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THE EFFECT OF DEVELOPMENT OF GEOGRAPHY, VITAMIN D, WEALTH, AND AGRICULTURAL PRODUCTIVITY ON TUBERCULOSIS MORTALITY: THE CASE OF THE 19TH CENTURY US

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Tuberculosis remains a major cause of international mortality, and researchers and policy advocates continue to seek a cost effective prevention and treatment. To better understand the current dilemma, this paper considers the physical and material environments associated with 19th century US tuberculosis mortality. Vitamin D was an historical remedy for tuberculosis, and sunlight-the primary source of vitamin D production and time of year-are documented here to have been associated with lower tuberculosis mortality rates. Occupations were also related with the physical environment and tuberculosis mortality, and workers in outdoor occupations, such as farmers and unskilled workers, were less likely than workers in other occupations to die from tuberculosis. Absolute wealth and agricultural productivity were associated with the likelihood of dying from tuberculosis, and people who lived in high wealth and low agriculturally productive states were less likely to die from tuberculosis.

Keywords: 19th Century US Tuberculosis Mortality, Insolation, Wealth, Agricultural Productivity
JEL classification: I12, N31, O15

1. INTRODUCTION

Tuberculosis is a common disease that affects millions of people in modern developing countries (Frew *et al*., 2008, p. 1033; Wardlaw *et al*., 2004, p. 248; Martinea *et al*., p. 793; Kiple, 2003, p. 342; Sleigh, 2007; Wang *et al*., 2007, p. 691). Recent estimates indicate that each year approximately eight million people are diagnosed with

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tuberculosis, of which three million people die (Kiple, 2003, p. 342). Tuberculosis is a bacterial infection primarily spread by inhaling air droplets contaminated with the *tubercle bacilli*, consuming infected meat, or drinking infected water. While the tubercle bacilli bacteria grows throughout the body, it thrives in environments rich in oxygen and blood, and 75 percent of tuberculosis cases are of the pulmonary variety (Johnston, 2003, p. 338).[1] Exposure to tuberculosis is also surprisingly wide spread; however, it remains dormant in the human body until conditions-such as malnutrition and unhealthy physical environments-are conducive to its activation, (Johnston, 2003, p. 338; Wardlaw *et al.*, 2004, p. 248). Primary tuberculosis symptoms include a chronic cough, marked paleness with accompanying loss of strength, fevers, night sweats, blood-tinged sputum, and weight loss.

Tuberculosis is related to occupations, and the economic consequences of tuberculosis are diminished health, declining productivity, and reduced economic output. Occupations are related to the amount of time spent outdoors, away from infected individuals where the bacteria are more easily transmitted. Occupations were also related with the hours exposed to solar radiation and vitamin D, which reduces the incidence of tuberculosis. Other economic variables are related with tuberculosis. For instance, greater overall material wealth and nutrition can strengthen immune systems by providing sufficient physical strength to withstand bacterial assault. Therefore, tuberculosis has a unique economic component in modern and 19th century health outcomes, and while vitamin D is not proposed here to be a panacea treatment, 19th century and modern tuberculosis rates may be reduced when vitamin D is used in conjunction with other low cost tuberculosis treatments.

It is against this backdrop this paper considers the relationship between US tuberculosis mortality and the 19th century economic variables of wealth, insolation, occupations, and agricultural production.[2] Three questions are considered. First, what was the relationship between 19th century tuberculosis mortality and insolation (sunlight), and how did tuberculosis mortality vary with demographic variables, occupations, time of year, nutrition, and insolation? Consistent with the biomedical literature, 19th century US tuberculosis mortality was related with insolation and vitamin D production, and

[1] Tuberculosis takes on many forms and names. Consumption, bloody cough, fever, pallor, long relentless wasting, lung sickness, lupus vugaris (tuberculosis of the skin), mesenteric disease (tuberculosis of the abdominal lymph glands), phthisis pulmonalis (original Greek name for tuberculosis), scrofula (tuberculosis of the lymphnodes), wasting disease, white disease, King's evil (tuberculosis of the lymph glands and neck), and Pott's disease (tuberculosis in the spine). While tuberculosis usually affects the respiratory system, it can also affect the bones, joints, central nervous, lymphatic, circulatory, and gastrointestinal systems.

[2] The 19th century US was a developing economy. In 1840, the US GDP per capita was approximately $1,600, which is between Iraq and Turkey's 2005 GDP per capita of $1,000 and $1,600, respectively. Therefore, when considering 19th century US economic development, we are observing conditions similar to many modern developing countries.

individuals in states that received more insolation were less likely to die from tuberculosis. Second, what was the relationship between 19th century tuberculosis mortality and material wealth? This paper demonstrates that the likelihood of 19th century tuberculosis mortality was lower in states that had greater average wealth and agricultural productivity. Third, what were the geographic and economic regions associated with tuberculosis mortality? This paper reports that the admonition of 19th century medical practitioners for their tuberculosis patients to seek out more healthy western environments had a beneficial effect, and the likelihood of tuberculosis mortality was around 20 percent lower for 19th century Westerners than Easterners.

2. VITAMIN D, TUBERCULOSIS, AND 19TH CENTURY US MORTALITY

Because of its high cost on human health and lost economic output, a search for a cure for tuberculosis began early. One historical tuberculosis remedy was drier climates with less cloud cover, which are associated with greater vitamin D production (Davies, 1985, pp. 302-303). The primary source of vitamin D is not dietary but produced by the synthesis of cholesterol and sunlight in the stratum granulosum (Holick, 1994, p. 590; Holick, 2007, p. 270; Holick 2007 video), and vitamin D is receiving increased attention in economic development and biomedical studies as a low-cost tuberculosis treatment in developing countries (Davies, 1985, pp. 302-303; Lee and Jiang, 2008, pp. 138-139; Kappelman *et al*., 2008, p. 10). Greater direct sunlight (insolation) produces more vitamin D, and vitamin D modulates immune response through cellular vitamin D production.[3] As in modern developing countries, 19th century tuberculosis imposed a heavy burden on European and US populations. Tuberculosis mortality rates were at their peak in developed countries during the early 19th century, and the root causes were poor nutrition and appalling urban sanitation conditions. For example, between 1810 and 1815, tuberculosis was probably the most common mortality among American colonial adults and accounted for approximately 25 percent of New York City adult mortality (Murray, 2004, p. 1181). Until around 1890, Europe and the US accepted the ghastly toll tuberculosis claimed from their populations. However, a major reversal in tuberculosis mortality occurred in 1853, long before modern medical intervention developed effective treatments. Among the first of these treatments occurred in Europe. Hermann Brehmer was a 19th century German medical student who contracted tuberculosis, and German physicians instructed him to seek-out more healthy climates. Brehmer subsequently relocated to the Himalayas, continued to study medicine, and in the

[3] The primary source of vitamin D is the synthesis of ultraviolet B and cholesterol, and insolation is the primary source of ultraviolet B. Photosynthesis of vitamin D_3 in the epidermis depends on season, latitude, time of day, and the amount of pigmentation in the epidermis (Holick, 1981; Lips, 2006; Mawer and Davies, 2001).

process, Brehmer's tuberculosis abated. His success created a wave of optimism in the search for a cure, and physicians soon recommended their other tuberculosis patients seek out healthier physical environments with better nutrition and fresh air. These recommendations in the US frequently included migrating west, and the West receives more hours of direct sunlight per day because of less cloud-cover, which allows more insolation exposure and vitamin D production.

Another early treatment was the sanatorium. Tuberculosis sanatoriums were medical facilities that quarantined patients and served the dual role of guaranteeing them from the unexposed and allowing infected individuals the physical rest necessary for recovery. During the early 1900s, two other treatments were introduced. First, building on Louis Pasteur's vaccination in 1908, Albert Calmette and Camille Guérin developed a vaccine against tuberculosis. Second, in 1944, Schatz, Bugie, and Waksman discovered streptomycin, which kills the mycobarterium tuberculosis (Johnson, 2004, p. 237). Since these 20th century treatments were developed, tuberculosis has become easy to diagnose, and treatment success rates are up to 95 percent effective in industrialized economies. Modern researchers are likewise searching for cost-effective tuberculosis treatments in countries such as Africa, China, and India, where the incidence of tuberculosis persists (Sleigh, 2007; Wang *et al*., 2007).

Two material factors related to the incidence of tuberculosis is wealth and nutrition. Greater absolute wealth is related to better material and biological conditions, and cleaner environments (Steckel, 1995; Carson, 2009).[4] Wealth may also represent part of the relationship between nutrition and tuberculosis, because wealth is correlated with nutrition and diet (Komlos, 1987; Hilliard, 1972). Therefore, in this study of 19th century tuberculosis mortality, if vitamin D was significant as a tuberculosis remedy, individuals who lived in Northern latitudes and worked indoors away from the beneficial aspect of insolation were more vulnerable to tuberculosis mortality. If wealth and nutrition are significant in tuberculosis mortality, individuals in low wealth and low agricultural productivity areas were likewise more vulnerable to tuberculosis mortality.

[4] The use of state-level wealth is complicated. Ideally, we would like individual-level wealth to be tied to individual mortality. Since these linkages are not possible we rely on state-level wealth as a reasonable proxy for individual-level wealth for at least two reasons. First, there were spillover or positive external effects. Individual-wealth was likely to be greater in areas that had greater average state wealth. For example, an individual is more likely to be wealthy in Massachusetts, which had $2,511 in 1860 and $2,326 in 1870 state average wealth, compared to New Mexico, which had $539 in 1860 and $438 in 1870 state average wealth. Second, wealthy states had more developed public infrastructures and other health improving amenities.

3. 19TH CENTURY US CENSUS MORTALITY DATA SET

Multiple 19th century data sets are required to consider the relationship between the physical environment, wealth, agricultural productivity, and tuberculosis. Tuberculosis mortality data is from the 1860 and 1870 census mortality schedules. Sunlight exposure data is constructed from modern incident solar radiation estimates.[5] Average state wealth and agricultural productivity estimates are from 1860 and 1870 population and agricultural censuses.

3.1. Mortality Data

The 19th century US creates an environment to observe the effects of tuberculosis and its treatment during the process of industrialization. However, reliable 19th century mortality data have been slow to emerge.[6] One possibility is the 1860 and 1870 census mortality schedules. When conducting the 1860 and 1870 federal deci-annual population censuses, enumerators inquired from household heads concerning the individuals in their households who had died in the previous 12 months, and these data form the basis of this study. Census mortality schedule enumerators recorded gender, cause of death, occupation, age, death years, and death month. There were a broad set of death causes, and tuberculosis, digestive system, and infectious diseases were prominent mortalities. These census mortality schedules, therefore, create a plethora of 19th century US mortality data and are a rich source for epidemiology and historical health studies.[7]

Nevertheless, census mortality schedules are not complete enumerations, and decisions made at the state level render some key states inaccessible and even non-existent.[8] Moreover, the census mortality records are not above scrutiny for the purposes in which they are used. Edward Meeker suggests that census enumeration data give a large and unpredictable undercount of deaths; however, his reluctance to use census mortality data is related to the purpose of his study, to establish 19th century US life expectancy estimates.[9] On the other hand, Michael Haines suggests that the census

[5] Data for US insolation are available from the National Aeronautics and Space Administration.

[6] There is the possibility of mis-diagnosis for 19th century tuberculosis; however, 19th century tuberculosis mortality diagnosis was relatively accurate (Haines, 1979, pp. 289-291; Haines, 1998. p. 150). Among modern mortalities in developing countries misdiagnosis remains probable in many developing societies, except for tuberculosis directly observed by medical professionals.

[7] Mortality data is from the Inter-University Consortium for Political and Social Research. The data is under Fogel, Ferrie, and Costa's "United States Census of Mortality: 1850, 1860, and 1870" data file.

[8] Since county level census records did not survive in the mortality census, states of California, New York and Massachusetts are omitted. There remain certain biases in these data, which are covered by Gretchen Condran and Eileen Crimmins, and Joseph Ferrie.

[9] Meeker (1972), "The Improving Health".

schedules do not affect results too dramatically, and that the census mortality schedules are sufficiently complete to accurately address factors associated with 19th century tuberculosis. Since there is little evidence that there were large undercounts for specific mortalities, the census mortality schedules provide the data to consider the influence of occupation and location on mortality. Therefore, like Ferrie and Haines, I believe the advantages of using these data exceed the costs of ignoring their availability.[10]

How the physical and material environments were related to 19th century US tuberculosis mortality illustrates their relative importance in health outcomes. Table 1 summarizes 1860 and 1870 census mortality by state.

Table 1. 1860 and 1870 US Census Mortality Schedule by State Residence

	N	*Percent*		*N*	*Percent*
Alabama	5,749	2.58	Mississippi	20,809	9.33
Arkansas	9,414	4.22	Montana	168	0.08
Colorado	343	0.15	Nebraska	1,336	0.60
Connecticut	12,193	5.47	Nevada	611	0.27
Washington, DC	3,194	1.43	Oregon	1,071	0.48
Delaware	2,757	1.24	Pennsylvania	69,459	31.14
Florida	2,901	1.30	South Carolina	2,821	1.26
Georgia	5,449	2.44	South Dakota	77	0.03
Idaho	46	0.02	Tennessee	9,345	4.19
Illinois	18,662	8.37	Texas	12,081	5.42
Indiana	230	0.10	Utah	1,235	0.55
Kansas	5,868	2.63	Vermont	6,814	3.05
Kentucky	12,694	5.69	Washington	274	0.12
Louisiana	6,123	2.74	West Virginia	7,234	3.24
Missouri	4,049	1.82	Wyoming	68	0.03
			Total	223,075	100.00

Source: 1860 and 1870 US Census Mortality Schedules.

Notes: Category counts and proportions represent total 1860 and 1870 US Census mortalities. Category counts and proportions do not represent share of tuberculosis to total US mortality sources.

Although proportionally more tuberculosis deaths were recorded in the 1860s, there were more tuberculosis mortalities recorded in the 1870s (Table 2). Tuberculosis was related to age, and individuals who were in their twenties and thirties were more likely to die from tuberculosis. Tuberculosis was also related to occupational environments, and individuals who worked indoors and lived in the Northeast were more vulnerable to

[10] Ferrie (2001), "The Poor and the Dead," p. 2; and Haines, "Estimated Tables," p. 150.

tuberculosis than individuals who worked outdoors in the South. Seasonal variation was related to tuberculosis mortality and winter months were associated with higher tuberculosis mortality rates. Nevertheless, proportions provide only a partial view of 19th century tuberculosis because of potential compositional effects, which are accounted for in the regression models that follow.

Table 2. 19th Century US Mortality Descriptive Statistics

	Number	Percent		Number	Percent
Death Year			*Residence at Death*		
1860	133,091	59.66	Northeast	19,007	8.52
1870	89,984	40.34	Middle Atlantic	75,410	33.80
Birth Decade			Great Lakes	18,892	8.47
1700s	22,650	10.15	Plains	11,330	5.08
1800s	12,875	5.77	Southeast	82,539	37.00
1810s	13,839	6.20	Southwest	12,081	5.42
1820s	17,074	7.65	Far West	3,816	1.71
1830s	22,662	10.16	*Death Month*		
1840s	23,058	10.34	January	18,907	8.48
1850s	69,798	31.29	February	19,632	8.80
1860s	40,505	18.16	March	23,120	10.36
1870s	614	0.28	April	21,279	9.54
Ages			May	22,503	10.09
0-9	98,805	44.29	June	14,932	6.69
10-19	22,901	10.27	July	17,760	7.96
20-29	24,410	10.94	August	19,697	8.83
30-39	18,643	8.36	September	18,652	8.36
40-49	15,106	6.77	October	16,781	7.52
50-59	12,512	5.61	November	13,970	6.26
60-69	12,701	5.69	December	15,842	7.10
70-79	10,715	4.80			
80-89	5,775	2.59			
90-99	1,250	0.56			
100+	257	0.12			
Occupation					
White-Collar	4,170	1.87			
Skilled	8,753	3.92			
Farmer	22,039	9.88			
Unskilled	30,954	13.87			
No Occupation	157,159	70.45			

Source: See Table 1

Note: Mortality represents county and proportions for all 1860 and 1870 US census mortalities without respect to cause.

3.2. United States' Insolation

Vitamin D production is related to the physical environment, indicating occupations and migration status influenced vitamin D production. Modern studies illustrate the beneficial role that vitamin D has on health outcomes,[11] and the pathways by which vitamin D influences health have come into focus. Vitamin D acts as an autoimmune regulator, which may limit hyperproliferate cell growth, subsequently, the spread of cancer (Holick, 2004, p. 366; Martineau *et al*., 2007, p. 794). Increased vitamin D leads to increased levels of monocytes and macrophage activity against mycobacterium tuberculosis (Martineau *et al*., 2007, p. 794; Kappelman *et al*., 2008, p. 114).[12]

To account for the relationship between vitamin D and tuberculosis, a measure is constructed here that accounts for solar radiation. Insolation is the incoming direct sunlight that reaches the earth, its atmosphere, and surface objects.[13] Insolation is also the primary source of vitamin D (Holick, 1981, p. 590; Holick, 2007, p. 270). Because US historical insolation is unavailable, a modern insolation index (1993-2003) is constructed, and monthly insolation values are measured from January through June. The insolation index measures statewide average insolation levels across each of the states based on the hours of direct sunlight per day at county centroids.[14] Each state estimate was then determined by summing the average hours of direct sunlight for each county (at its centroid), weighted by the proportion of the county's total land area (in square miles) to the state's total land area (in square miles). While this index is a rough approximation for historical insolation, it provides sufficient detail to capture state latitudinal insolation variation and consequently, vitamin D production. Predictably, Southern states have greater insolation than Northern states. For example, Texas receives 1.43, or 29 percent, more hours of direct sunlight per day than New York. It is

[11] Multiple cancers-including prostate, colorectal, breast, and ovarian-are linked to insufficient vitamin D. Other chronic diseases, such as multiple sclerosis and rheumatoid arthritis, have been tied to insufficient vitamin D consumption.

[12] Monocytes are a type of white blood cell in the human immune system and have two main functions. First, monocytes replenish resident macrophages and dendritic cells. Second, in response to inflammation, monocytes can move to infection sites in tissue and differentiate into macrophage cells to elicit an immune response. Macrophages are white blood cells within tissues, and are produced by the division of monocytes. Macrophages assist neutralizing and eliminating harmful pathogens within the human body.

[13] Insolation is an acronym for incident solar radiation, and is a measure for sunlight energy received for a given surface area at a given time. If w equals watts, m equals meters, and i equals insolation, $i = \frac{w}{m^2} = \frac{kwh}{m^2 \cdot day}$.

[14] Insolation is not the insolation in the county that surrounds the state's centroid, but insolation in each county's geographic center. The range of state insolation values extends from Maine's minimum of 3.43 hours of direct sunlight to Arizona's maximum of 5.22 hours of direct sunlight per day.

also difficult to interpret insolation's net direct effect on human health, because greater insolation reduces calories required to maintain body temperature and produces more vitamin D, but greater insolation also warms surface temperatures, which may have made disease environments less healthy from water-borne diseases, especially in the South (Steckel, 1992, p. 501).

Blacks and whites are not equally efficient at producing vitamin D. Greater melanin (skin pigmentation) in the stratum corneum interferes with vitamin D's synthesis in the stratum granulosum, and darker pigmentation filters between 50 percent and 95 percent of the sunlight that reaches the stratum granulosum (Jablonski, 2006, pp. 80-81; Kaidbey *et al*., 1979, pp. 249 and 253; Loomis, 1967, p. 502; Weisberg *et al*., p. 1703; Holick, 2007, p. 270).[15]

3.3. US Average Wealth and Agricultural Productivity

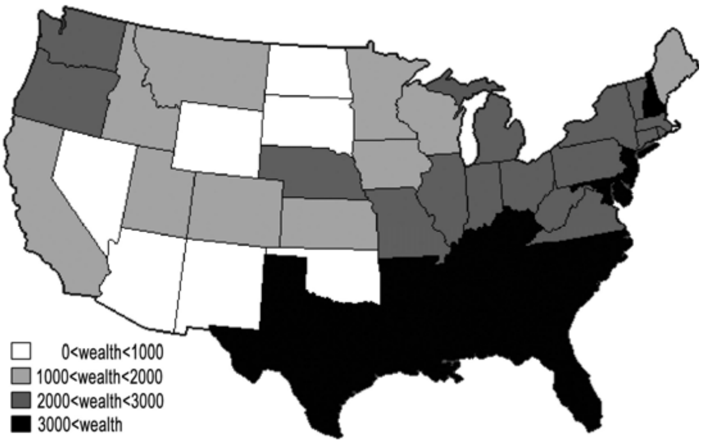
The 1860 and 1870 federal population censuses have been the subject of numerous 19th century wealth studies and provide unique insight into the historical relationship between material conditions, agricultural productivity, and health as development occurred. Lee Soltow (1975) uses an 1860 and 1870 US wealth sample to demonstrate that wealth inequality did not start with industrialization and changed little between 1800 and 1940. Atack and Bateman (1981) use 1860 and 1870 census wealth to show that although wealth in the rural North was distributed more equitably than in the South, it was not a classical egalitarian society. Kearl, Pope, and Wimmer (1981) and Pope (1989) use census records to demonstrate that wealth in the Far West was distributed more equitably; however, western wealth accumulation lagged behind that of the East.

Using the Integrated Public Use Microdata Series, US wealth is considered here for male headed households over the age of 18.[16] Between 1860 and 1870, average total wealth decreased from $3,289 in 1860 to $3,018 in 1870 (Figures 1 and 2). Compared to the South, Northern wealth holdings increased between 1860 and 1870 while

[15] To address rickets in the US population, in the 1930s, the federal government advocated fortification of the US milk supply with vitamin (Bishai and Nolubola, 2002, p. 41; Holick, 2004, 1679s). However, blacks, who are more likely to be lactase intolerant, did not consume milk to the same degree as that consumed by whites (Kiple and King, 1981).

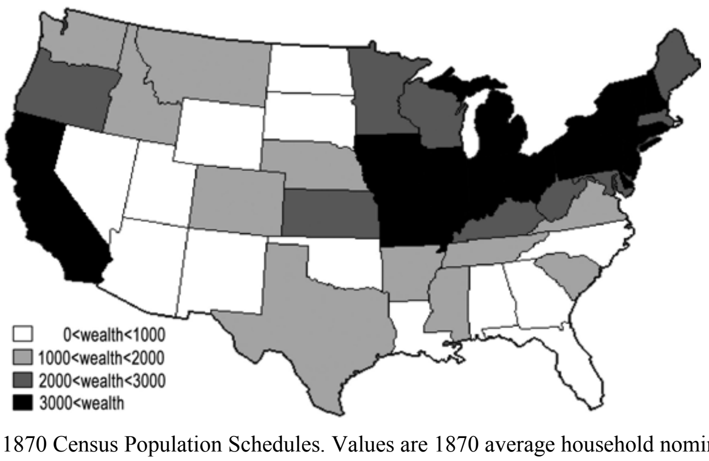
[16] No upper bound is placed on ages and all US geographic regions are considered. The interpretation of total wealth is complicated because household wealth was self-reported in the 1860 and 1870 population censuses. According to the instruction for census enumerators, individual wealth less than $100 was recorded as zero in the 1860 and 1870; the distribution of 'zero' wealth was considerable. As much as one third of households reported holding zero total wealth, which undercounts household wealth because, at the limit, households at least some level of personal wealth. In the absence of a better estimate, it has been customary in census wealth studies to treat these households as holding zero wealth; consequently, households reporting zero total wealth are treated as holding zero wealth.

maintaining relatively high wealth equality. Nevertheless, it was the North's industrialization that may have threatened Northern biological conditions. In 1860, the South had the highest average wealth and had greater wealth inequality than the North; however, with the end of slavery, average Southern wealth declined considerably, while continuing to have high wealth inequality (Saltow, 1975; Easterlin, 1971). Of course, the difference was Southern chattel slavery, and once slaves were freed, southern personal wealth declined.



Notes: 1860 Census Population Schedules. Values are 1860 average household nominal total wealth dollars as reported in the 1860 Census.

Figure 1. 1860 US Average State Wealth



Notes: 1860 and 1870 Census Population Schedules. Values are 1870 average household nominal total wealth dollars as reported in the 1870 Census.

Figure 2. 1870 US Average State Wealth

Finally, because race was not recorded in the census mortality schedules the last piece of the tuberculosis-insolation hypothesis is not possible to isolate with the 1860 and 1870 census mortality schedules. However, archival evidence indicates that African-Americans were consistently more likely than whites to die from tuberculosis (Kiple and King, 1981, pp. 139-140; Bates, 1992, p. 293; Kappelman *et al*., 2008, p. 114). Higher levels of African-American tuberculosis mortality also adds to the insolation hypothesis. Lower average wealth, greater melanin in the stratum corneum interfered with vitamin D production and vitamin D production provided an auto-immune response against tuberculosis.

4. THE COMPARATIVE EFFECTS OF DEMOGRAPHICS, SOCIOECONOMIC CHARACTERISTICS, AND INSOLATION ON 19TH CENTURY TUBERCULOSIS

We now test how the material and physical environments were related with 19th century US tuberculosis mortality. To start, tuberculosis is assumed to be associated with age, gender, occupations, time of year, insolation, state average wealth, and agricultural productivity.

$$\begin{aligned} Tuber\,Mort_{i,t} &= \alpha + \beta_1 Age_{i,t} + \beta_2 Age_{i,t}^2 + \beta_3 Male_i + \sum_{l=4}^{7} \beta_l Occupation_{l,t} \\ &+ \sum_{m=8}^{17} \beta_m Death\,Month_m + \beta_{18} Census_t + \beta_{19} Insolation_j + \beta_{20} Wealth_{j,t} \\ &+ \beta_{21} Cheese\ per\ Capita + \beta_{22} Cows\ and\ Swine\ per\ Capita \\ &+ \beta_{23} PopulationDensity_i + \varepsilon_i . \end{aligned}$$

The age variable is age at death as recorded in the 1860 and 1870 census mortality schedules. Occupation dummy variables are included for white-collar, skilled, farming, and unskilled occupations. Death months and census decade are those recorded in the census mortality schedules. A continuous insolation term is added to account for the relationship between tuberculosis and insolation (Carson, 2009, p. 155). A continuous wealth variable is included to accountant for relationships between material wealth and tuberculosis mortality. Population density is included to account for the relationship between population density and tuberculosis mortality. State-level cheese per capita is included to account for the relationship between tuberculosis mortality and dairy production. The state-level number of cows and swine per capita are included to account for the relationship between tuberculosis mortality and animal proteins.

Table 3. 1860 and 1870 Youth, Adult, and Combined US Tuberculosis Mortality

	Model 1. Coefficient	*Total* Standard Errors	*Model 2.* Coefficient	*Youth* Standard Errors	*Model 3.* Coefficient	*Adult* Standard Errors
Ages						
Age	1.6270***	0.0163	0.1126***	0.0290	0.0893***	0.0446
Age^2	-0.0318***	0.0005	0.0209***	0.0014	-0.0053***	0.0004
Age^3	0.0002***	0.0000				
Gender						
Male	-2.4001***	0.1268	-1.3105***	0.1020	-3.5725***	0.3223
Female	Reference		Reference		Reference	
Occupations						
White-Collar	3.6062***	0.3392	3.1458***	0.4928	3.8808***	0.6850
Skilled	3.8134***	0.2535	1.5813***	0.4125	5.3894***	0.5144
Farmers	0.9872***	0.2008	-0.4858*	0.2662	0.5668	0.4264
Unskilled	1.061***	0.1619	1.2228***	0.1830	-0.1070**	0.3426
No Occupations	Reference		Reference		Reference	
Death Month						
January	0.0436	0.2783	-0.0816	0.1542	0.3124	0.6412
February	0.0479	0.2765	-0.2673	0.2531	0.6895	0.6384
March	0.6775***	0.2643	0.1091	0.2417	1.7476***	0.6096
April	0.7143***	0.2679	0.0526	0.2457	1.9543***	0.6181
May	1.1793***	0.2656	0.6010***	0.2414	2.2565***	0.6128
June	1.0225***	0.2942	0.5686***	0.2613	1.8141***	0.6879
July	-0.0495	0.2886	-0.1926	0.2555	0.4574	0.6803
August	-0.7311***	0.2872	-0.6873***	0.2543	-0.6459	0.6785
September	-1.1725***	0.2945	-0.5353**	0.2613	-2.1701***	0.6880
October	-0.5768**	0.2941	-0.4148	0.2673	-0.8826	0.6789
November	-0.3702	0.3016	-0.3662	0.2814	-0.3810	0.6685
December	Reference		Reference		Reference	
Physical and Economic Environment						
Insolation	-7.4627***	0.1784	-3.9678***	0.1632	-13.9887***	0.4136
Total Wealth	-0.0001***	0.0000	-0.0001***	0.0000	-0.0002***	0.0001
Population Density	0.0029***	0.0002	0.0021***	0.0002	0.0039***	0.0006***
Nutrition						
Cheese per Capita	-0.3387***	0.0136	-0.1269***	0.0134	-0.7301***	0.0300
Cows & Swine per Capita	-0.8918***	0.0868	-0.3569***	0.0804	-2.1964***	0.2013
N	223,075		130,100		92,975	
R^2	0.1660		0.1705		0.0752	
χ^2	18,758.83		8,472.38		6,129.61	

Notes: For more meaningful coefficient interpretation, all observations are divided by 100 prior to estimation. Therefore, coefficient values are interpreted as percents. Youth age is 22 years old and younger. Adult age is 23 years and older. *** significant at 0.01; ** significant at 0.05; * significant at 0.10.

Table 3 presents probit model marginal probabilities associated with 19th century tuberculosis mortality, and tuberculosis was related with both the physical and material environments. Two general patterns emerge from the tuberculosis mortality models. First, tuberculosis mortality was inversely related with insolation. For each additional hour an individual was exposed to insolation, they were between 4 (youths) and 14 (adults) percent less likely to die from tuberculosis, indicating 19th century medical advice to seek more healthy environments had beneficial results. However, this tuberculosis-insolation relationship is counter-intuitive, because greater direct sunlight warms surface waters, and standing waters served as tuberculosis disease vectors. Nevertheless, tuberculosis is also related to vitamin D, and the Southern insolation and the vitamin D effect dominated any elevated tuberculosis mortality associated with water as a disease vector.

Time of year was also related to sunlight exposure and vitamin D production, and individuals were less likely to die from tuberculosis during summer and autumn months and more likely to die from tuberculosis during winter and spring months. In summer months, when individuals were more likely to be outdoors, tuberculosis was less virulent; however, summer and autumn months are also the months when insolation and vitamin D production are at their peak (Holick, 1995, p. 642). As autumn turns into winter, cloud cover increases, fewer hours are spent outdoors, and less vitamin D is produced. During winter and early spring months, fat cells release stored vitamin D, which augments lower circulatory vitamin D that results from lower sunlight exposure. More tuberculosis deaths may have occurred in the spring because individuals frequently did not have sufficient diets and nutrition to withstand bacterial assault when food supplies were nearly exhausted in the early spring, especially for children. This lagged effect with summer and autumn months is consistent with the insolation- tuberculosis hypothesis. Consequently, sunlight and vitamin D were inversely related with 19th century US tuberculosis mortality.

Second, tuberculosis mortality was inversely related with state wealth; however, the effect was small. A one thousand dollar difference in average state wealth only decreased the likelihood of tuberculosis mortality by one-tenth of one percent for youths and two-tenths of one percent for adults.[17]

Other patterns are consistent with expectations. The likelihood of age-related tuberculosis mortality was highest just before age 40, indicating that, like the Spanish Influenza of the early 20th century, 19th century tuberculosis had specific economic effects and killed victims during prime working ages. Gender also had a significant role in 19th century tuberculosis mortality, and males were two percent less likely to die from tuberculosis than females. Males, in general, were more likely to work outdoors exposed

[17] Inequality had other negative health outcomes. Individuals in states and countries with greater inequality have shorter statures and average statures represented net cumulative biological conditions (Carson, 2009b).

to insolation, produce more vitamin D, which reduced the likelihood of tuberculosis mortality. Males were also more likely to have accumulated wealth holdings, which also reduced the likelihood of tuberculosis mortality. Because close proximity with infected individuals facilitates tuberculosis transmission, greater population density was associated with a greater likelihood of tuberculosis mortality.

Occupations are related to both the material and physical environment, and occupations were related to tuberculosis mortality. Farmers and laborers-who are more likely than white-collar and skilled workers to work outdoors-were less likely to die from tuberculosis. Farmers were outdoors removed from close proximity with others, where tuberculosis is more easily propagated. Moreover, farmers were also closer to nutritious food supplies, which gave farmers the strength and stamina to withstand the deleterious effects of a tubercle bacilli infection. Farmers also had greater wealth and frequently lived in rural environments where wealth was distributed more equitably. State agricultural productivity in cheese, cows, and swine per capita were inversely related with tuberculosis mortality. However, the magnitude of state agricultural productivity in reducing tuberculosis was small relative to insolation, demonstrating insolation had a direct effect in reducing individual mortality. Therefore, 19th century tuberculosis was closely related with economic factors, wealth accumulation, occupations, and insolation, and individuals in developing economies with greater access to vitamin D supplementation may be less vulnerable to tuberculosis mortality.

5. AN INDEX FOR 19TH CENTURY REGIONAL TUBERCULOSIS MORTALITY

Having considered individual factors associated with 19th century US tuberculosis mortality, it is useful to weigh the relative regional effects associated with tuberculosis.[18] A tuberculosis index is constructed by first imputing individual-level characteristics from Table 3, Model 1. Imputed values are then sorted and averaged by state. These index values are a relative likelihood of tuberculosis mortality by geographic regions after controlling for individual differences.

Three geographic regions are considered: North, South, and West. The average value of Northern state tuberculosis index was .141 (Table 4); the average value for Southern states was 0.087; the average value of Western states was 0.116. Therefore, after considering, wealth, and agricultural productivity, tuberculosis in the South and West were lower than the East, and advice of 19th century health providers to go west and seek

[18] The issue of selection is relevant when considering geographic location. Individuals who had tuberculosis may have chosen unhealthy environments. However, physician's council to seek-out more healthy environments in the West makes less of a concern because the West had lower incidence of tuberculosis mortality.

healthier climates was well founded.

Table 4. 19th Century Regional Tuberculosis Index

Region	*Index*	*Region*	*Index*
North	0.141	South	0.087
Connecticut	0.156	Alabama	0.076
Delaware	0.126	Arkansas	0.094
Illinois	0.097	Florida	0.060
Indiana	0.242	Georgia	0.071
Kentucky	0.103	Louisiana	0.090
Pennsylvania	0.166	Missouri	0.153
South Dakota	0.130	Mississippi	0.076
Vermont	0.106	South Carolina	0.079
West Virginia	0.141	Tennessee	0.082
		Texas	0.058
West	0.116		
Colorado	0.085		
Idaho	0.184		
Kansas	0.085		
Montana	0.228		
Nebraska	0.095		
Nevada	0.081		
Oregon	0.101		
Utah	0.047		
Washington	0.178		
Wyoming	0.179		

Source: See Table 1.
Note: Index created with imputed values calculated in Table 3.

6. CONCLUSION

Our understanding of the number of diseases related to vitamin D has expanded considerably, and tuberculosis is one disease that may be related with access to vitamin D. This paper illustrates that 19th century US tuberculosis mortality was related to both the physical and material environments. Sunlight is a factor related to the physical environment and vitamin D production, and after controlling for insolation, incident solar radiation reduced the incidence of tuberculosis. The quantity of hours exposed to solar radiation was determined, in large part, by occupations and workers in outdoor occupations, such as farmers and laborers, produced more vitamin D and were less likely to die from tuberculosis. Tuberculosis mortality was also related to time of year and was greatest during that time of year when less insolation was received and temperatures lowest. Nineteenth century tuberculosis mortality was also related with the material environment and agricultural productivity. Average state wealth and nutrition were inversely related with lower tuberculosis mortality; however, the effects were smaller than insolation. Therefore, given the low cost of vitamin D supplementation relative to the potential reduction in tuberculosis and certain cancers, additional study of the role of vitamin D supplementation in developing economies is warranted.

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