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THE ENGINE AND THE REAPER: INDUSTRIALIZATION AND MORTALITY IN EARLY MODERN JAPAN

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THE ENGINE AND THE REAPER: INDUSTRIALIZATION AND MORTALITY IN EARLY MODERN JAPAN

By JOHN P. TANG*

Economic development leads to improved health over time due to increased access to medical treatment, sanitation, and income, but in the short run the relationship may be negative given disease exposure from market integration. Using a panel dataset of vital statistics for late nineteenth century Japan, I find mortality rates increased during the country's early industrialization period and that railroad access accounts for over five percent of average mortality. Estimates from a triple-differences framework indicate that communicable disease mortality accounts for 91 percent of the additional incidence, which suggests that improved transport may have operated as a vector for transmission.

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In the year 1886, a major wave of cholera swept through Japan and killed 108,405 people by the year's end.[1] This single disease accounted for more than 1 out of 9 deaths that year, compared to the previous year's toll of 9,310 deaths and the following year's total of 654. While most of the country experienced high rates of mortality, areas that had railroad access had a higher incidence, 336 deaths per 100,000 relative to the 245 in prefectures without rail access. Curiously, mortality rates for all areas were similar in the years immediately before and after the epidemic, around 1 death per 100,000. Another outbreak of cholera four years later claimed only one third the number of casualties, but again prefectures with rail access had higher mortality rates, 81 per 100,000 compared to 66 in areas without rail.

Whether these two seemingly unrelated phenomena, transport infrastructure and disease incidence, are connected is a simple question that may be illustrative of a more provocative issue: can industrialization be hazardous to a country's health? Conventional wisdom views economic growth as leading to better health outcomes, supported by extensive scholarship that finds improvement in longevity, child mortality, and adult height (McKeown 1976; Fogel 1986; Hatton 2014). These gains in turn can foster increases to productivity and promote continued development as part of a virtuous health-wealth cycle (Costa 2013). Health improvements arise from two forces: macroeconomic growth, which funds investments in sanitation, medical facilities, and other public health measures; and higher living standards, including greater access to and consumption of food as well as the acquisition of human capital. That said, the health benefits of industrialization may be overstated, unevenly distributed, or even absent in its initial stages and vary by cause of death. Some examples include unsafe work conditions killing laborers; unhealthy environments caused

[1] Mortality rates based on resident population figures; these statistics are from Japan Statistical Association (1967) and are further described in the section on data.

by urban crowding; exposure to foreign diseases; and industrial pollution poisoning communities (Johnston 1995; Walker 2009).

To estimate the short run impact on health from industrial development, this paper examines the introduction of the railroad in Japan at the end of the nineteenth century. Railways, powered by the steam engine, were one of the first modern technologies diffused around the world and credited with leading industrialization through domestic and international market integration, cheaper and faster shipping, and intersectoral linkages (Fogel 1964; Summerhill 2005; Donaldson, forthcoming). In Japan, their adoption and use led to increased firm activity and industrial agglomeration, and over the period between the 1870s, when railroads were introduced, to the eve of the First World War, the economy was transformed from an isolated, agrarian society to an emerging industrial power with higher income levels, burgeoning trade, and a nascent colonial empire (Tang 2014).[2] The country's rapid transformation, however, was remarkable as well for its persistently high mortality rates and differential trends between regions, with rural death rates steadily converging upward toward urban ones. Compared to the experiences of other countries during the 1800s, this rural mortality increase is striking given that these areas had outward migration, less industrial activity, and healthier environmental and nutritional conditions (Taeuber 1958; Johansson and Mosk 1987; Honda 1997).[3]

What can explain these unusual mortality patterns on the eve of Japanese industrialization at a time when mortality rates in western economies were declining? One hypothesis is that the railroad's role in integrating the domestic

[2] During the Meiji Period (1868-1912), Japan acquired the Ryukyu islands (1879, now known as Okinawa), Taiwan (1895) and Korea (1910).

[3] During Britain's industrialization (1776-1841), while urban mortality rates were consistently higher than rural ones, their ratio was relatively stable (Williamson 1990, p. 54). In contrast, Sweden's rapid industrialization was not associated with negative health outcomes (Sandberg and Steckel 1997). Szreter (2004, p. 81) suggests that industrialization "exerts intrinsically negative population health effects among those communities most directly involved in the transformations with it entails."

market allowed not only goods and labor mobility, but also the transmission of communicable diseases like tuberculosis and influenza. A net increase in overall mortality due to disease exposure is non-obvious, however, as improved transport can lower mortality from more stable food supplies.[4] Because the rail network expanded discretely over space and time, this hypothesis can be tested by comparing regions with similar initial levels of development but differing in rail access to see whether the latter acted as a channel through which mortality spread. Separating mortality by disease group further sharpens the transmission mechanism played by the railroad since increased exposure and mobility would likely have a stronger impact on food-related and communicable diseases and not on others.

Using a linear regression framework and disaggregated regional and disease mortality panel data, I find rail access accounts for over 5 percent of average mortality rates across the prefectures analyzed over the eight-year treatment period, between 1886 and 1893. In terms of the share of additional mortality compared to the pre-rail access years, this is an increase of over 72 percent, or 116 of the 161 deaths per year in each of the affected prefectures.[5] The regression estimates, which include measures for per capita income, urbanization, industrial activity, and medical treatment, are robust to different model specifications and the intensity of rail use. Estimates from a triple difference specification indicates that the bulk of these rail-associated deaths is due to communicable diseases, which is consistent with the hypothesis that improved transport facilitated the transmission of contagion, but had no net impact for non-

[4] While food production and access to foreign supplies may have mitigated mortality from nutrition and disease, improved transport also increased exposure to contagion (Taeuber 1958, p. 50).

[5] The difference in average annual mortality rates by prefecture before and after rail access period is 161 additional deaths per 100,000; of which 123 deaths are associated with rail;. The 116 deaths figure is based on the panel of 12 disease groups, each of which averaged an increase of 9.7 deaths per year; see Table 3 for results.

communicable illnesses.[6] Corroborating these results is the separate finding that higher population density is associated with lower mortality among regions with rail access, despite extensive historical scholarship that establishes a link between urbanization and poorer health outcomes.

These findings in turn may have implications for the economy at large, which is that a faster industrial transition comes at the expense of human health. Extrapolating from trends observed in the control group prefectures during the treatment period, while mortality rates would have fallen without railway expansion, so too would have capital investment. This may be due to increased development owing to railways and industrial agglomeration (Tang 2014). In the counterfactual scenario with no additional railways in the mid 1880s and early 1890s, Japan's population would have been similar but had 14.2 percent less capital investment. This is equivalent to a 13.4 percent per capita decrease in the years preceding the country's industrial takeoff in the late 1890s, and by which time manufacturing and exports had grown significantly in scale and economic importance (Perkins and Tang 2015). While the arrival of the steam engine may not have explicitly heralded the grim reaper in late nineteenth century Japan, the relationship between the two is suggestive that rapid Japanese industrialization had an unintended consequence in terms of human lives lost.

I. Background and literature review

Studies on the relationship between economic development and health outcomes have a long pedigree and generally find a positive relationship. This depends on a number of factors, including laborers earning higher wages and thus consuming more and better nutrition as well as governments providing public

[6] The three disease groups classified as communicable are digestive, infectious, and respiratory; see the appendix for a list of diseases within each category.

health services and clean water (Costa and Steckel 1997). The availability of medical treatment also delivered improved outcomes, with the development of vaccines, medications, and disease prevention techniques leading to substantial reductions in mortality across a range of diseases (Cutler et al 2006).[7]

Notwithstanding health gains in the long term, the effects from economic development may be unclear in the short run and differ between regions. For example, during Britain's high period of industrial activity in the mid-nineteenth century, the decrease in mortality rates may have owed more to improved nutrition than to public health measures or medical treatment, with similar mortality reductions in France (McKeown 1976; Cutler et al 2006; Fogel 1986).[8] For the United States in the mid 1800s, soldiers experienced declines in heights and life expectancy before recovering later in the century even as industrial activity and average incomes grew steadily over the period (Margo and Steckel 1983; Komlos 1998). Around the turn of the twentieth century, American mortality rates in rural areas declined despite a relative undersupply of water treatment and physicians (ibid; Higgs 1973).[9]

A typical feature of industrialization is increased urbanization, which historically has been associated with higher mortality rates (Cutler et al 2006; Atack et al 2010). Contributing factors include crowded living and unhealthy work environments, which aid the spread of communicable diseases, as well as limited access to fresh food, clean water, and clean air, although this may be outweighed by higher wages (Johnston 1995; Williamson 1982). Economic

[7] Smallpox vaccination reduced the severity of epidemics in Japan between 1886 and 1908, while cholera and bubonic plague saw substantial reductions in mortality by the early 1900s (Taeuber 1958, p. 51).

[8] McKeown (1976) differentiates between airborne versus water- or food-borne communicable diseases, with the former unaffected by sanitation measures. Improved food hygiene practices like pasteurization started in the late 1800s, while effective medical intervention, such as the development of penicillin (1928), streptomycin for tuberculosis (1946), and cardiovascular treatment were developed after the nineteenth century.

[9] Countering these studies is research that finds no causal link between income and life expectancy starting in the nineteenth century (Lindert 1983), and the interplay between nutritional intake and disease regardless of how they are carried (Preston and van de Walle 1978).

development may also have a more direct effect in the creation of industrial hazards like the transmission of respiratory diseases in confined spaces, toxic pollution and effluent, and longer work hours (Lewchuk 1991; Macintyre 1997; Ferrie 2003; Gagnon et al 2011; Tang 2015). In the United States during the 1800s, increased disease exposure had a major impact on life expectancy, with mortality rates corresponding to population and housing density (Meeker 1972; Preston and van de Walle 1978). Healthier disease environments via hygienic practices in Europe over the same period contributed more strongly to adult heights compared with increased income and education (Szreter and Mooney 1998; Millward and Baten 2010; Hatton 2014).

The difference in the timing of these factors gives rise to what can be considered a mortality Kuznets curve for industrialization, where the impacts of industrial activity worsen health outcomes initially but improve later as rising living standards, investments in public health measures, and medical treatment exert their influences (Johansson and Mosk 1987; Honda 1997; Szreter 2004).[10] While this relationship has been fairly well documented for heights, it is less clear for mortality and in countries industrializing over a shorter time period (Costa and Steckel 1997). One channel for the delay in health gains may be access to modern transportation, which speeds up the process of industrialization by increasing production efficiency, the movement of goods and people, and urbanization while generalized economic improvements lag behind (Haines et al 2003; Atack et al 2009). In the United States, for example, access to transport via rail or water was associated with an increase in mortality and a decrease in height during the mid

[10] Cutler et al (2006) credit improvements to public health measures after 1870, with the "acceptance of the germ theory of disease in the 1880s and 1890s, which led to a wave of new public health initiatives and the conveyance of safe health practices to individuals" (ibid, p. 102). They identify three stages in the historical change in mortality: the first phase, from the mid 1700s to the mid 1800s, due to increased nutrition and economic growth; the second phase up to the 1930s, where public health mattered most; and the third phase thereafter, with reductions due to medical treatment and advances (ibid, p. 106).

1800s, although the effect obtains alongside changes in wealth and urbanization that are less obvious in the case of Japan (Haines et al 2003).

The Japanese experience is illustrative given its historically rapid transition from a traditional economy to an industrialized one at the end of the nineteenth century. Reasons for its remarkable performance include its adoption of foreign technologies and institutions, the activities of its entrepreneurs, and the favorable conditions in which it integrated with the world economy (Sussman and Yafeh 2000; Mitchener et al 2010; Tang 2011, 2013). Based on industrial growth rates and the share of manufacturing value to total output, Japan's arrival as an industrialized economy can be dated as early as the mid 1890s (Benetrix et al 2012; Perkins and Tang 2015). A major innovation, the railway, was introduced in 1872 and in the following three decades reached most regions throughout the country. In practical terms, rail transport allowed a day's journey to be shortened to an hour, bringing mineral ores and perishable silk in neighboring prefectures within easy reach of major cities and the international markets.[11] Recent work shows that railroad expansion led to increased firm activity and investment in areas that received the transportation infrastructure earlier (Tang 2014).

At the same time, better transportation links, coupled with unfettered migration, urbanization, and population growth, may have been an unintended means to transmit communicable diseases like tuberculosis and cholera, and mortality rates rose significantly in the same period (Johnston 1995).[12] Increased commercialization and exports of agricultural output, particularly textiles like silk in the late 1800s, may have had an ambiguous effect on local food production, but in terms of average national consumption, food spending increased by about two

[11] Tokyo was connected to Yokohama, in neighboring Kanagawa prefecture, in 1872 and brought deep-sea access to the capital.

[12] The six largest cities grew from 2.4 million inhabitants in 1888 to 6.1 million in 1918, or 11 percent of the total population, while urban areas exceeding 50,000 inhabitants increased their population share from 7 to 17 percent over the same period (Johnston 1995, p. 64). Mortality from respiratory illnesses, which included tuberculosis, bronchitis, and pneumonia, rose from 17.8 percent of total mortality in 1888 to 29.2 percent in 1898 (ibid, p. 60).

percent each year in real terms between 1885 and 1900 while exports increased by nearly nine percent per annum (Japan Statistical Association 1962; Yamazawa and Yamamoto 1979, table 3; Hayami and Ruttan 1985).[13] Surprisingly, mortality rates also increased during the 1880s, stayed relatively constant at 21 deaths per thousand in the next decade, and did not decline until the turn of the century, with industrialized prefectures experiencing higher rates throughout this period (Honda 1997, pp. 276-77). This general pattern also masks significant variation between disease types, as shown in Table I.

[Table I]

Starting in the early 1870s, government concern about the social impact of communicable diseases led to policies targeting cholera, dysentery, typhoid fever, smallpox, diphtheria, and typhus, which were legally designated as infectious diseases.[14] Despite regulations to control their spread (including revocation of medical licenses for physicians caught concealing diagnosed cases), epidemics of cholera continued over the next few decades, albeit with decreased mortality over time (Johnston 1995, p. 62). In contrast, cases of tuberculosis, a chronic respiratory disease, increased dramatically in the late 1800s through the early twentieth century, reaching an all time high in 1918 (ibid, p. 87). Although mortality rates during this period were similar to those in western Europe, Japan had much lower average income levels and public health spending, and the incidence of tuberculosis remained high well into the 1900s even as it fell in other industrial economies (Honda 1997, p. 265).

Apart from these regulations, central government spending on sanitation services was initially rather low, averaging 10,000 yen in real terms per year

[13] Between the years 1886 and 1899, silk reeling factories increased from 411 to 2,217 and those for cotton spinning and weaving increased from 89 to 1,370 (Johnston 1995, pp. 75-77). Silk textiles used domestically sourced cocoons, which competed with land used for rice cultivation; cotton textiles relied primarily on imported raw cotton.

[14] Most contagious diseases were already present in Japan prior to industrialization, with the exception of plague and typhus (ibid, p. 257).

between 1885 and 1894 before increasing significantly in the next decade to reach 220,000 yen in 1904, with a similar pattern for water treatment and provision (Emi and Shionoya 1966, table 13).[15] Only at the turn of the century did population mortality rates begin to fall from an average of 21 to 19 deaths per thousand by the late 1930s, with a more marked decrease among industrialized prefectures (Honda 1997, p. 276).[16] It is during the late nineteenth century, however, with the large mortality differential between industrial and agricultural regions as well as the relative neglect in public health spending and increasing industrial activity, that one can assess more clearly the relative contributions of transport access on disease mortality.[17]

II. Research design

This paper tests the hypothesis that improved transport access corresponds with higher mortality rates in early stages of industrialization, ceteris paribus. This may be surprising since railroad construction itself is usually part of the late development process: on the one hand, industrialization leads to higher average incomes, allowing for better public health, medical treatment, and nutrition; on the other, urbanization and workplace hazards may have deleterious impacts, especially for certain disease types. However, these factors neglect the role of transport in raising the frequency of disease exposure and transmission to areas that may have been naturally protected due to isolation (Johansson and Mosk 1987).

[15] Government spending on public health was mostly limited to smallpox vaccination and sanitary education, with considerably more money devoted to military and industrial activities (Honda, 1997, p. 267).

[16] The probability of death for males improved markedly in the 1890s, especially for those under 15 years and between 25 and 49 (Taeuber 1958, p. 51).

[17] Honda (1997) finds higher mortality rates in industrialized prefecture compared to agricultural ones before 1900, but does not differentiate between those with and without rail access. Modern medical treatment such as vaccines and antibiotics were not developed until the first half of the twentieth century, postdating the period of analysis.

As many of these economic and social changes occurred simultaneously during Japan's industrialization, showing causality is problematic. Rail access, however, was a discrete change that occurred over time and across regions, so one can isolate its effect as the network expanded.[18] In other words, one can estimate the impact of railways on mortality rates by trends in regions before and after their received rail access (first difference) and compare them to regions that did not over the same period (second difference), all while accounting for changes in other observable activities taking place across all prefectures. This change in rail access provides the heterogeneity for a treatment-control research design, where prefectures integrated into the national rail system can be considered a treatment group while those without access during the same period comprise a control group in a quasi-experimental setting. To further improve identification of transport access as the mechanism for transmitting contagion, the disease groups are separated into those that are likely to spread compared to those that are not (third difference). This highlights the role of exposure facilitated by labor mobility and increased urbanization; deaths due to communicable diseases or food supplies should be affected, but other disease types should not.

A. Data sources

The newly assembled data used in the analysis come from multiple sources, and are novel for both their level of disaggregation by disease and region and in the matching of regional mortality rates with economic and industrial indicators at the same geographic level. Moreover, these data are comprehensive and cover the entire population and economy, providing an unbiased, but detailed view of changes occurring within the country. For vital statistics, the

[18] Railway construction began in the 1870s, but it was not until the early 1880s that significant lengths of track were laid across the country, coinciding with the collection of vital statistics across regions.

government's Cabinet Bureau of Statistics compiled annual prefecture-level mortality data on twelve different disease categories starting in 1883 (Japan Statistical Association 1962).[19] These include: blood, bone and joint, developmental and nutritional, digestive, external injury, infectious, nervous, poisoning, respiratory, skin and muscle, urogenital, and unclear groups. The statistics, which apply to the resident population in a prefecture, were recorded under the central government's classification system by local administrative offices (Johnston 1995, pp. 57-58).[20] In 1901, the government revised this system with different, more clinically precise categories, but there is no direct mapping between the two classifications. Besides mortality data, the government also collected data on the number of public and private hospitals in operation, pharmacies, and health professionals for each prefecture annually.[21]

For industrial and demographic data, the Cabinet Bureau yearbooks also provide prefectural figures of firms, capital investment across industry types, population, and different measures of land area and value. The first two economic series can be used both as a measure of industrialization in each region, while per capita income can be proxied by privately owned land value divided by the resident population as well as invested capital per capita. Urbanization, which was inconsistently documented before the 1920 population census, can be approximated with population density based on habitable land area. This is preferable to the total land area since only 16 percent of total Japanese land is arable and most of the population resided in these low-lying coastal areas and

[19] Aside from the poisoning and unclear groups, each disease category comprises multiple diseases ranging from 8 (skin and muscular) to 29 (digestive); see appendix for details.

[20] These categories are not precise in that digestive illnesses may have included gastrointestinal illnesses due to unclean water as well as stomach cancer while nervous conditions may include both cerebral hemorrhages and tertiary syphilis. Developmental and nutritional diseases included different forms of cancer, senility, and old age (Johnston 1995, p. 323). Local physicians made the diagnoses, which may also be imprecise given that the majority was not trained at medical schools and used traditional homeopathic techniques (ibid, p. 58). Deaths for the registered population (*honseki*) are separately recorded after adjustment for the migrant population, but do not have disease disaggregation.

[21] There are also data on disease mortality by age group, although these are not disaggregated by prefecture and are considered unreliable for younger age groups (Taeuber 1958, pp. 42-43).

alluvial plains (Trewartha 1945; Taeuber 1958). In particular, land area is subdivided into by gradient level as well as into fields, forests, and mountainous areas; both systems are used in the analysis. To measure railroad network expansion, I use the *Rail Stations of Japan* handbook, which includes all rail stations built in the country by date and location starting in 1872 (Chuo Shoin 1995; Tang 2014). Together, these data are used to construct a balanced panel dataset of mortality rates by disease group, prefecture, and year, and includes controls for economic activity and other determinants of health.

B. Empirical framework

The empirical analysis uses a difference-in-differences model that compares mortality rates for each disease group before and after a prefecture receives rail access (i.e., treatment) against regions that do not receive access over the same period. The period of analysis covers the years 1883 to 1893, which covers the first major expansion of railroad construction across regions in Japan as well as the economy's industrial takeoff as measured by the share of industrial output to national production.[22] Over this period, main trunk lines increased from 202 to 897 kilometers, while local railways grew from 101 to 2,223 kilometers (Japan Statistical Association 2007, table 12-7).[23] Annual passengers carried increased six-fold, from 5.2 million in 1883 to 32 million in 1893 (ibid, table 12-8a). The starting year was chosen since consistent vital statistics on disease groups do not begin until 1883. For the end year, 1893 precedes the First Sino-Japanese War (1894-95), which corresponded with increased use of railways to transport wounded soldiers and thus may potentially confound the results for disease transmission. Government spending on public health measures also

[22] Tang (2014) uses the same treatment period to analyze regional firm activity patterns, while Perkins and Tang (2015) estimate Japan's entry to industrialized status as occurring between 1897 and 1907, based on five-year moving averages.

[23] The number of public and private rail stations grew from 53 to 394 between 1883 and 1893.

quadrupled in 1895, from 76 thousand yen the previous year to 307 (Emi and Shionoya 1966, table 13). Thus, the effect of missing data for prefecture level government spending would be magnified starting in the mid 1890s, potentially biasing the results.

To estimate a clean treatment effect, all prefectures that gained rail access prior to 1883 are excluded; these include the major urban areas of Tokyo and Osaka. Furthermore, since there were a number of major prefectural border changes until 1886 or had missing data before 1886 (e.g., Okinawa), those areas are also excluded, bringing the number of prefectures to 29 out of 47 in the disease mortality panel. Figure I shows the treatment and control group prefectures on a map of Japan both prior to and at the end of the treatment period. The treatment group comprises 13 prefectures that gained rail access between 1886 and 1893: Aichi (1886), Aomori (1891), Fukuoka (1889), Fukushima (1887), Hiroshima (1891), Kumamoto (1891), Mie (1890), Miyagi (1887), Nagano (1888), Niigata (1886), Okayama (1890), Saga (1889), and Shizuoka (1888). The control group includes 16 prefectures that did not receive railways until after 1893: Akita (1899), Chiba (1894), Ehime (1914), Ishikawa (1897), Kochi (1924), Miyazaki (1911), Nagasaki (1897), Oita (1897), Shimane (1908), Tokushima (1899), Tottori (1902), Toyama (1897), Wakayama (1898), Yamagata (1899), Yamaguchi (1897), and Yamanashi (1901).[24] No treatment occurs in the three years between 1883 and 1885, which are used to test for pre-treatment differences between the two groups.

[Figure I]

The basic reduced form linear regression model is:

(1) $y_{ijt} = \beta_0 + \beta_1 \cdot x_{1jt} + \beta_2 \cdot x_{2jt} + \beta_3 \cdot x_{3jt} + \beta_4 \cdot x_{4i} + \beta_5 \cdot x_{5j} + \beta_6 \cdot x_{6t} + \varepsilon_{ijt}$, where

[24] Okinawa, which gained rail access in 2003, is omitted from the control group given that it is composed of multiple small islands separated far from the four main islands of Japan and thus had no interregional rail connection. Hokkaido is similar in lacking rail connections with other prefectures until 1988, but is omitted from the analysis since it gained railways in 1880, before standardized vital statistics were collected.

y_{it} = mortality rate for disease group *i* by prefecture *j* in year *t*

x_{1jt} = rail access variable for prefecture *j* in year *t*

x_{2jt} = control variables for per capita income, urbanization, industrial activity, and medical services for prefecture *j* in year *t*

x_{3jt} = interaction of rail access and control variables for prefecture *j* in year *t*

x_{4i} = disease fixed effect

x_{5j} = prefecture fixed effect

x_{6t} = year fixed effect

ε_{ijt} = error term

The dependent variable y_{ijt} is measured in the annual number of deaths per 100,000 inhabitants for each disease group in a prefecture. The main explanatory variable for rail access x_{jt} is a dummy variable of zero for no rail access or one for access beginning in the year when the prefecture first has a rail station built. This variable can also be continuous, measuring the number of rail stations per 100,000 inhabitants in the prefecture to approximate the density of transportation access and intensity of use. Direct measures of prefecture level freight and passengers are unavailable. The other explanatory variables are: the value of privately owned land divided by the population as a proxy for economic growth since prefectural output statistics are unavailable; the population density of each prefecture using low gradient land (i.e., less than 3 degrees in gradient) as a proxy for urbanization; the number of industrial firms per 100,000 inhabitants in each prefecture as a measure of industrial activity; and the number of public and private hospitals per 100,000 inhabitants in each prefecture as a proxy for medical service provision. Note that the population figures, like those for the mortality statistics, are based on the resident population, not only those officially registered, and thus accounts for inter-prefectural migration flows.

To improve identification of rail access as a vector of disease transmission, I also include an indicator variable for communicable disease, which applies to the three categories of digestive (e.g., hepatitis, food-borne illnesses), infectious, and respiratory (e.g., pneumonia, tuberculosis) ailments. This variable is interacted with rail access and reported as an additional specification and serves as the third difference compared to the above difference-in-differences model. In all specifications, I include fixed effects for disease group, prefecture, and year.

As with substituting rail station density for rail access, I also use alternative measures for the control variables: total capital investment across industries divided by the resident population as an income proxy; population density based on arable land (i.e., rice paddies, fields, and residential land); the share of capital invested in industrial firms (excluding transport) to total capital; and the number of doctors per 100,000 inhabitants, respectively. For robustness, rail access is also interacted with these four control variables since railways have been shown to facilitate economic activity as well as urbanization and land value (Atack et al 2010; Tang 2014; Donaldson and Hornbeck, forthcoming). These in turn provided government and private resources for public health services (Allen 1946; Onji and Tang 2015).[25]

To have a meaningful interpretation of the estimates from a difference-in-differences framework, a number of issues need to be addressed. The first is in the selection of treatment and control groups, which should not differ in observables prior to the onset of the treatment. To test for pre-treatment comparability, I run the full specification of the reduced form model on the panel of diseases by prefecture for the years 1883 to 1885. Instead of the rail access indicator variable, I substitute an indicator for future rail access to the applicable prefectures; when

[25] The Japanese government relied on the 1875 land tax for the bulk of its revenues in the early Meiji Period prior to the implementation of personal and corporate income taxes later in the century.

interacted with the control variables, this identifies whether the two groups differ in observables prior to actual rail access. None of the results, given in the tables, has statistically significant results for rail access, the other control variables, and their interactions prior to treatment. This is also suggested in Table II, which compares outcomes by treatment and control group prefectures before and at the end of the treatment period.

[Table II]

The second consideration is whether the dependent variable, mortality, had an influence on the treatment, i.e., access to railways. Based on historical documents describing the construction of the railways, health outcomes were not a consideration prior to the Sino-Japanese War, which postdates the treatment period (Tang 2014). Rather, the motivation to build the rail system was primarily for political centralization, market integration, and national defense, with construction of railways from the main cities of Tokyo and Osaka to other major urban areas in all prefectures (Free 2008). The timing of construction and routes was also subject to geographical conditions and thus do not strictly adhere to shortest distances or the government's anticipated time frame (Japan Railway Bureau 1887).

III. Results

A. Graphical analysis

Before considering the regression results, can we observe differences in crude mortality rate trends between the treatment and control groups in the raw data? Figure II shows three graphs of mortality rates for the across all disease groups and separated by communicability. Since treatment group prefectures received rail access in different years starting in 1886, the data are presented as pre- and post-access averages, beginning with 3 years before access and up to 3 years after. The six-year window allows for all treatment prefectures to be included since the last set of prefectures gained rail access in 1891. Control group values are first taken for the given year depending on the treatment group cohort year, and then averaged together to generate pre- and post-access comparison values in each of the six years.

[Figure II]

In all three graphs, the pre-rail access years show similar mortality trends for both the treatment and control group prefectures. Starting in the first year of access (year 1), the values for treatment group prefectures diverges and remains higher than those for control group prefectures, especially in the total and communicable disease mortality figures. These graphs are striking in that they do not account for other observables influencing mortality such as income levels and medical access, which can be tested for in the regression model.

B. Difference-in-differences results

In the regression results, Table III shows the estimates for both aggregate mortality rates and the panel of disease groups. In the simplest bivariate analysis of the aggregate mortality rates between 1883 and 1893 (column A), the coefficient on rail access is positive but insignificant. This changes once additional control variables are included, with rail access associated with a statistically significant increase in mortality of 123 deaths per annum for treatment prefectures.[26] The third column uses the disaggregated disease group panel and has similar estimates for the impact of rail access, calculated at 116 deaths for the twelve disease groups as a whole.[27]

[26] When log values of mortality are regressed on the same set of control variables, this is approximately a 6.2 percentage increase in total mortality for the average prefecture at less than ten percent statistical significance.

[27] The coefficient on rail access in column C is 9.718 per disease group, which multiplied by 12 equals 116 deaths across all disease groups.

The fourth specification includes the interaction of prefectural rail access and the communicable disease indicator, whose coefficient of 34.624 is positive and significant at less than one percent. This coefficient can be interpreted as nearly 35 deaths per 100,000 population from communicable diseases are associated with rail access per year following railway introduction in a prefecture. In contrast, all the other control variables are statistically insignificant, which indicates that the main effect from railways is observed in mortality rates for communicable diseases. This is corroborated by the calculated average treatment effect of railways, which evaluates the combined effect of rail access and its interaction with communicable diseases (i.e., net rail access effect).[28] Of the estimated 35.375 annual deaths following rail access, the bulk is from the three disease groups classified as communicable.

Given an average annual mortality rate of 2,078 deaths per 100,000 residents between 1886 and 1893 in prefectures with rail access, these estimates represent between 5.1 (panel) and 5.6 (aggregate) percent of this figure, and a 72 to 77 percent of the increase in mortality rates compared to pre-rail access years. Pre-treatment comparison estimates (column E) show that there is no statistically significant difference between the treatment and control groups in rail access nor in its interaction with the other control variables, which would also account for any level differences between the two groups prior to rail access.

[Table III]

To check whether usage intensity as opposed to general access can provide more precise estimates, I substitute prefecture rail station density (i.e., stations per 100,000 resident population) for the rail access dummy variable; results are shown in Table IV. For all specifications, magnitudes are lower than in

[28] The average treatment effect is calculated using a Wald test on the linear combination of rail access, other control variables (e.g., communicable disease dummy), and their interactions evaluated at the treatment group means if applicable during the treatment period.

for the rail access indicator estimates as prefectures varied in the number of rail stations built during the period of analysis. Thus, the average treatment effect of rail access for the aggregate mortality series (column B) is approximately 72 deaths per rail station for 100,000 inhabitants instead of 124 deaths in the previous table. In the panel specifications, only the one with the communicable disease dummy (column D) has a statistically significant rail effect, with the coefficient on its interaction with rail stations is 26.368. The average treatment effect is also significant, with 24.354 communicable disease deaths attributable to each rail station per 100,000 inhabitants. As with the previous table, this suggests the impact of railways on mortality is largely felt through communicable illnesses and not on other causes of deaths. Pre-treatment comparison estimates from the previous table apply to the station density specifications as future rail station construction is conditional on rail access itself.

[Table IV]

To see whether rail access had differential effects on the other control variables associated with mortality, specifications interacting access with each of these variables are shown in Table V. Of these, only those where population density is interacted with rail access have a statistically significant coefficient (columns B and E). Surprisingly, the coefficient on these interactions is negative, indicating that prefectures with lower population densities had disproportionately higher mortality rates. Although the variable for population density is not an exact measure for urbanization, these results suggest that railways created an integrated market for disease transmission, with contagious diseases moving from urban to rural areas and raising mortality rates in the latter toward the higher levels observed in the former. This is corroborated by the pre-treatment estimates for these specifications, which are all statistically insignificant for future rail access and its interactions, similar to those without the additional interaction terms.

[Table V]

One interpretation of these results is that less densely populated areas experienced higher death rates from these diseases following the introduction of railways due to increased exposure to urban-oriented contagions in outlying areas before the implementation of quarantines and investment in sanitation measures like water treatment. In rural areas without rail access, relative isolation provided a naturally protective environment against these ailments (Johansson and Mosk 1987, p. 213). The negative relationship between mortality and the interaction of rail access and population density in the short run, while unusual compared with the experiences of other countries like the United Kingdom, has some support in the early development of the Japanese industrial economy. Since the analysis excludes the largest cities of Tokyo and Osaka, the areas that remain in the sample are mostly mid-sized municipalities and prefectural capitals, which may have experienced disproportionately higher mortality rates given inflows of migration and a lack of other forms of infrastructure able to cope with the growth facilitated by railways (Cain and Hong 2009).

There is also anecdotal evidence of Japanese textile laborers who "faced crowded and unsanitary living and working conditions," ate "poor-quality rice supplemented with little vegetable and almost no animal protein," and were "ready hosts" for tuberculosis, influenza, peritonitis, pleurisy, and other respiratory illnesses (Johnston 1995, pp. 75-76).[29] Many of these workers were working class, from rural areas, and recruited on short-term contracts who then returned home to convalesce or die, acting as vectors of disease in their communities. This transmission mechanism may also be at work with the digestive and infectious disease categories, which cover food-borne illnesses and diseases like cholera, hepatitis, typhoid, and typhus. Gastrointestinal diseases

[29] Unlike cotton textile factories, which were largely based in urban areas, silk filatures were found in rural locations close to silkworm producers. Factory workers in general "were subject to high rates of morbidity from tuberculosis" and that this disease "presented the largest single threat to the health of the women who worked in the textile industry" (Johnston 1995, pp. 81, 84).

were one of the leading killers across the country during the prewar period, along with respiratory diseases like tuberculosis and pneumonia (Honda 1997, p. 265). Wages of agricultural workers, who still comprised the vast majority of the population, were virtually unchanged over this period, averaging 0.15 yen per day for men and 0.09 for women between 1885 and 1892 (Japanese Statistical Association 2007, Table 16-01, first edition). This meant that the beneficial effects from income would be absent or subdued for these types of diseases compared to similar periods of development in other countries like the United States (Eli 2015).

C. Robustness checks

To check the robustness of the different control variables associated with mortality, I substitute alternative measures for each of the four non-rail variables used in the previous tables. In Table VI, the four proxy variables for per capita income, urbanization, industrialization, and medical services are substituted with per capita capital investment; population density in low-lying areas; the share of capital invested in industrial sectors to total capital; and the number of doctors per 100,000 inhabitants, respectively. The last column uses all four alternative measures together. For all five specifications, the coefficient on the interaction of rail access and communicable disease is highly significant and positive, consistent with estimates from the previous tables. Moreover, this is also observed in the average treatment effects, which have nearly identical magnitudes to each other and earlier estimates at 35 deaths per 100,000. Qualitatively similar estimates (not shown) obtain with rail station density as the main independent variable.

[Table VI]

To verify whether the results may be driven by serial correlation in time trends, which may bias the standard errors in the estimates, I collapse the panel data of twelve diseases into two period observations, pre- and post-treatment (Bertrand et al 2004). For the control group, the pre-treatment comparison period is for the years before 1888 and the post-treatment comparison the years after 1888. For the treatment group, all years before and after the year of rail access are collapsed into two periods, respectively. These results are shown in Table VII, which has rail access measured both as an indicator and in station density, with a separate specification for pre-treatment period comparison. In both sets of estimates, the coefficient on the interaction of railways and communicable diseases is positive and statistically significant and similar in magnitude to the panel with individual years. Furthermore, the average treatment effects are also positive and significant of comparable size to earlier estimates.

[Table VII]

Taken together, the findings indicate that the introduction of railways is strongly associated with increased disease mortality in the short run, particularly those that are communicable in nature. Moreover, this is robust to specifications either aggregating by disease group or in a panel of the twelve, which mitigates concern about misclassified diseases, improved diagnosis, or multiple causes of deaths. What may be somewhat surprising is that the other control variables have a modest or no relationship with mortality rates. A possible explanation for this is in the short period of analysis, with the effects of generalized growth not felt as quickly as the discrete change in transport access. Specifically, both proxies for per capita income are imprecise as the distribution of land and capital ownership was highly unequal during the Meiji Period, and thus the income effect would be minimal especially in areas outside the major cities of Tokyo and Osaka (Moriguchi and Saez 2008). Urbanization is also imperfectly captured by the modified population density measures, and this is compounded by the exclusion of prefectures with the highest urbanization since the latter has access to railways before the period of analysis. Their exclusion also affects the measures of industrial activity, since much of the investment in firms and capital was located in the two metropolitan areas and surrounding prefectures. Regarding medical services, government investment in public welfare and sanitation was minimal before the 1890s and both the measures of doctors and hospitals overstate their efficacy in treatment (Eli 2015).

Notwithstanding the negative short-term impact on health, the broader economic impact from railway expansion can also be inferred from the regression estimates. While extrapolating demographic and economic changes observed in control group prefectures to the country as a whole is tenuous given unobserved externalities from railways on other sectors, one can consider how the national economy would have behaved without rail network expansion in the treatment prefectures given the observed changes among regions without railways. Capital investment nationwide would have been lower by approximately 14.2 percent, with similar decreases in per capita investment, by the end of the treatment period in 1893. Since the period of analysis immediately preceded Japan's industrial takeoff in the late 1890s and saw rapid growth in large-scale manufacturing and resource extraction, railway expansion is likely to have provided the margin needed for the economy to industrialize.

IV. Conclusions

Increased industrial activity and market integration via the expansion of the rail network suggest that differential health impacts may be observed over time and space, and the results from this paper's analysis support this hypothesis. Railroad access, whether as a categorical or continuous variable, accounts for at least 5 percent of observed mortality rates in rail-accessible prefectures over an eight-year period, and is equivalent to nearly three-quarter of the increase in mortality compared to pre-rail access years. The higher incidence is due in large part to communicable diseases that could take advantage of increased labor mobility, urbanization, and market integration. While these mechanisms are suggestive and data limitations currently prevent more detailed exploration of specific diseases, municipalities, and the direction of transmission, the findings are consistent with earlier research and case studies on why mortality rates increased during the early years of Japanese industrialization and why regions differed in outcomes.

In a more general context, the Japanese experience may appear unusual compared with earlier industrializing countries in Europe and North America, which had more gradual development periods, but it provides insight to economies that industrialized following Japan's lead (Williamson 1990, p. 52). Despite improvements in medical technology and public health measures, heterogeneity in their provision among developing countries is common. Moreover, transport infrastructure remains a primary target of public and private investment in these economies, even if the short-run implications remain unclear. This research indicates another channel through which railways have an aggregate and distributional impact on the economy, albeit in a negative manner. That said, higher mortality occurred in tandem with increased capital investment, both in the direct form of railway construction and indirectly through industrial agglomeration and restructuring. Lagging behind was public health spending, which the government subordinated to military spending (Honda 1997, p. 253). Whether on balance the long-term benefits of economic growth outweigh the health hazards occurred in the process is a tradeoff that policymakers need to anticipate as industrialization continues to advance at an ever rapid pace.

APPENDIX: DISEASE CATEGORIES

The following breakdown of included diseases for each disease group in the analysis comes from the Cabinet Bureau of Statistics, although the two disease categories of poisoning and unclear illness are not further disaggregated (Japan Statistical Association 1962, volume 9, table 243).

blood (9): heart inflammation, cardiac hypertrophy, intracardial meningitis, valvular disease, inner heart inflammation, heart attack, artherosclerosis, arterial disease, venous disease

bone and joint (9): bone and joint inflammation, bone inflammation, periostitis, osteomyelitis, bone ulcer, bone necrosis, joint abcess, bone injury, osteomalacia

developmental and nutritional (18): structural abnormality, hypoplasia and stunting, dental illness, adenopathy and swollen lymph nodes, rickets, gout, leprosy, edema, diabetes, gangrene, cancer and tumors, nutritional deficiency, *shikoujibaigutsu*, anemia, chlorosis, leukemia, senility, goiter

digestive (29): mouth and tongue disorder, parotid gland disorder, stomach disorder, peritonitis, abdominal abcess, intestinal parasite, ascites, hernia, intestinal blockage, abdominal catarrh, gastric ulcer, stomach stenosis, gastric distension, stomach pain, hematemesis, intestinal bleeding, diarrhea, intestinal catarrh, acute gastroenteritis, chronic gastroenteritis, appendicitis, intestinal disorder, mesentery disorder, spleen disorder, cholelithiasis and gallstones, jaundice, acute hepatitis, chronic hepatitis

external injury (14): burns, frostbite, electric shock, crushing, shooting, incision, stabbing, bites, bruising, suffocation, hanging, strangling, drowning, suicide infectious (27): typhoid, typhus, dysentery, Asia cholera, diphtheria, croup, smallpox, measles, scarlet fever, beriberi, undulant fever, Ross fever, sepsis, septicemia and blood poisoning, hospital gangrene, whooping cough, puerperal fever, contagious parotitis and mumps, malignant salivary gland inflammation, cerebrospinal meningitis, rheumatism, gonorrhea, syphilis, herpes, chancre, rabies, anthrax

nervous (21): meningitis, brain edema, encephalitis, stroke, cerebral embolism, cerebral palsy, cerebral anemia, cerebral hyperemia, insanity, spinal myelitis, spinal meningitis, spinal exhaustion, spinal paralysis, hypochondria, eclampsia, pediatric epilepsy, hysteria, epilepsy, chorea, tetanus, ear disease

poisoning (1)

respiratory (16): laryngitis, tracheal tuberculosis, bronchodialation, pneumonia, tuberculosis, hemoptysis and lung hemorrhage, emphysema, asthma, lung inflation failure, lung gangrene, lung paralysis, pulmonary edema, pleurisy, pleural effusion

skin and muscular (8): bleeding ulcers, subcutaneous ligament inflammation, carbuncle, mange, myositis and muscle inflammation, phlebitis and vein inflammation, umbilical disorder, muscular atrophy

urogenital (12): urinary cystitis, bladder stones, urethral stricture, uremic, orchitis, Bright's disease, vaginal catarrh, endometritis, uterine prolapse, uterine bleeding, uterine cramps, ovarian cyst

unclear (1)

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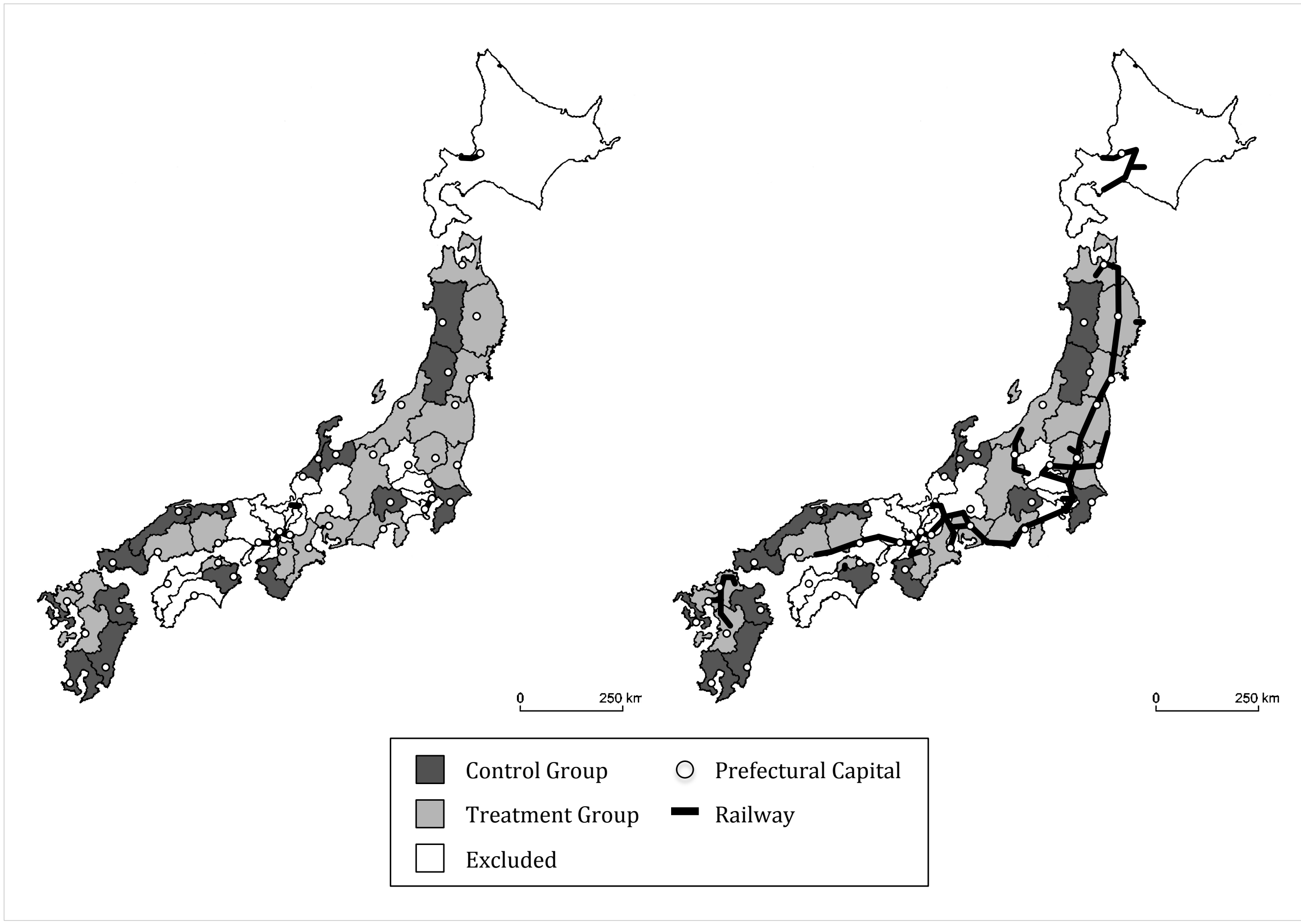

Figure I: Japanese Rail Network, 1883 and 1893

Source: see text.

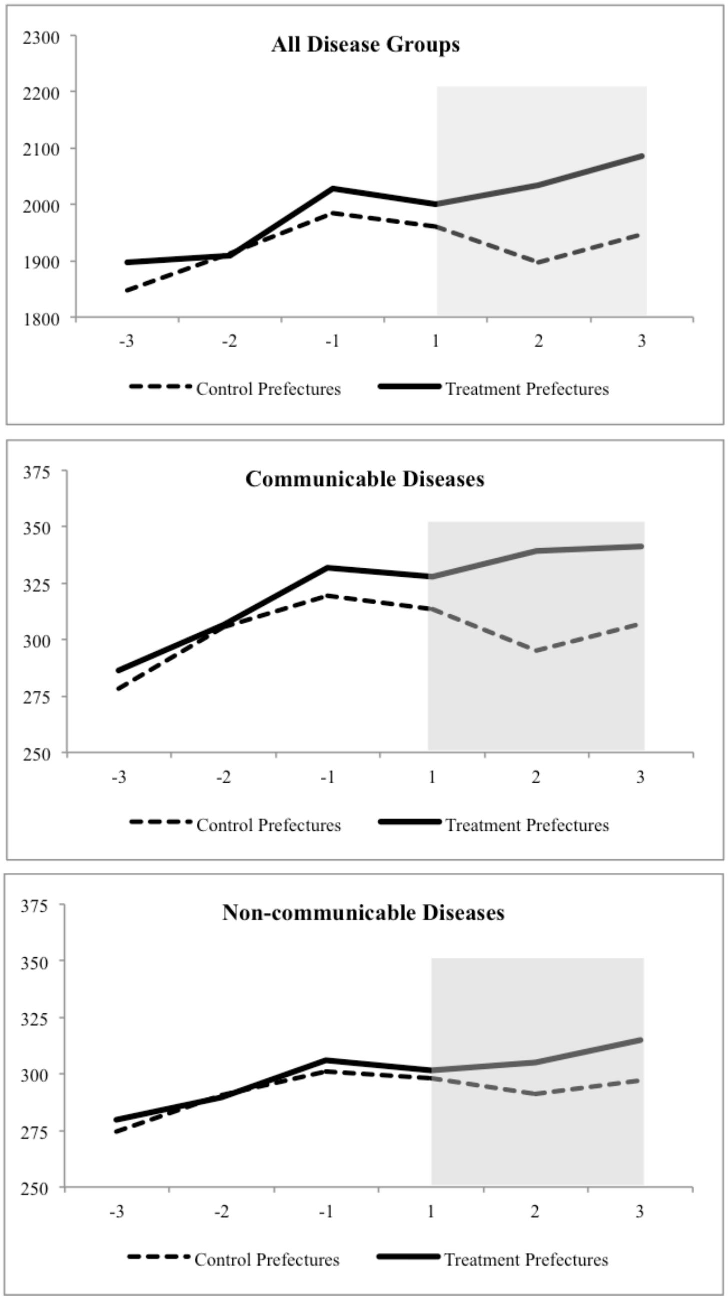

Figure II: Disease Mortality Trends, 1883 to 1893

Source: see text. *Notes*: mortality rates per 100,000 by prefecture and disease group.

Table I: Mortality Rates, Prefectural Averages

Year	1883	1887	1891	1895	1899
Population	881,364	862,965	871,677	902,787	966,022
Mortality per 100k	1,661	1,935	2,059	2,002	2,025
Annual percent change		1.4	0.7	-1.3	-0.7
Disease Groups					
Blood Related	21.3	62.9	76.7	86.6	107.6
Bone and Joint	5.0	16.1	19.8	20.2	23.9
Developmental	163.9	319.1	327.9	307.4	315.1
Digestive*	244.1	448.8	497.7	423.9	430.6
External Injury	20.9	42.4	61.4	46.4	50.3
Infectious*	61.8	149.8	143.0	206.5	149.8
Nervous	200.8	418.7	419.1	408.6	417.3
Poisoning	0.9	1.0	1.4	1.5	2.6
Respiratory*	124.2	321.7	371.6	355.8	398.2
Skin and Muscle	14.1	31.6	30.5	26.9	31.3
Urogenital	28.1	64.5	66.0	70.0	77.4
Unclear	24.1	58.2	44.0	47.9	21.3

Notes: Annual percentage change for disease mortality rates calculated using previous four years; due to a major cholera epidemic, the percentage change between 1886-87 is excluded. Population and mortality rates based on resident statistics. Disease groups with asterisks are designated as communicable in the analysis.

Source: Author's calculations.

Table II: Treatment And Control Groups, Prefectural Averages

	Treatment Group: Rail Access 1886-1893		Control Group: Rail Access Post-1893	
Year	1883-85	1893	1883-85	1893
Prefectures	13	13	16	16
Rail stations	0	11.8	0	0
Land value per capita	46.5	39.9	41.1	34.8
Population	998,414	1,081,698	749,337	723,314
Capital Investment	466,429	3,547,972	317,464	1,054,997
Industrial Firms	21.7	56.2	14.0	49.8
Hospitals	10.5	11.2	7.8	8.5
Mortality per 100k	1,852	2,179	1,823	2,221
Disease Groups				
Blood Related	36.4	78.2	35.9	84.8
Bone and Joint	7.8	19.1	7.9	19.3
Developmental	295.2	350.9	295.3	359.8
Digestive*	410.7	518.5	403.1	522.2
External Injury	38.8	48.2	32.2	50.1
Infectious*	119.0	204.7	120.9	235.3
Nervous	356.5	427.3	368.7	452.1
Poisoning	1.6	0.9	2.0	0.9
Respiratory*	254.3	407.1	243.7	391.3
Skin and Muscle	19.7	24.9	19.1	26.2
Urogenital	46.3	69.2	50.2	70.9
Unclear	33.7	30.3	21.0	8.2

Notes: Land value and capital investment in nominal yen, and population and mortality rates based on resident statistics. Disease groups with asterisks are designated as communicable in the analysis.

Source: Author's calculations.

Table III: Disease Panel Regression Results, Rail Access Dummy

DV: Mortality (100k)	A	B	C	D	E
Rail Access, 1886-93	58.033	123.544*	9.718**	1.062	dropped
	(68.842)	(67.213)	(4.170)	(3.615)	
Land Value p.c. (100)		251.412	16.872	16.872	748.964
		(333.724)	(16.782)	(16.670)	(751.372)
Population Density		-150.179	-7.120	-7.120	48.942
		(108.035)	(5.895)	(5.892)	(119.795)
Industrial Firms (100k)		-0.385	0.022	0.022	-1.420
		(4.931)	(0.465)	(0.465)	(11.840)
Hospitals (100k)		55.924	4.366	4.366	-42.751
		(66.559)	(5.197)	(5.189)	(49.797)
Interaction with Rail					
Communicable Dummy				34.624***	dropped
				(12.266)	
Land Value p.c. (100)					-672.982
					(2195.043)
Population Density					249.099
					(513.171)
Industrial Firms (100k)					9.248
					(14.950)
Hospitals (100k)					39.672
					(68.446)
Avg. Treatment Effect on	58.033	123.544*	9.718**	35.375***	752.262
Treatment Prefectures	(68.842)	(67.213)	(4.170)	(11.484)	(1702.534)
Year Coverage	1883-93	1883-93	1883-93	1883-93	1883-85
					(Pre-Treatment)
Disease Groups	1 (Total)	1 (Total)	12	12	12
Observations	316	276	3,312	3,312	564
F-statistic	31.57***	60.71***	19.37***	20.22***	19.17***
Within R-squared	0.451	0.513	0.216	0.222	0.428

Notes; All specifications include fixed effects for disease group, prefecture, and year. Robust standard errors are clustered by disease group and prefecture. Average treatment effect of rail access calculated for rail access and its interactions over treatment period.

Significance levels: *10%, **5%, ***1%

Table IV: Disease Panel Regression Results, Rail Station Density

DV: Mortality (100k)	A	B	C	D	E
Rail Stations (100k)	34.970	76.233*	5.878	-0.714	dropped
	(40.620)	(40.303)	(3.754)	(3.028)	
Land Value p.c. (100)		259.830	17.574	17.574	748.964
		(335.578)	(16.793)	(16.690)	(751.372)
Population Density		-143.731	-6.599	-6.599	48.942
		(109.214)	(5.885)	(5.886)	(119.795)
Industrial Firms (100k)		-0.527	0.010	0.010	-1.420
		(4.969)	(0.466)	(0.466)	(11.840)
Hospitals (100k)		50.720	3.939	3.939	-42.751
		(67.622)	(5.231)	(5.206)	(49.797)
Interaction with Rail					
Communicable Dummy				26.368**	dropped
				(10.708)	
Land Value p.c. (100)					-672.982
					(2195.043)
Population Density					249.099
					(513.171)
Industrial Firms (100k)					9.248
					(14.950)
Doctors (100k)					39.672
					(68.446)
Avg. Treatment Effect on	33.186	72.343*	5.578	24.345**	752.262
Treatment Prefectures	(38.547)	(38.246)	(3.563)	(9.911)	(1702.534)
Year Coverage	1883-93	1883-93	1883-93	1883-93	1883-85
					(Pre-Treatment)
Disease Groups	1 (Total)	1 (Total)	12	12	12
Observations	316	276	3,312	3,312	564
F-statistic	32.02***	50.51***	19.33***	19.76***	19.17***
Within R-squared	0.450	0.508	0.216	0.220	0.428

Notes; All specifications include fixed effects for disease group, prefecture, and year. Robust standard errors are clustered by disease group and prefecture. Average treatment effect of station density calculated at treatment group averages for station density and its interactions over treatment period.

Significance levels: *10%, **5%, ***1%

Table V: Disease Panel Regression Results, Interaction Effects

DV: Mortality (100k)	A	B	C	D	E
Rail Access, 1886-93	-9.569	8.432*	-1.618	-0.544	7.049
	(19.362)	(5.000)	(5.061)	(7.821)	(30.849)
Land Value p.c. (100)	17.800	16.822	16.091	16.773	16.811
	(16.772)	(16.637)	(16.601)	(16.675)	(16.657)
Population Density	-7.024	-6.768	-7.240	-7.099	-6.816
	(5.912)	(5.908)	(5.894)	(5.891)	(5.925)
Industrial Firms (100k)	0.015	-0.050	-0.097	0.031	-0.115
	(0.464)	(0.462)	(0.477)	(0.463)	(0.478)
Hospitals (100k)	4.242	4.404	4.106	4.444	4.171
	(5.135)	(5.186)	(5.244)	(5.143)	(5.179)
Interaction with Rail					
Communicable Dummy	34.624***	34.624***	34.624***	34.624***	34.624***
	(12.235)	(12.034)	(12.235)	(12.286)	(11.989)
Land Value p.c. (100)	25.224				5.582
	(45.074)				(53.132)
Population Density		-4.636**			-4.736**
		(1.984)			(2.249)
Industrial Firms (100k)			0.612		0.263
			(0.926)		(0.934)
Hospitals (100k)				1.489	-1.819
				(6.288)	(7.433)
Avg. Treatment Effect on	42.840***	27.624**	35.423***	40.520***	33.543**
Treatment Prefectures	(14.354)	(13.894)	(12.024)	(12.327)	(17.585)
Year Coverage	1883-93	1883-93	1883-93	1883-93	1883-93
Disease Groups	12	12	12	12	12
Observations	3,312	3,312	3,312	3,312	3,312
F-statistic	18.93***	18.93***	18.99***	19.14***	16.22***
Within R-squared	0.222	0.223	0.222	0.222	0.223

Notes; All specifications include fixed effects for prefecture and year. Robust standard errors are clustered by disease group and prefecture. Average treatment effect of rail access calculated at treatment group averages for rail access and its interactions over treatment period.

Significance levels: *10%, **5%, ***1%

Table VI: Disease Panel Regression Results, Alternative Measures

DV: Mortality (100k)	A	B	C	D	E
Rail Access, 1886-93	-0.291	1.367	0.407	-4.810	-5.198
	(3.655)	(3.629)	(3.645)	(3.577)	(3.700)
Land Value p.c. (100)		16.434	17.318	-2.925	
		(15.040)	(16.728)	(14.448)	
Population Density	-8.011		-7.146	-12.168**	
	(5.690)		(5.898)	(5.991)	
Industrial Firms (100k)	-0.077	0.035		0.030	
	(0.452)	(0.464)		(0.479)	
Hospitals (100k)	3.444	4.564	4.228		
	(5.291)	(5.229)	(5.212)		
Alternative Measures					
Capital Investment p.c.	1.005				0.820
	(0.856)				(0.906)
Pop. Density, Lowland		-15.287			-27.610**
		(12.286)			(11.831)
Industrial Cap. Share			-0.082		-0.007
			(0.057)		(0.054)
Doctors (100k)				0.210	0.166
				(0.164)	(0.150)
Interaction with Rail					
Communicable Dummy	34.941***	34.624***	34.624***	40.185***	40.360***
	(11.964)	(12.277)	(12.191)	(11.673)	(11.388)
Avg. Treatment Effect on	34.649***	35.991***	35.030***	35.375***	35.162***
Treatment Prefectures	(11.171)	(11.801)	(11.706)	(11.484)	(10.997)
Year Coverage	1883-93	1883-93	1883-93	1883-93	1883-93
Disease Groups	12	12	12	12	12
Observations	3,348	3,312	3,312	3,648	3,648
F-statistic	20.33***	20.25***	20.10***	19.70***	19.62***
Within R-squared	0.222	0.222	0.222	0.215	0.216

Notes; All specifications include fixed effects for disease group, prefecture, and year. Robust standard errors are clustered by disease group and prefecture. Average treatment effect of rail access calculated at treatment group averages for rail access, other independent variables, and their interactions over treatment period.

Significance levels: *10%, **5%, ***1%

Table VII: Two-Period Disease Panel Regression Results

DV: Mortality (100k)	A	B	C	D	E
Rail Access, 1886-93	9.227	-0.223			dropped
	(5.719)	(5.183)			
Rail Stations (100k)			6.715	-0.971	
			(4.995)	(4.274)	
Land Value p.c. (100)	0.439	0.439	0.508	0.508	dropped
	(0.482)	(0.471)	(0.476)	(0.468)	
Population Density	-8.570	-8.570	-7.606	-7.606	-3.748
	(5.338)	(5.344)	(5.214)	(5.214)	(3.762)
Industrial Firms (100k)	-1.188	-1.188	-1.282	-1.282	-1.538
	(0.881)	(0.880)	(0.894)	(0.891)	(2.456)
Hospitals (100k)	12.813	12.813	10.962	10.962	-25.638
	(8.521)	(8.501)	(8.175)	(8.199)	(18.987)
Interaction with Rail					
Communicable Dummy		37.800***		30.745***	-3.542
		(11.048)		(11.106)	(14.540)
Land Value p.c. (100)					dropped
Population Density					-0.518
					(4.249)
Industrial Firms (100k)					-7.872
					(5.921)
Hospitals (100k)					15.839
					(12.760)
Avg. Treatment Effect on Treatment Prefectures	9.227	37.577***	6.375	28.266***	-41.522
	(5.719)	(11.646)	(4.742)	(10.815)	(34.213)
Period Coverage	Pre-/Post-Treatment	Pre-/Post-Treatment	Pre-/Post-Treatment	Pre-/Post-Treatment	Pre-Treatment
Disease Groups	12	12	12	12	12
Observations	696	696	696	696	348
F-statistic	15.77***	15.29***	15.53***	14.58***	93.52***
Within R-squared	0.172	0.219	0.171	0.204	0.911

Notes; All specifications include fixed effects for disease group, prefecture, and period. Robust standard errors are clustered by disease group and prefecture. Average treatment effect of rail access calculated for rail access and its interactions over treatment period. Average treatment effect of station density calculated at treatment group averages for station density and its interactions over treatment period.

Significance levels: *10%, **5%, ***1.