusters of regions exhibiting the expected negative relationship, whereas other regions demonstrating no such relationship.[10] Shi and Starfield further investigated the role of race in the United States, and found that physician supply remained a significant predictor of lower mortality among White Americans after controlling for socioeconomic factors, but not among African Americans.[11]

Other studies focusing squarely on amenable mortality also showed that clinical, health services, and/or sociodemographic context matters: Two studies from England concluded that mortality is negatively associated with physician partnership size but not with the supply of available general practitioners.[14] A German study found a negative association between physician supply and avoidable deaths due to cancer of the female breast, as well as colorectal cancer in both sexes.[15] However, a Polish study pointed out that an initially significant correlation between physician supply and amenable mortality was reduced once education and income were controlled for in the analyses.[12] Indeed, a study using OECD data for 19 countries did not find any association between overall physician supply and amenable mortality.[13] In Asia, a single study from Korea determined that a higher number of primary care physicians was associated with lower cancer and cardiovascular mortality.[16] The authors, however, also noted that socioeconomic and population factors seemed to have a greater impact on avoidable mortality rates than physician supply.[16]

We examined whether greater physician supply is associated with lower amenable mortality rates using population-level data of all deaths in Taiwan from 1971 to 2008. Our study contributes to the literature by being, to our knowledge, only the second to explore this question in Asia, which has significant structural and cultural differences in healthcare delivery compared to Western countries. Most East Asian countries, including China, Japan, Korea, and Taiwan, lacked or continue to lack a gatekeeping system for referrals to specialists.[17] This may make results on the relationship between primary care physician supply and amenable mortality from Western countries less generalizable to East Asia since patients can and often do self-refer to specialists directly.[17] Different cultural attitudes to medicine, in particular an emphasis on pharmacotherapy in Asian countries,[18] may also alter the effect of physician supply on mortality rates. This study also extends our previous work that investigates the association between township wealth and amenable mortality[19] to assess the potential impact of physician supply above and beyond income and wealth. Finally, our nearly 4-decade-long study period spans significant changes in medical technology and the health policy landscape in Taiwan and affords a long-term, longitudinal analysis of the association between physician supply and amenable mortality.

Taiwan is a particularly interesting case to study in our selected period. Between 1971 and 2008, Taiwan experienced rapid economic development, and by many measures reached the status of a developed economy by the end of the 20th century. In 1970, Taiwan's life expectancy was 67.88 years, which grew to 78.19 by 2008.[20] The number of physicians per 1000 grew from 0.4 in 1970 to 1.8 in 2008.[21] In 1970, per capita GDP was $396 United States Dollars, and increased nearly 100-fold to $34 936 in terms of purchasing power parity by 2008.[22,23] Before 1995, only half of Taiwan's population had health insurance coverage, but the implementation of its National Health Insurance (NHI) in 1996 extended coverage to nearly the entire population virtually overnight.[24] A government-sponsored single-payer system with a mix of private and public providers, NHI has been credited with reducing disparities in access to care and health outcomes in Taiwan.[25] It remains to be seen, however, whether the increasing numbers of physicians reduced disparities in amenable mortality over the nearly 4-decade-long period of our study.

As healthcare systems around the world face the twin challenges of health disparities and resource constraints, it is important to understand whether increasing scarce healthcare resources, such as the supply of physicians, will mitigate disparities and improve health outcomes. If so, better policies to recruit additional physicians to under-resourced areas should be a top health policy priority. If not, policymakers should consider pursuing other evidence-based policies, such as education and health literacy campaigns and/or better housing and other improvements to the built environment, in order to improve health in disadvantaged areas.

Methods

Data

Our primary data source consists of Taiwan's National Death Certification Registry from 1971 to 2008.[26] The data include information on age, sex, location of death, and cause of death for *all* deaths of Taiwanese nationals. We collected data on the number of physicians per 1000 residents by township from Taiwan's Ministry of Health and Welfare's statistics on healthcare institutions and healthcare utilization,[27] supplemented with data on hospitals and physicians from the National Health Insurance Research Database.[28] For township-level information on mean household income, population, and education attainment, we acquired data from Taiwan's National Statistics Bureau.[29] We obtained data on township urbanization levels from Tzeng and Wu.[30]

Variables

Amenable mortality. We followed the definition created by Concerted Action of the European Community on Avoidable Mortality (CAEC) to classify each death in the Death Registry as either an "amenable death" or "non-amenable death."[31] Amenable deaths include those causes of death that can be delayed with appropriate and timely medical treatment and/or public health measures. We present the CAEC classification of amenable mortality and the corresponding codes under the International Classification of Diseases, 9th Edition, Clinical Modification (ICD-9-CM Codes) in Table 1.

Age-standardized mortality rates by sex. To account for differing age structures between townships, mortality rates were age-standardized in 5-year intervals by physician supply quartile and by sex, except for years 2006 to 2008. We disaggregated by sex because some diseases are specific to women (eg, breast and cervical cancer), and some may have mortality differences based on

Table 1. CAEC classification of avoidable deaths.

CAUSE OF DEATH	INTERVENTION	ICD9 CODE	AGE-GROUPS (YEARS)
Deaths amenable to both medical care/public health		001-999	0-64
Ischemic heart disease	Public health	410-414, 429.2	35-64
	Smoking cessation, lifestyle modification		
	Medical care		
	Pharmacotherapy, angioplasty, surgery		
Deaths amenable to medical care			
Tuberculosis	Immunization, contact tracing, pharmacotherapy	010-018, 137	5-64
Malignant neoplasm of the breast (breast cancer)	Screening, surgery, radiation therapy, chemotherapy	174	25-64
Malignant neoplasm of the cervix uteri (cervical cancer)	Screening, surgery, radiation therapy, chemotherapy	180	15-64
Malignant neoplasm of the uterus (uterine cancer)	Screening, surgery, radiation therapy, chemotherapy	179, 182	15-64
Hodgkin's disease	Chemotherapy, radiation therapy,	201	15-64
Hypertension and cerebrovascular disease	Pharmacotherapy, carotid endarterectomy	401-405, 430-438	35-64
Asthma	Pharmacotherapy	493	5-44
Gastric and duodenal ulcer (ulcers)	Pharmacotherapy, surgery	531-534	25-64
Appendicitis	Surgery	540-543	5-64
Hernia	Surgery	550-553	5-64
Cholelithiasis, cholecystitis, and cholangitis (gallbladder diseases)	Pharmacotherapy, surgery	575-476	5-64
Complications of pregnancy (maternal mortality)	Pharmacotherapy, surgery	630-676	0-64
Perinatal conditions	Screening, pharmacotherapy, surgery	760-779	>28 weeks, gestation < 1 week and stillbirths

Adapted from the European Community Working Group on Health Services and Avoidable Deaths, 1997.

sex.[32,33] We used the direct method, as described below, to calculate age-standardized mortality rates (ASMRs) per 100 000 residents for each sex and physician supply quartile[34]:

$$ASMR = \frac{\sum W_i \times A_i}{\sum W_i}$$

In the formula above, W_i is the population in the ith age class of the reference population (world population) in 2000, and A_i is the age-specific mortality rate in the ith age class in Taiwan. We chose to use the world population as the reference population to be consistent with prior literature adopting this population,[19,35,36] and to provide results that are more readily interpretable across countries and jurisdictions across the world.

Physician supply levels. We obtained the number of physicians per 1000 residents in each of Taiwan's 357 townships or city districts (hereinafter "townships") from Taiwan's Ministry of Health and Welfare.[29] (The official number of townships fluctuated because several smaller townships were consolidated over the years.) The figure represents the headcount of Ministry of Health and Welfare-licensed physicians working at a hospital or clinic located in each township, per 1000 individuals registered in the household registries in the same township. In our study, we counted all physicians, not just primary care physicians, to reflect the lack of gatekeeping in Taiwan, where most physicians serve roles similar to primary care physicians in the West. Official statistics showing the number of physicians per 1000 do not distinguish between hospital or clinic physicians, but we also estimated the number of clinic physicians per 1000 in each township using data on hospitals and workforce from the Bureau of National Insurance to assess whether type of physician differentially affects ASMRs. This estimation, however, is available only for 1997 and beyond, substantially shorter than our nearly 40-year study period, and, therefore, we later report the results as secondary to analyses using all physicians as the primary independent variable.

We used the number of physicians per 1000 directly in our regression specifications. For the trend analyses of ASMRs, however, we categorized the townships into quartiles based on the number of physicians per 1000 residents, with the first quartile having ⩽0.277 physicians; the second quartile, >0.277 and ⩽0.483 physicians; the third quartile, >0.483 and ⩽0.984 physicians; and the fourth quartile, >0.984 physicians per 1000.

Control variables. Mean household income at the township level was obtained directly from the National Statistics Bureau of the Ministry of the Interior and measured in New Taiwan Dollars. We calculated the percentage of the population with at least a junior high school education in each township. We collapsed Tzeng and Wu's[30] 8 levels of urbanization into 4 levels by combing levels 1-2, 3-4, 5-6, and 7-8, and created 3 of the 4 levels as a series of dummy variables, with level 4 (the most urbanized townships) as the omitted reference level. Taiwan implemented its National Health Insurance (NHI) policy in 1996, with a dramatic increase in insurance coverage—from 57% to virtually the entire population overnight. This expanded access may impact mortality rates, and we controlled for the effect of the policy change by including a dummy variable that equals 1 for all years starting in 1995. We also included slope variables for pre-NHI and post-NHI years, respectively, as a variable that counted the number of years from the beginning of the study period, and another counter that remains 0 until 1995, after which it began counting from 1 and increased by 1 for each advancing year. Finally, given the long study period and the evolution of medical technology over time, we also constructed decade dummy variables in an alternative specification to control for decade fixed effects, using 1971 to 1980 as the referenced decade.

Multivariate regression analyses. We conducted several multivariate regressions with ASMRs (for all amenable deaths, and key individual amenable causes of death) as the dependent variable, using physician supply as the main predictor variable with the addition of different subsets of the control variables listed above. Our unit of observation was the township-year, and we ran the following regression for each sex separately, where *i* represents township and *t* represents year:

$$\begin{aligned} ASMR_{it} = {} & \alpha + \beta_0 \cdot physicians\ per\ 1{,}000_{it} \\ & + \beta_1 \cdot mean\ household\ income_{it} \\ & + \sum_{j=2}^{4} \beta_j \cdot urbanization\ level_i \\ & + \beta_5 \cdot percent\ junior\ high\ graduates_{it} \\ & + \beta_6 \cdot pre\ NHI\ year\ counter_t + \beta_7 \cdot post\ NHI_t \\ & + \beta_8 \cdot post\ NHI\ year\ counter_t + \varepsilon_{it} \end{aligned}$$

The key coefficient of interest is β_0, which denotes the relationship between number of physicians per 1000 residents and age-standardized mortality rates for amenable causes. The suite of coefficients for the NHI variables (pre NHI year counter, post-NHI and post NHI year counter) should be interpreted as the slope of the trend in amenable mortality rates in the pre-NHI years, the discontinuous change in amenable mortality rates in the year of NHI implementation, and the change in slope of the trend in amenable mortality rates in the post-NHI years relative to the pre-NHI years. We clustered our Huber-White robust standard errors at the township level to account for correlations between observations within the same township over time. In addition, because our unit of observation (the township) varied widely in population, we used the township-level population as probability weights in our regressions.

This study is exempt from Institutional Review Board review because it relies solely on existing secondary data.

Results

Summary statistics

We first present the summary statistics of our analytical sample in Table 2. From 1971 to 2008, Taiwanese townships had an average of approximately 0.956 physicians per 1000, ranging from 0 to 17.54 physicians per 1000 population. Average annual household income in 2001 New Taiwan Dollars (NTD) was approximately \$362 502 NTD (\$12 083 United States Dollars) over all years, with a minimum of \$10 453 NTD (\$348 U.S. Dollars) and a maximum of \$2 007 955 NTD (\$66 931 U.S. Dollars). Around 73.4% of all townships were in the 2 most rural categories (rural1 and rural2), and the average junior high school graduation rate across townships over the years was approximately 73.1%. Average all-cause ASMR was about 336.23 per 100 000, and 77.57 per 100 000 for amenable ASMR. Injuries (81.22 per 100 000), followed by hypertension/cerebrovascular disease (36.64 per 100 000), lung cancer (8.92 per 100 000), ischemic heart disease (IHD) (7.45 per 100 000), and asthma (3.47 per 100 000) rounded up the top 5 amenable causes of death.

Overall results

Our findings differed depending on the statistical approach taken, but overall the results did not show that more physicians were associated with lower amenable mortality rates. In our simple trend analyses, the results initially suggested that townships with

Table 2. Summary statistics.

VARIABLE	MEAN	SD	MIN	MAX
	N = 27 028[a]			
Physicians per 1000	0.96	1.64	0.000	17.54
Mean annual household income[b]	362.5	295.14	10.45	2007.96
% junior high	0.73	0.11	0.46	0.95
Rural level 1 (%)[c]	0.39			
Rural level 2 (%)	0.35			
Rural level 3 (%)	0.14			
Age std mortality rates[d]				
All cause	336.23	210.02	0	3222.24
Amenable	77.57	60.32	0	1500.9
IHD	7.45	11.99	0	368.42
Injuries	81.22	74.92	0	1293.33
Hypertension/CVD	36.64	36.25	0	1005.84
Lung cancer	8.92	12.11	0	313.60
Breast cancer	2.88	6.91	0	155.02
Cervical cancer	2.66	7.54	0	313.18
Uterine cancer	1.49	5.64	0	175.36
Hodgkin's lymphoma	0.11	1.54	0	150.53
Asthma	3.47	10.83	0	588.24
Ulcers	2.49	8.48	0	395.17
Appendicitis	0.12	1.76	0	106.07
Hernia	0.04	0.85	0	84.34
Gall bladder	0.48	3.08	0	120.05
Maternal mortality	0.54	4.16	0	141.79

[a]Percent junior high only has 26 886 observations.
[b]Mean annual household income in 1000 New Taiwan Dollars.
[c]Rural 1 represents the most rural townships.
[d]ASMR in number of deaths per 100 000.

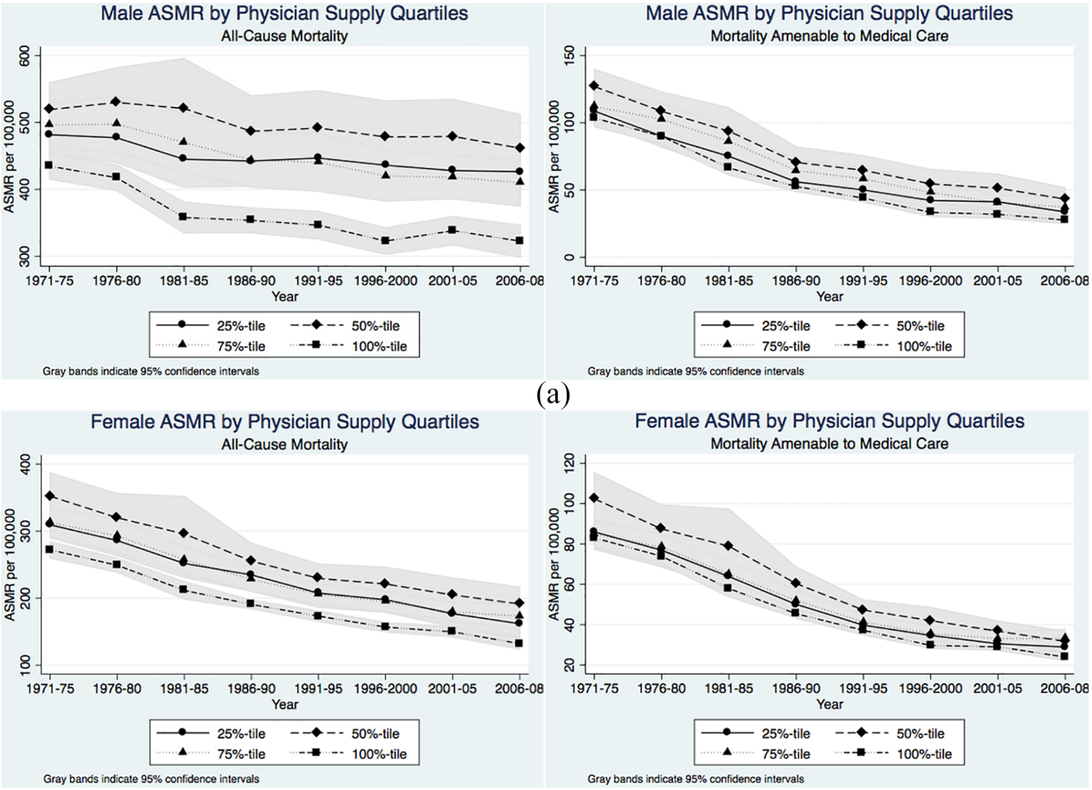
more physicians had lower amenable mortality rates. In our multivariate regressions, however, the negative association between physician supply and amenable mortality lost statistical significance in almost all specifications after adjusting for our control variables. This pattern held even when we separated physicians into clinic and hospital physicians per 1000 population. Below we unpack these overall results in greater detail.

Trend analysis results

Aggregate amenable mortality rates fell during our study period for all physician supply quartiles, and the highest quartile enjoyed the lowest rates over the entire study period. (See Figure 1 and Supplemental Appendix Table A, top portion in each quartile). However, for the remaining quartiles, the ranking of mortality rates was not strictly monotonic based on physician supply quartiles. Moreover, all-cause mortality rates and *non-amenable* mortality rates (which are not modifiable by medical intervention) were the lowest in townships in the highest quartile of physician supply, suggesting that non-physician factors also contribute to better health in areas with more physicians.

Multivariate regression results

Our baseline regression using only physician supply as the explanatory variable in Table 3 is consistent with the trend analysis results. A unit increase in the number of physicians per



(b)

Figure 1. Age-standardized mortality by physician supply quartiles. (a) Males. (b) Females.

1000 is associated with a reduction of 1.7 ($P<.01$) and 0.97 ($P<.01$) in ASMR for males and females, respectively (Table 3, columns (1) and (6)). However, when we also controlled for at least income, the negative and significant association between physician supply levels and amenable mortality disappeared. See Table 3, specification (2) to (5) and (7) to (10).

On the other hand, mean household income is negatively associated with ASMR for both males and females regardless of the specification (See Table 3, specifications (2) to (5) and (7) to (10)). For each additional dollar in mean household income, ASMR fell by 0.023 ($P<.05$) to 0.04 ($P<.01$) per 100 000 for men, and 0.016 ($P<.05$) to 0.023 ($P<.01$) for women. Education attainment (at the junior high level) is associated with lower amenable mortality rates among men (ranging from −29.28 (not statistically significant) to −64.34 ($P<.01$) per 100 000). Among women, however, it is significant in none of the specifications.

In Table 4, we turn to the association between condition specific ASMRs and physician supply. We report the results of our preferred specification with NHI implementation rather than decade fixed effects, using as dependent variables 5 of the most important individual causes of death (ischemic heart disease (IHD), injuries, cerebrovascular disease (CVD)/hypertension, lung cancer, and for women only, breast cancer). Greater supplies of physicians are generally not statistically associated with lower ASMRs, except for IHD (−0.13 ($P<.05$) per 100 000 for men, and −0.066 ($P<.05$) for women).

For condition specific ASMRs as well, mean household income is generally negatively associated with mortality rates, except for lung cancer and breast cancer for women. The associations between rurality and condition specific amenable ASMRs varied widely but, in general, the most rural townships had lower rates. The only noteworthy exception is deaths from injuries, where the most rural townships had higher mortality rates [42.59 ($P<.01$) per 100 000 for men and 16.53 ($P<.01$) for women]. Again, education attainment is generally negatively associated with these 5 amenable causes of death among men, but not among women. (See Table 4, all specifications). As in the main regressions using all amenable deaths as the dependent variable (Table 3), NHI implementation is associated with a reduction in individual amenable deaths, except for breast cancer among women. (See Table 4, specification (9)).

Finally, we briefly report the results corresponding to Tables 3 (overall amenable SMR) and 4 (individual causes of death) when we separated physicians into clinic and hospital physicians per 1000. The key insight is that a similar overall pattern holds as when we used the total number of physicians per 1000—that a greater supply of either clinic or hospital physicians is statistically significantly associated with lower overall amenable mortality, but this association lost statistical significance once we controlled just for township mean income. In the simple bivariate regressions, overall amenable mortality per 100 000 fell, by −8.762 ($P<.05$) and −3.601 ($P<.01$) for every additional clinic physician per 1000 (Supplemental Appendix

Table 3. Associations between age-standardized amenable deaths and physician supply.

DEP VAR:	MEN					WOMEN				
AMENABLE SMR	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Physicians per 1000	−1.7** (0.49)	0.39 (0.57)	0.57 (0.47)	0.20 (0.44)	0.23 (0.44)	−0.97** (0.30)	0.083 (0.35)	0.12 (0.30)	−0.17 (0.29)	−0.15 (0.29)
Mean income		−0.040** (0.0079)	−0.023* (0.011)	−0.033** (0.011)	−0.032** (0.011)		−0.020** (0.0048)	−0.016* (0.0071)	−0.023** (0.0070)	−0.023** (0.0070)
Rural1 (most rural)			−1.014 (5.17)	−1.39 (4.94)	−1.27 (4.95)			−0.82 (3.30)	−1.11 (3.12)	−1.003 (3.13)
Rural2			−4.86 (2.96)	−5.99* (2.76)	−5.85* (2.78)			−2.37 (1.90)	−3.39 (1.752)	−3.26 (1.76)
Rural3			0.97 (3.57)	1.28 (3.39)	1.32 (3.40)			1.35 (2.31)	1.63 (2.16)	1.67 (2.17)
Percent >junior high			−64.34** (19.53)	−29.28 (18.86)	−31.44 (18.89)			−20.42 (12.89)	13.86 (12.26)	11.92 (12.30)
Post NHI				2.14** (0.78)	−9.12** (0.74)				0.12 (0.65)	−7.052** (0.61)
Pre-NHI trend				−2.73** (0.086)					−2.29** (0.057)	
Change trend post-NHI				2.22** (0.14)					1.77** (0.092)	
Decade (1981-1990)					−31.10** (1.23)					−23.88** (0.92)
Decade (1991-2000)					−43.03** (1.37)					−38.24** (0.99)
Decade (2001-2008)					−44.28** (1.62)					−39.87** (1.12)
Constant	78.62** (1.25)	106.0** (5.22)	146.3** (14.65)	174.7** (14.00)	161.7** (13.99)	57.94** (0.76)	71.79** (3.19)	85.36** (9.48)	106.6** (8.94)	95.18** (8.93)
Observations	13514	13514	13443	13443	13443	13514	13514	13443	13443	13443
R-squared	0.006	0.042	0.056	0.36	0.34	0.003	0.018	0.02	0.38	0.35

Robust standard errors in parentheses.
$^{*}P < .05$. $^{**}P < .01$.

Table 4. Associations between select causes of death amenable to medical care and physician supply.

VARIABLES	MEN				WOMEN				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	IHD	INJURIES	HYPERTENSION/ CVD	LUNG CANCER	IHD	INJURIES	HYPERTENSION/ CVD	LUNG CANCER	BREAST CANCER
Physicians per 1000	−0.13* (0.050)	0.29 (0.15)	0.17 (0.10)	−0.033 (0.047)	−0.066* (0.037)	0.25 (0.19)	−0.073 (0.15)	−0.053 (0.046)	−0.00443 (0.0414)
Mean income	−0.00092 (0.00086)	−0.042** (0.0032)	−0.020** (0.0018)	−0.0011 (0.00072)	−0.0013** (0.00048)	−0.014** (0.0040)	−0.016** (0.0036)	0.00049 (0.00073)	0.000920 (0.000764)
Rural1 (most rural)	−2.21** (0.39)	42.59** (1.73)	−3.36** (0.88)	−2.065** (0.39)	0.11 (0.37)	16.53** (2.32)	−0.050 (1.61)	−1.43** (0.45)	−1.583** (0.342)
Rural2	−1.98** (0.28)	31.06** (1.022)	−3.38** (0.59)	−1.79** (0.27)	−0.21 (0.24)	10.85** (1.21)	0.067 (0.97)	−1.30** (0.25)	−1.164** (0.241)
Rural3	−0.013 (0.29)	16.48** (1.068)	1.15 (0.61)	−0.53* (0.25)	0.28 (0.22)	5.61** (1.37)	1.43 (1.15)	−0.26 (0.23)	−0.101 (0.249)
Percent > junior high	−4.76** (1.50)	−19.67** (6.89)	−0.52 (3.44)	−8.017** (1.57)	1.22 (1.52)	4.99 (8.86)	19.02** (6.17)	−2.93 (2.15)	1.962 (1.277)
Post NHI	−1.27** (0.34)	−11.84** (1.21)	−2.90** (0.55)	−0.81** (0.30)	−1.12** (0.18)	−3.81** (0.56)	−3.59** (0.47)	−0.011 (0.20)	0.819** (0.246)
Pre-NHI trend	0.26** (0.014)	0.45** (0.057)	−1.38** (0.035)	0.19** (0.013)	0.027* (0.012)	0.18** (0.033)	−1.35** (0.041)	0.078** (0.011)	0.152** (0.00914)
Change in trend post-NHI	−0.14** (0.038)	−2.57** (0.12)	0.85** (0.063)	0.041 (0.034)	−0.080** (0.020)	−1.061** (0.079)	0.81** (0.055)	0.046* (0.023)	0.0924** (0.0280)
Constant	11.59** (1.15)	122.60** (5.21)	82.59** (2.69)	16.37** (1.23)	4.41** (1.19)	33.36** (6.52)	47.66** (4.64)	7.53** (1.65)	1.389 (0.986)
Observations	13443	13443	13443	13443	13443	13443	13443	13443	13443
R-squared	0.062	0.35	0.34	0.059	0.019	0.18	0.43	0.035	0.185

Robust standard errors in parentheses.
$*P < .05$. $**P < .01$.

Table B1); and by −1.914 ($P<.05$) and −0.769 ($P<.01$) for every additional hospital-physician per 1000 (Supplemental Appendix Table B2). All of these point estimates became smaller and lost statistical significance as soon as we controlled for mean township income. In the regressions with individual causes of amenable death, as in the main analyses using all total physicians, we found that increasing numbers of clinic and hospital physicians generally remained negatively associated with IHD (−1.118 ($P<.05$) (among men in the regression with clinic physicians, Supplemental Appendix Table C1), −0.696 ($P<.01$) (women, clinic physicians, Supplemental Appendix Table C1), −1.188 ($P<.05$) (men, hospital physicians, Supplemental Appendix Table C2). It is important to note that not all results remained identical in these secondary results separating clinic and hospital physicians to the ones found in our main analyses. Because of data limitations, our secondary data analyses covered only the period from 1997 to 2008.

Discussion

Overall, our results show that physician supply was not statistically associated with amenable mortality rates once we controlled for income. Rather than physician supply, greater income was almost always linked to lower mortality, with the notable exception of deaths from breast cancer among females. Again, this pattern remains whether we used total number of physicians, clinic physicians, or hospital physicians as the primary independent variable of interest. Our results are consistent with those of Gulliford, who concluded that a strong negative univariate association between supply of general practitioners and mortality disappeared after adjusting for health status and sociodemographic factors.[37] Similar results, showing that adjusting for socioeconomic factors attenuated the relationship between health infrastructure measures (ie, physician supply), were also found in the study by Wróblewska.[12]

It may not be surprising that we found no statistically significant relationship between physician supply and ASMR once socioeconomic factors were taken into consideration. It is essential to recall that physicians do not choose practice locations randomly. In Taiwan until 1983, for example, physician location was determined solely by market forces, and physicians heavily favored rich, urban areas.[38] Post-1983, Taiwan mandated the assignment of certain government-subsidized physicians to underserved rural areas, but physician supply remained largely concentrated in urbanized centers.[38] Physician supply level is therefore likely confounded with areas with higher income. In our data, for example, physician supply is positively and statistically significantly associated with township mean annual income (every additional $1 in mean income is associated with 0.0045 ($P<.01$) additional physician per 1000). In turn, these wealthy areas are likely to have better overall health outcomes due to a combination of sociodemographic and structural factors. Analyses not accounting for wealth/income when exploring the association between physician supply and health outcomes, would therefore likely suffer from omitted variable bias and are biased downward to show a negative relationship.

Our findings that greater mean household income often predicts reduced mortality are consistent with existing studies.[39] Income and wealth, at the individual level, are often proxies for a host of sociodemographic, environmental, and behavioral constructs that are associated with better health.[40] As such, it is not surprising that richer townships have lower rates of amenable mortality.

We note also that in our descriptive analyses (Supplemental Appendix Table A1), even causes of death *not amenable to medical care* are the lowest in townships with the greatest number of physicians. This pattern further supports the argument that physician supply is not the sole contributor to population health. It appears that factors other than access to physicians explain in part geographical disparities in mortality outcomes across Taiwan.

This is not to say that health care does not contribute to population health. In our analyses of individual major causes of death, we show that certain diseases may benefit from additional physician supply. In particular, ASMRs for IHD for both males (−0.13 ($P<.05$)) and females (−0.066 ($P<.05$)) decreased with increasing physician supply even when controlling for income (Table 4, specifications (1) and (5)).

Additional evidence showing the importance of medical care is provided by the negative coefficients for certain medical conditions after the introduction of NHI. This significant change in social policy extended health insurance coverage, and therefore access to physician care, from 57% to virtually the entire population.[41] There were especially large reductions in deaths for injuries, IHD and CVD/hypertension around the introduction of NHI, with continued acceleration in lower amenable deaths from injuries and IHD for both men and women in the years following NHI adoption. (See Table 4). Removing cost barriers for over 40% of the population through increased health insurance coverage may explain some of these reductions in several condition specific ASMRs around 1995 to 2000 and thereafter. As the differing signs of the coefficients on our NHI-related variables demonstrate in Table 4, NHI implementation may not have uniformly affected individual amenable diseases in the same manner. This result is not surprising, as different types of medical conditions may be differentially affected by the availability of medical care. Control of hypertension, for example, may be much more easily attained with more physicians compared to reducing mortality from vehicular accidents, which may require limited surgical ward resources.

Limitations

There are several limitations to this study. First, miscoding of the ICD-9-CM cause of death codes may exist, although Taiwan's household death registry data are generally considered accurate and complete.[42] Second, an independent variable used in our study—urbanization levels—was defined in 1 single year. We were unable to control for changing urbanization over the years in our regressions, but, likely, relative urbanization levels between townships did not change much during our study period.[43] Moreover, our main results were unchanged whether or not the urbanization variables were included. Another limitation is that the primary independent variable of interest, physicians per 1000 in each township, is only an approximation of the true construct measure of physician supply available to the public, as residents living on the border of townships may seek medical care across the township border. While we recognize this as a potential confounder, Taiwan is a small and densely populated island, and it is unlikely that there are many instances of neighboring townships with drastically different physician supply levels. That our study period ends in 2008 is a limitation as well. Newer data are unavailable to our U.S.-based study team because of post-2008 privacy laws in Taiwan. However, the long overall study period of this study, in addition to the population-level microdata, provides insight into the evolution of physician labor force and amenable mortality over nearly 40 years. Finally, we chose the 1997 CAEC definition given that it is located near the midpoint of our long 38-year study period. Newer definitions of amenable mortality, which include diseases now considered to be amenable to medical care in modern medicine, may not apply to the older years of our long study period.

Conclusion

We found that areas with more physicians did not have lower amenable mortality rates after controlling for socioeconomic factors. Instead, higher income emerged as one of the most consistent predictors of lower amenable mortality. The importance of income suggests that a host of income/wealth-related sociodemographic factors, including environmental contexts, health behavior, and literacy, may play a larger role than medical treatment in reducing mortality in jurisdictions with similar healthcare resources as Taiwan. However, physician supply may still be important for some diseases such as heart disease. Given growing health disparities and healthcare resource constraints around the world, future studies should consider investigating diseases and disease characteristics that benefit from greater physician supply. Policymakers should allocate scarce physician labor resources to areas with such need and implement broader social policies in areas where enough numbers of physicians already exist.

Acknowledgements

We acknowledge Mark Gordon and Christian Nelson for their helpful feedback on revised versions of our manuscript.

Author Contributions

Brian Chen and Chun-Yuh Yang conceived of the research idea, and conducted the initial data analyses. Chen wrote the first draft of the manuscript, and Hair and Y. Tony Yang verified the analytical methods and provided critical feedback. Chen also supervised Dakshu Jindal, a doctoral student, who performed additional analyses in response to feedback from peer reviewers. All authors discussed the results and edited the final version of the manuscript.

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Supplemental Material

Supplemental material for this article is available online.

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