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WATERSHEDS IN INFANT MORTALITY:
THE ROLE OF EFFECTIVE WATER AND SEWERAGE INFRASTRUCTURE, 1880 TO 1915

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ABSTRACT

We explore the first period of decline in infant mortality in the U.S. and provide estimates of the independent and combined effects of clean water and effective sewerage systems on infant mortality. Our case is Massachusetts, 1880-1915, when state authorities developed a sewerage and water district for municipalities in the Boston Greater Metropolitan area. We find that the two interventions were complementary and together accounted for approximately 37 percent of the total decline in log infant mortality among treated municipalities during the 36 years considered. Considerable research has documented the importance of clean water interventions for improvement in population health, but there is less evidence on the importance of sewerage systems. Our findings are directly relevant to urbanization in the developing world and suggest that a dual-pronged approach of safe water and sewerage is important to improving infant and early child survival.

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“The interactions of water, sanitation, and hygiene with health are multiple. On the most direct level, water can be the vehicle for the transmission of a large number of pathogens. Human faeces is a frequent source of pathogens in the water and the environment ... In fact, it is virtually impossible to have a safe water supply in the absence of good sanitation”

Dr. Margaret Chan (2013)
Director-General, World Health Organization

I. Introduction

For much of the nineteenth century infant and child mortality were the prime causes of short lifetimes at birth in the United States and much of Europe. In 1880 Massachusetts, for example, infant deaths were 20.4 percent of all deaths even though births were 2.5 percent of the total population. Similarly in 1900 infant deaths were 22.5 percent of all deaths whereas births were 2.6 percent of the total population. But change occurred precipitously and for reasons that have mainly eluded researchers and contemporary observers. From 1870 to 1930, life expectation conditional on reaching age 20 changed little but infant mortality plummeted from around 1 in 5 white infants to 1 in 16 for both the entire U.S. and Massachusetts (see Figure 1).[1]

Recent empirical work on the U.S. historical mortality decline has focused on clean water.[2] Cutler and Miller’s influential analysis examined the impact of water chlorination and filtration across 13 U.S. cities from 1900 to 1936 and found large declines in death rates from various water-borne diseases (Cutler and Miller, 2005). Their estimates suggest that improved water quality accounts for 47 percent of the decline in log infant mortality during the period.[3] In addition to clean water, effective sewerage systems were installed in the late nineteenth century across many U.S. and European metropolitan areas but the role of sewerage infrastructure in the

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[1] By the “infant mortality rate” we use, as is common practice, the number of infants less than one year of age who died during a year divided by the number of births in that year. The modern historical literature on infant mortality is extensive. Among the most important is *Fatal Years* by Preston and Haines (1991). See also Cheney (1984), Condran and Lentzner (2004) and Condron and Murphy (2008).

[2] Troesken (2001, 2002) investigates the effect of water filtration and public versus private ownership on race-specific typhoid mortality and shows that public ownership had a greater effect than did private ownership in reducing black typhoid mortality. In contrast, Galiani, Gertler and Schargrodsky (2005), investigating privatization of water services in Argentina, finds that child mortality fell by 8 percent in areas that privatized their water source and that the decline was greatest (26 percent) in the poorest areas. Ferrie and Troesken (2008), in a study of Chicago, find that many non-waterborne diseases are significantly reduced after the introduction of water purification methods. Subsequent research by Beach, Ferrie, Saavedra and Troesken (2014) linking individuals over time demonstrated that investments in water purification technologies had long-run effects on human capital and earnings.

[3] Cutler and Miller (2005, table 5) compute the decrease in IMR due to clean water and sanitation to be 46 log points from 1900 to 1936 in their 13 cities. The total decrease in those cities was 98 log points (log [189.3/71.3], table 2) or a 47 percent change. Cutler and Miller report a 74 percent change but had divided by the percent decline (0.62) rather than by the log point decrease. They correct this in a forthcoming comment.

decline of infant mortality has yet to be rigorously assessed.[4]

From a biomedical perspective, the two infrastructure investments should be complementary. Fecal-oral transmission of pathogens can occur through multiple pathways. Sewerage acts as the primary barrier—removing excrement from drinking water sources, and also reducing the ability of feces to contact hands. Excrement also serves as potent attractant for flies—and therefore its removal reduces the enteric diseases they may transmit. Finally, excrement can enter into the food supply through fields, either intentionally or unintentionally because of run-off or flooding. Clean water assures that water used for drinking and washing food is safe but neglects these other pathways of transmission. Together, strategies that emphasize both clean water and sewerage provide more than one barrier, and therefore may play complementary roles in reducing disease transmission.

This paper provides the first empirical examination of the causes for the earliest recorded sustained decline in infant mortality in U.S. history. Our estimation strategy exploits a mandate originating from the Massachusetts State Board of Health that all municipalities surrounding Boston join the Metropolitan Sewerage District.[5] We also rely on the fact that infrastructure roll-out was based on technocratic considerations (such as distances to various outfalls and terrain).[6] Unanticipated delays further staggered the rollout thus infrastructure completion dates were not very predictable.[7] Because of the negative externalities associated with upstream dumping of sewage, all municipalities located within the watershed area of the Boston Harbor were compelled by law to join (and pay for) the sewerage district. Although each could elect to receive water from the Metropolitan Water District, the timing of the intervention was beyond

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[4] Sewerage and safe water could be substitutes or complements, but see Bennett (2012) for the substitution between personal hygiene and piped water provision. For our period, countervailing risky health behavior was likely muted by the overwhelming benefit of moving sewage out of the local environment and piping in clean water. Nevertheless, our results should be interpreted as the reduced form effect, net of any behavioral response. Watson (2006) finds that about 40 percent of the decline in IMR since the 1960s (from 50/1000 to 10/1000) on U.S. Indian reservations was due to sanitation interventions. Preston and Van de Walle (1978) attribute the decline in child mortality in nineteenth century France to improved water and sewage disposal but do not provide an empirical test. Kesztenbaum and Rosenthal (2014) find that a one standard deviation increase in the sewer connection rate in Paris, during a similar period as ours, increased life expectancy at age one by two years. Brown and Guinnane (2015) find that a connection to piped water contributed to the decline in mortality, though other factors (such as fertility) were also found to be important.

[5] The Massachusetts State Board of Health published its first annual report in 1870. In 1914, when it published its 46th annual report it changed its name to the State Department of Health and began numbering reports from the first. See Whipple (1917).

[6] We provide statistical evidence that indeed the timing was related to technical engineering features in Section IIB and Appendix Table B1.

[7] Construction teams often encountered quicksands and large stones that delayed the placement of main lines. For further details see Section IIB.

the control of any given municipality.[8]

Our differences-in-differences estimates show that appropriate sewerage systems and safe water are complements in the production of infant health and a major contributing factor to the initial decline in infant mortality in U.S. history. Using our preferred specification, sewerage and safe water together lowered the infant mortality rate (IMR) by 22.0 log points or 37 percent of the total change in log IMR in the treatment towns and cities.[9] Taken separately, each of the two interventions had a small or negligible effect. As the financial and political powerhouse of the Commonwealth, as well as the recipient of much of the downstream waste, Boston initiated the pure water and sewerage projects. In consequence, we exclude Boston from our main analysis but show the robustness of our results to its inclusion.

A variety of informal tests bolster our main findings regarding the complementarity of infrastructure investments including: (1) that our treatment and control municipalities show few baseline differences in infant mortality or other determinants of population health; (2) a sharp and persistent level shift in the evolution of infant mortality upon the introduction of the two technologies; and (3) the robustness of our results to the inclusion of municipality-level linear trends.

We provide further support of a causal interpretation of our estimates by examining age and cause-specific mortality, similar to Galiani, Gertler and Schargrodsky (2005). We find that enteric-related diseases are heavily affected by the introduction of the sewerage and safe water interventions whereas deaths from etiologies with a different pathological basis are not affected. Consistent with this finding, only the less than five-year old population, those most likely to succumb to enteric disease given their susceptibility to dehydration, experienced a survival benefit from the treatments. In addition, the infrastructure improvements had a larger impact on infants in municipalities that contained large numbers of immigrants (particularly the Irish) thus suggesting the interventions positively impacted economically disadvantaged groups.

The rest of the paper is structured as follows: we discuss the decline in infant mortality in historical background and then turn to the circumstances surrounding the creation of the enormous sewerage and water infrastructure in the Greater Boston Metropolitan area. Next we outline our empirical strategy, sources of data, present the results and conclude.

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[8] Municipalities also had to own the water pipes, or purchase them from private providers if they did not already own them.

[9] The total change in log (IMR) is 59.3 log points calculated as the (unweighted) average of log (IMR) in the 15 towns and cities, from 1880-84 to 1911-15, that had both treatments. Five-year averages of the aggregate log (IMR) are used because of volatility.

II. Historical Background:

A. The First Sustained Decline in Infant Mortality in U.S. History

The aggregate U.S. series for infant mortality starts around 1850, as does that for Massachusetts.[10] For both series, as shown in Figure 1, the infant mortality rate (IMR) begins to decline sometime in the late nineteenth or early twentieth century and continues to the present day. Our focus on Massachusetts is due to its relatively high frequency and high quality data, as well as because the pre-1900 U.S. series is derived, in part, from that for Massachusetts.

Although the Massachusetts series is highly volatile to around 1880 due often to epidemics, it is clear that IMR underwent a watershed change in the late 1890s. In just a few years the rate fell from around 163/1000 (1 in 6.14) in 1896 to 151/1000 (1 in 6.62) in 1898 and then to around 100/1000 (1 in 10) by 1915.[11] The series continued to decline after 1915, with an upward spike in 1918 due to the influenza pandemic and a few periods of stagnancy or actual increase. To understand the initial period of decline, we limit our analysis of the Massachusetts data to 1880 to 1915 because of the volatility in the series in the 1870s and the pandemic in 1918. What allowed more babies in the Commonwealth to escape early death beginning in the late nineteenth century?

Several facts from the Massachusetts data provide hints regarding the cause of the initial decline in IMR in the Commonwealth. The first is that the initial decrease was greater in more urbanized areas of the Commonwealth than in rural areas (Figure 2). Thus, there was a decrease in the "urban penalty."[12]

Another hint is that whatever caused infant mortality to decline apparently affected infant and child mortality but not that of older individuals. Infants were primarily dying of diarrheal-related illnesses, whereas adults were succumbing mainly to pulmonary tuberculosis.[13] We show this in Figure 3 for a sample of the 15 cities and towns that eventually underwent both the water

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[10] See Haines (1978, 1998a) for the construction of the aggregate series. The series is largely inferred from the construction of model life tables but also uses data from the 1900 and 1910 U.S. population censuses on children ever born and children surviving. The Massachusetts data are one input to the construction of the model life tables. Lemuel Shattuck, statistician and luminary in Massachusetts public health history, was the major driving force behind the early establishment of vital statistics in Massachusetts. His lobbying efforts led to the *First Annual Report on Births, Marriages and Deaths,* in 1843. His 1850 *Report of the Sanitary Commission* proposed the establishment of a General Board of Health to oversee the enumeration of vital statistics and the public health of the Commonwealth.

[11] The United Nations data (2005-10) on infant mortality has eight nations with a rate exceeding 100/1000 and all of these are under 127 and in Africa. See http://esa.un.org/unpd/wpp/Excel-Data/mortality.htm

[12] Preston and Haines (1990) confirms the urban penalty. See also Glaeser (2013).

[13] In Appendix Figure B1 we demonstrate the prevalence of gastrointestinal (GI)-related deaths among infants in our sample (approximately half of all, readily coded, causes of death), Appendix Figure B2 demonstrates the reduction in infant GI-related deaths in municipalities that received both versus only one intervention.

and sewerage treatments that we will soon exploit. Infant mortality in these urban places was around 166/1000 births, with some volatility, in the early 1880s. It fell to around 88 by 1911-15.

We focus on a specific group of municipalities that experienced sudden changes to their water supply and sewerage systems. These cities and towns underwent a larger decrease in IMR than occurred in the Commonwealth as a whole in our analysis period, 1880 to 1915. And these cities and towns underwent a larger decrease than in comparable urban areas with no treatment. Infant mortality declined by about 38 log points in the entire Commonwealth from 1880-84 to 1911-15 (from 161.4 to 110.7/1000) but by 59.3 log points in our (unweighted) sample of the 15 municipalities that received a treatment, compared with about 36 log points in the (unweighted) sample of municipalities that received no treatment.[14] Figure 4 gives the IMR data for the municipalities.

Our answer to what caused the initial decline in infant mortality in Massachusetts is the radical change in water and sewage disposal and the protection of "watersheds" to feed purer water to the greater Boston area. An extensive public water and sewerage project created a large watershed from which potable water could flow to homes and in which water would be protected from potentially polluting sewage that would be piped and pumped into the Boston Harbor. The area eligible to receive pure water contained more than one-third of the state's population at the time, but included only cities and towns within a ten-mile radius of the Massachusetts State House in Boston. Even though much of the state was not directly affected by the water project, the Commonwealth in 1886 began to protect all inland waterways and to employ water engineers who provided assistance to all cities and towns.[15]

B. The Creation of the Metropolitan Water and Sewerage Districts

The Boston Metropolitan District (MSD) was an area of rapidly increasing population density in the post-Civil War era.[16] The main impetus behind the creation of the Metropolitan Sewerage District (MSD) was complaints regarding the stench the sewage among Boston's upper class citizens: "The first of a series of hearings was given by the sewerage commission at the City Hall on Friday night ... From the statements made it would appear in various parts of the district including most of the finest streets, the stench is terrible, often causing much sickness"

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[14] We use the unweighted sample and average the five-year log IMR at the start and at the end.

[15] Infant mortality also declined in many parts of Europe in the early twentieth century. In England and Wales the rate remained in the 150/1000 range until around 1900 when it decreased to the 130 range and then to just above 100 about 1910. Although Woods, Watterson and Woodward (1988, 1989) discuss the role of clean water and proper sanitation, it is mentioned as only one of the contributory factors and not the major one.

[16] In 1898 the Metropolitan Sewerage District, with Boston, contained 36 percent of the state's population and 55 percent of its total assessed valuation, but just 2.5 percent of its land area. The "District" included 23 towns: Arlington, Belmont, Brookline, Cambridge, Chelsea, Dedham, Everett, Hyde Park, Lexington, Malden, Medford, Melrose, Milton, Newton, Quincy, Somerville, Stoneham, Wakefield, Waltham, Watertown, Winchester, Winthrop, and Woburn (Metropolitan Sewerage Commissioners 1899, p. 3).

(Boston Medical and Surgical Journal 1875, p. 79).

The sewage had two main sources. The direct outfalls from Boston dumped into the Harbor: “As early as 1870, an aggregation of old sewers discharged by about seventy outlets into tide water, chiefly along the harbor front.”[17] The second was that surrounding municipalities discharged into the Mystic, Charles and Neponset Rivers that eventually emptied into the Harbor. A joint engineering and medical commission was appointed in 1875 to devise a remedy.

The report of the 1875 Sewerage of Boston Commission (Chesbrough et al. 1876) recommended a drainage system for Boston and its surrounding municipalities. Boston City authorities acted and, from 1877 to 1884, constructed a comprehensive system of sewage disposal works that discharged into the deep shipping channels off Moon Island (in Quincy Bay, Boston Harbor). Attention then shifted to sources of pollution beyond its immediate control, namely the municipalities of the Neponset, Charles and Mystic River valleys that comprised the Harbor’s immediate watershed area.[18] But the obvious problems of public works coordination across municipalities complicated the control of sewage.

In 1887, the Boston General Court instructed the State Board of Health to revisit the question of a regional sewerage system for the MSD. The Board was authorized to decide the municipalities to be included and how the sewerage system would be constructed.[19] The report had similar recommendations to that of its predecessor and divided the District into separate sewerage systems by geographical features. The 1889 Report (Massachusetts State Board of Health 1889) suggested an additional outfall to be constructed at Deer Island (near Winthrop in Boston Harbor) draining the northern Charles River Valley and the Mystic River Valley and also intercepting sewers connecting the southern portion of the Charles River Valley to the outfall on Moon Island. The Court approved further recommendations by the Board to drain the Neponset River Valley with a separate outfall off Nut Island (in Quincy Bay) in 1895 (see Map 1).

As mentioned above, completion dates were determined mainly by the engineering considerations and unanticipated delays further staggered the rollout. The engineers considered the proximity of the municipalities to the harbor (which was the location of the three major outlets) as well as elevation. A Cox hazard model (provided in Appendix Table B1) demonstrates that the timing of water and sewerage interventions was strongly affected by geographic features and not consistently influenced significantly by pretreatment demographic characteristics of the municipality. The analysis provides further evidence that technocratic

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[17] Metropolitan Sewerage Commissioners (1899), p. 5.

[18] In addition to the immediate Harbor watershed area of the Charles, Mystic and Neponset River Valleys, the Commonwealth paid for sewerage infrastructure to be built in the towns of Clinton and Marlborough.

[19] The General Court of Massachusetts had resolved that the engineers appointed to the Sewage Commission were to “designate the cities and towns...which shall be tributary to and embraced by the district” and “determine and show, by suitable plans and maps, such trunk lines and main branches as it shall recommend to be constructed, with outlet, (Massachusetts State Board of Health, 1889 page 3-4).”

considerations were paramount, rather than pressing need. The construction teams encountered numerous challenges along the way, including quicksand and boulders, further delaying the completion of the construction of lines in an idiosyncratic manner.[20]

Coincidental with the construction of a regional sewerage district, Massachusetts took several steps to ensure a safe water supply. The "Act Relative to the Pollution of Rivers, Streams and Ponds Used as Sources of Water Supply," passed in 1878, forbade persons and corporations from dumping human excrement or effluent into any pond, river or stream used as a source of water supply (Secretary of the Commonwealth 1878, p. 133). But three of the most polluted rivers—the Merrimack, Connecticut and Concord Rivers—were exempt from the law because they were heavily used by industry and manufacturers protested their protection.

In 1886, the General Court extended the State Board of Health oversight of all inland bodies of water and directed the Board to offer advice to municipalities on water and sewerage and to employ engineers to aid the process. The Board was reorganized that year and Hiram Mills, a hydraulic engineer, became chair of the Committee on Water Control and Sewerage. Mills, a resident of Lawrence, established the Lawrence Experiment Station as a trial station for the filtration of tainted water, the first in the nation. Mills persuaded Lawrence to adopt a sand filter since its water supply was taken from the heavily polluted Merrimac River.[21]

In general, however, the State Board of Health eschewed filtration techniques for water purification, instead preferring that the water be derived from impounding reservoirs in which spring floodwaters were stored. The storage process clarified the water and killed off bacteria, which eventually starved or burst. The distinctive Massachusetts methods for providing pure water would soon be contrasted to those of other cities when these places, in the early twentieth century, began using the new filtration and chlorination techniques.

As a consequence of the safe water strategy that Massachusetts adopted, population growth posed a serious threat to the water supply because growth inevitably led to encroachment on watersheds. The concern led to the passage of an act by the General Court in 1893 that paved

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[20] Timing to sewerage and water are modelled separately since distinct engineering factors affect each one of them. Time to the interaction is difficult to model since various geographic considerations may have impacted the infrastructure timing differently. The Charles River System, begun in May 1890, was completed in spring 1892 despite "difficulties." It was the fastest to complete since it was an extension of the extant Boston system. The North Metropolitan System began at the same time of the Charles River System but "was slower in progress and much later in its completion." It required the construction of a new pumping station and various other engineering challenges. The Neponset Valley System was mainly completed in 1897. The High-level System was still in progress in 1899 (Metropolitan Sewerage Commissioners 1899, pp. 15).

[21] See Whipple (1917), chap. 4 on the reorganization of the Board. With regard to the Lawrence filter, it has been pointed out that: "The plans were not furnished by the Board, but by Mr. Hiram F. Mills [who] gave his services to the city and received no compensation for them. … He was Chief Engineer of the Essex Company [which] had created Lawrence, and was, perhaps, more directly interested in its welfare than any other corporation" (American Society of Civil Engineers 1901, p 319).

the way for the creation of the Metropolitan Water District (MWD).[22]

In 1895, the Board of Health recommended the creation of reservoirs in Sudbury and Wachusetts by taking water from the South Branch of the Nashua River and flooding the town of West Boylston (Whipple 1917). Large aqueducts would bring the fresh water to a renovated Chestnut Hill Pumping Station where it would be distributed through newly constructed iron main lines to municipalities in the District (see Map 2). Construction on the waterworks began soon after and water started to flow into municipalities in January 1898.

Evidence that water quality improved after the intervention comes from a report of the Metropolitan Water Board. Organisms were reduced from 351 per cubic centimeter in 1897, before the intervention, to 192 per cubic centimeter in 1899, after. Oxygen consumed fell by half during the same period (Sprague 1900, p. 39). Similar observations came from the Lawrence filter. The average number of bacterial counts per cubic centimeter fell from 10,800 to 110 after filtration in 1894 (*JAMA* 1903). But were these interventions responsible for the initial decline in infant mortality in Massachusetts?

III. Estimating Equations and Empirical Results

A. Empirical Strategy

Our empirical analysis exploits the plausibly exogenous timing and geographic penetration of safe water and sewerage interventions. We assume that infant mortality in municipalities with differentially timed access to clean water and sewerage would have evolved similarly in the absence of the interventions. We assess the validity of that assumption below.

We use a differences-in-differences framework to estimate the impact of these interventions on population health. Specifically, we estimate:

$$\log\,(\mathrm{IMR})_{ijy} = \alpha + \beta_1 W_{iy} + \beta_2 S_{iy} + \gamma(W_{iy} \cdot S_{iy}) + \Omega X_{ijy} + \delta_i + \delta_y + \delta_i \times y + \varepsilon_{ijy} \qquad (1)$$

where i stands for municipality, j for county and y for year. W and S are dummy variables indicating whether or not a municipality adopted the safe water (W) and/or sewerage (S) intervention by year y. The interaction of safe water and sewerage ($W \cdot S$) is included to test whether infrastructure investments are complements or substitutes. The βs and γ are differences-in-differences estimates of the impact of the interventions on infant mortality, conditional on municipality (δ_i) and time fixed effects (δ_y) as well as municipality-specific time

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[22] The Act stated: “The state board of health is hereby authorized and directed to investigate, consider and report upon the question of a water supply for the city of Boston and its suburbs within a radius of ten miles from the state house, and for such other cities and municipalities as in its opinion should be included in connection therewith” (Secretary of the Commonwealth 1893, p. 761). Before the establishment of the MWD, a variety of sources (including lakes, ponds, private wells and reservoirs) supplied water to the municipalities.

trends ($\delta_i \times y$). X represents a vector of time- and municipality-varying demographic controls including (the log of) population density, the percentage foreign-born and male, as well as the percentage of females employed in manufacturing. The latter variable might be important if mothers who are working in factories are less likely to breastfeed, and breastfed infants are less likely to be exposed or succumb to diarrheal illness.

In robustness tests we also include county-level time-varying covariates, such as the quality of dairy milk or a vector of dichotomous county-year fixed effects (λ_{jy}). Our main outcome of interest is the (log) infant mortality rate.[23] Standard errors are clustered at the municipality level throughout the analysis since the treatments were at the municipality level.

In order to explore the validity of our underlying assumption, we estimate changes in infant mortality rates prior to the introduction of the safe water and sewerage interventions and trace their evolution to 1915. Our main analysis of eq. (1) will suggest that the combination of safe water and sewage removal was the most effective intervention for reducing IMR, thus we would anticipate a level shift in the evolution of IMR upon their introduction. To discern whether such a shift existed, we use the following equation:

$$\log(\mathrm{IMR})_{ijy} = \alpha + \sum_{k=-10}^{10} \gamma_k \left(W_{ik} \cdot S_{ik}\right) + \beta_1 W_{iy} + \beta_2 S_{iy} + \Omega X_{ijy} \qquad (2)$$

$$+\delta_i + \delta_y + \delta_i \times y + \varepsilon_{ijy}$$

where all variables are defined as in eq. (1) except γ_k refers to a series of dummy variables equal to 1 if a municipality received both interventions k years before or after. The coefficients map out the dynamic response to the introduction of the safe water and sewerage combination.

B. Data Sources

The precise dates of water and sewerage interventions are crucial to our empirical strategy. We obtained the dates from annual reports of the State Board of Health, the Metropolitan Sewerage Commission, the Metropolitan Water District (MWD) and the Metropolitan Water and Sewerage Board.[24] We code a municipality as treated if a main sewerage or water pipe was linked to the municipality from the Metropolitan System or if a local innovation was adopted at the request and expense of the Board of Health.[25] Figure 5 gives the total population covered by

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[23] The log transformation is preferred given the positive skew in the mortality data. In the robustness tests we assess the sensitivity of our results to functional form.

[24] We used Massachusetts State Board of Health (1880 to 1915), Metropolitan Sewerage Commissioners (1899), and Commonwealth of Massachusetts (1914), which is a compilation of all the laws affecting the MWD, the MSD and the union of the two.

[25] We consider three additional local interventions: the placement of a filter in Lawrence (1893), the permission to take water from sources protected by the MWD (for Worcester in 1903 and Malden in 1904) and the insistence and financing of sewerage infrastructure in Marlborough. Marlborough was of concern to the Commonwealth since its effluent could contaminate municipal water. In the appendix, we

either safe water, sewerage or both interventions (see Appendix Table A1 for the dates).

Municipality-level data on births are drawn from annual vital statistics registration reports of births, marriage, and deaths (Secretary of the Commonwealth 1870-1915).[26] Although annual reports prior to 1891 included deaths under one year of age for every municipality, citing a mandate to publish only information of "practical utility," infant deaths between 1891 and 1897 are available only at the county level. After 1897, infant deaths are reported in the vital statistics for all counties and cities.[27]

To establish a consistent measure of infant mortality for our sample of municipalities during our analysis time period, we created a dataset of infant deaths from FamilySearch.org, which is a typescript of most of the information contained in the death records. The source includes infant deaths for (almost) every year and for every municipality in our main sample. (Details about the search algorithm and the correlation between infant mortality rates from the vital registration reports and FamilySearch.org are in Appendix C.)

The information underlying the Secretary of the Commonwealth's *Reports* and the FamilySearch.org website are the same death certificates and death registries collected at the municipality level.[28] Stillbirths and early infant deaths were not reliably distinguished.[29] In compiling births, the Secretary of Commonwealth data tried to exclude stillbirths, whereas the FamilySearch.org data does not make a systematic attempt to do so. To harmonize these two data sources we chose to include stillbirths in both the numerator and denominator since the definition was fluid during the period of our analysis. Therefore, we add stillbirths to the official birth data.

In our robustness tests we normalize infant deaths by total population instead of total births. We also entered cause of death for each infant death that was legible. These additional data allow us to probe whether deaths from gastrointestinal illness as opposed to deaths due to

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drop these three municipalities to assess robustness of our results to their inclusion. None of our control municipalities is a pure control since attempts were made to improve water and sanitation across the Commonwealth. If these efforts were successful, our estimates are biased towards the null. But we have no reliable information that water quality was improved by them.

[26] The Commonwealth made an effort to exclude stillbirths from the counts of births and deaths but the concept of a stillbirth was ill-defined. As late as 1915, the ambiguity was still unresolved: "Apparently there is no precise definition of a stillbirth which the physicians or midwives are required to observe" (Secretary of the Commonwealth 1915, p. 18).

[27] Reporting was for incorporated cities with a population exceeding 12,000 in 1895.

[28] Our definition of an infant death is if the death and birth years are the same. The FamilySearch.org data listed an infant death with the actual death date but gave the birth year as the same as the death year if the infant was less than one year, even if the infant was born in the previous year. Therefore, we use the year at death, not birth. We cannot construct a municipality panel exclusively based on Registration report data since infant deaths for some years (1891 to 1897) are only available at the county level.

[29] The concept of a live birth evolved over time. The common practice for the period we examine is to count fetal deaths of pre-term fetuses as "miscarriages" and of fetuses of more than seven months gestation as stillbirths. Many infant deaths that were categorized as stillbirths would have been live births that died during delivery.

premature birth or cardiovascular causes were differentially affected by the two public health treatments.

Given the importance of a clean milk supply for the health of babies and the role it has played in the literature on infant mortality, we include data from the *Annual Report of the State Board of Health* (Massachusetts State Board of Health 1905-15) on the fraction of dairies at the municipality level that passed State Board of Health inspection.[30] The policy to inspect dairies and their milk started in 1905 and lasted until 1914 when inspection authority was devolved to the municipality-level. For Suffolk County, milk was transported by refrigerated trains and tested for bacteria on arrival, in transit and at stores. We define the milk market at the county-level and use the percentage of dairies that passed inspection as well as the percentage of milk relatively free from bacteria as our measure of milk purity. Testing for the impact of the type of pipes used, in particular the role of lead, was hampered by the absence of time-varying data. But our results are generally robust to the inclusion of the type of pipes used during the period.[31]

Time-varying demographic features of municipalities such as percentage foreign born, age and sex distribution and percentage of females employed in manufacturing are obtained from state and federal censuses, linearly interpolated between censuses (see Appendix A).[32]

Our main sample is a panel of 54 municipalities from 1880 to 1915 (excluding Boston). The sample consists of all municipalities within the immediate Harbor watershed area (approximately 12.5 miles from the Massachusetts State House) as well as municipalities outside the immediate Boston area that had incorporated as cities as of 1895.[33] The sample is drawn in Map 3. In Map 4 we focus attention on the Boston Metropolitan Area and use shading to represent municipalities that received water (light grey), sewerage (hatched), both (cross-hatched) and neither (white).

The main methodological concern is that the decision to join the Metropolitan Sewerage or Water District or to install a filter may not be orthogonal to unobserved factors that also determined infant mortality. The sewerage connection, however, was not a choice made by a local government, as we have already mentioned, but a requirement imposed by the

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[30] "Recognizing the well-demonstrated importance of an improved milk supply in its relation to the public health, the Board … began [in] 1905 a systematic investigation of dairies and the conditions under which milk is produced for public sale" (Massachusetts State Board of Health 1905, p. 520). We also used reports from the Health Department of the City of Boston (1905 to 1915).

[31] Clay, Troesken and Haines (2014) demonstrate that lead pipes were an important contributor to infant mortality. Because time-varying data on lead pipes are not available we test the robustness of our results to the inclusion of lead pipe status as of 1897. We find few differences.

[32] For Westwood, we interpolated by choosing starting values due to data limitations.

[33] The Boston metropolitan area is frequently described as including all municipalities within ten miles of the State House, but the sewerage district extended to municipalities as far as 12.5 miles.

Commonwealth and one that had an uncertain date of completion.[34] Although there was more local input to joining the water district or, in one instance, installing a filter, ultimately the timing of these interventions was determined by the overcoming of engineering difficulties, as demonstrated in Appendix Table B1.[35]

C. Estimating the Impact of Sewerage and Pure Water Treatments on IMR

1. *Main results*

We first test whether differences in IMR existed between municipalities that would eventually receive a safe water and sewerage treatment and those that would not, prior to the interventions. That is, we examine whether eventual participation in safe water, sewerage or both interventions is correlated with baseline covariates in 1880. Although this method is a reasonable way to assess baseline differences between groups, it is not entirely consistent with the definitions of treatment and control that we exploit in the regression analysis since the regressions utilize both geographic and time variation in the rollout of the interventions. Nevertheless, large differences between the groups at baseline, defined by their ex post treatment status, would be of concern. Table 1 presents these results.

The first column of Table 1 gives the mean health and demographic characteristics across the main sample. Col. (2) presents differences between those municipalities that improved water without the sewerage treatment and those that did neither. Col. (3) repeats the exercise for sewerage and col. (4) represents the difference between municipalities that received both versus neither. The subsequent cols. (5) to (7) give differences between the treatment groups.

The results demonstrate that there were no significant baseline differences in demographics or infant mortality across the intervention groups in the baseline period. The absence of baseline differences in IMR between the dual-treatment and non-treatment municipalities can also be seen in Figure 4. Because some of the cities and towns outside the Boston metropolitan area were manufacturing hubs, the percent of women employed in manufacturing was generally lower in the municipalities that received infrastructure interventions. However, directly adding the percent of females working in manufacturing as a control or dropping the untreated group from the analysis (thus using only variation in the timing of interventions) does not significantly change our estimates, suggesting these baseline differences do not bias our results.

Our baseline estimates of the impact of the sewerage and water interventions, from estimating eq. (1), are presented in Table 2 for the 54 control and treatment cities and towns. The regressions are unweighted and contain municipality and year fixed effects, as well as

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[34] Because the Metropolitan Sewerage District emerged primarily from a desire to serve the city of Boston, Boston is excluded from all our main analyses (though it is included in robustness tests).

[35] If we limit our sample to municipalities that received the water intervention at some point (thus only exploiting the time dimension of water installation), we obtain statistically significant and indistinguishable results from those reported in Tables 2 and 3.

municipality-specific linear trends, in every specification. By not weighting we are considering each city or town to be a separate experiment. Of the 54 towns and cities, 15 received both treatments during our sample period, whereas 23 received no treatment, 5 had only water and 11 had only sewerage.

In cols. (1) and (2) we test whether the water or sewerage intervention had a significant effect on infant mortality. These regressions provide estimates of the impact of one of the interventions in the absence of the other. Each separately lowered IMR, by 7.2 log points for sewerage and 12.4 log points for water alone. In col. (3) we include both safe water and sewerage. Although both have the expected sign, they are not individually significant. Their interaction (in col. 4) is economically and statistically significant.[36] We justify including the interaction without the main effects only if the "treatment" were clean water *and* good sanitation *combined*.

We test whether the two interventions are complements or substitutes by adding the interaction of the two in col. (5) and including the main effects. Our evidence points to a complementary relationship between the two since only the interaction term is significant. It indicates that IMR declined by 22.0 log points (0.038 – 0.027 – 0.231) when there are *both* interventions.[37] Neither the water nor the sewerage intervention is individually significant and water has an insignificant, positive impact on IMR in the absence of the sewerage intervention.

Figure 6 uses eq. (2) to map out the dynamic response to the introduction of the combination of the safe water and sewerage interventions. It is clear that the interventions reduced IMR, as can be seen in Table 2, col. (4), which considers both interventions as the treatment. It is also clear from Figure 6 that in the eight years preceding the intervention conditions were neither getting worse nor were they getting better. In addition, the effect of the intervention was immediate and persistent.

We limit the sample in Table 3 to the 31 municipalities that had at least one intervention. In this case only the timing of the intervention and whether a municipality received one or two interventions, not whether the town was potentially treatable, are assumed to be exogenous. The sample is reduced considerably in size, but the point estimates remain in the same range.

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[36] Our preferred estimation includes linear trends, which increases the variance inflation factor (VIF) of water, sewerage and their interaction above 10. However, when we exclude municipality trends, the VIFs are well below 10 and the coefficients are very similar to those reported in Table 2 (col. 5). Furthermore, when we include the main effects for sewerage and water, neither is individually significant (col. 1 and 2) but the interaction is statistically significant (col. 4). Adding the main effects to the interaction in col. (5) does not change the coefficient on the interaction significantly but does alter the main effects (without significantly increasing their standard errors)—which we interpret as evidence that the interaction is the primary driver of the infant mortality reductions, though we would caution against the interpretation that the main interventions held no individual benefits, since even the "control" municipalities in our sample were receiving advice on water and sewerage from the State Board of Health.

[37] Robust standard errors for the sum of coefficients for the three treatments are given in Tables 2 and 3.

2. *Channels*

How were infants affected by potentially contaminated water? In the period examined, most infants were not exclusively breastfed throughout their infancy but were, instead, often fed a gruel that contained water. Detailed information on breastfeeding practices from the extensive Children's Bureau Bulletins of the late 1910s and early 1920s shows that around half of all surviving infants were exclusively breastfed at six months, about a quarter were wholly bottle fed at six months and the rest were nurtured by a combination of the two methods (U.S. Department of Labor 1923).[38] Women from low income families who worked outside the home were less likely to breastfeed throughout infancy, although differences in breastfeeding practices by family income were not large. And some women across all economic classes were unable to breastfeed for a variety of reasons.

But even for women who did breastfeed, it was a common practice, and one that was later condoned and recommended by the Children's Bureau, to feed infants water. The advice often came with the admonition to boil water, but that was not always the case. "When the baby cries between feedings [at the breast] give him pure, warmed water without anything in it. Then let him alone" (U.S. Department of Labor, Children's Bureau 1914, p. 50).[39] Another possibility is that even if babies were not deliberately fed water they were bathed in water that may have been polluted. Finally, flies transmit disease from feces to milk or gruel that would have been fed to children from a very young age.

The notion that the channel was through reducing death from enteric disease is bolstered by the evidence presented in Table 4. We find strong evidence of a meaningful impact of the safe water and sewerage interventions for infants (less than one year of age) and for young children from one to less than five years old, which we term the child mortality rate (CMR).

For the CMR, the interaction of water and sewerage led to a 40.3 log point reduction in mortality over the period, though the total effect is more modest (17.3 log points). In contrast, we find no impact on the death rate for those five years and above, which we term the non-child mortality rate (NCMR). The combined effect is a mere -0.005 log points. Given that the

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[38] See Apple (1997), table 9.1. Because babies who were not exclusively breastfed died at higher rates than those who were, the fraction of survivors being breastfed at six months overstates the fraction breastfed if none had died. The Children's Bureau surveys were done in the late 1910s but Apple (1997) and Wolf (2001) use a range of sources revealing similar breastfeeding percentages for earlier decades. Both studies discuss why breastfeeding was not the (near) universal practice in the period. The main reason offered by Wolf (pp. 10) is that American women in the late nineteenth century began to rely more and more on artificial feeding formulas, even before inexpensive ones were marketed, and that the spread of the germ theory, ironically made mothers worried about the safety of their own breast milk. Although the reasons offered are not fully satisfactory, the conclusion that breastfeeding declined seems sound.

[39] The Bureau offered extensive advice on the use of water: "Early feeding. Feed the baby one part milk and two parts water during the first month … During the second and third months use one part milk and one part water … After the fourth month give two parts milk and one part water (U.S. Department of Labor 1914, p. 51).

overwhelming cause of death for adults at the time was tuberculosis, an airborne contagious disease, we view these findings as supportive of the notion that the mechanism by which safe water and sewerage interventions improved infant survival was by reducing death from enteric disease.

Indeed we test this exact mechanism in cols. (4) to (7) of Table 4. We find a statistically significant reduction in diarrhea related cause-specific mortality among infants (log GI) due to the interaction of water and sewerage (30.9 log points). We also find a strong effect (38.7 log points) for other vaccine preventable diseases (log OV), some of these diseases are transmitted via the fecal to oral route (i.e. polio). But we find no impact on pneumonia (log PNA), prematurity (log PREM) or cardiovascular disease (log CV).[40] Prematurity and (congenital) cardiovascular disease are generally not thought to be directly impacted by water contamination, therefore these findings are reassuring. Although the interaction coefficient is negative for pneumonia, the standard errors are large, possibly because of the smaller sample size or because a child who died with pneumonia and diarrhea was classified as the latter. Overall, the findings on cause and age of death are supportive of the water and sewerage interventions affecting the most critical age periods and most logical disease entities that would be anticipated by the biomedical literature.

3. *Heterogeneity by Immigrant Group and Female Literacy*

We also investigate whether the impact of the infrastructure improvements depended on the percentage of foreign-born in a given municipality. We test this hypothesis by dividing municipalities by the median percentage foreign born in 1880 (the start of the analysis period), and do the same for the Irish-born and British-born separately. Using the beginning of the period to divide the sample obviates concerns about endogenous migration response to the interventions. In 1880, the typical British immigrant (including those of Scottish and English descent) was considerably better off than the typical Irish Catholic immigrant in Massachusetts. Compared with British immigrants, Irish male immigrants between the ages of 15 to 45 had significantly lower occupational prestige scores (31.5 versus 27.8), lower rates of literacy (93 versus 87 percent), and more children under 5 (0.4 versus .62).[41] Having information on these two immigrants groups is analytically useful since they span the spectrum of immigrant income levels and living arrangements in New England at the time.

On the one hand, municipalities with more foreigners, especially those who lived in crowded and squalid conditions, could have had the most to gain from sewage removal and clean

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[40] Cardiovascular disease has many zeros (which are missing when we use the log transformation) because it mainly represents congenital abnormalities that are not very common.

[41] These calculations were made using data from the 10 percent IPUMS U.S. Census. Occupational prestige scores are calculated by the IPUMS on the basis of the occupation and a ranking that uses data for 1950. Appendix Figure B3 shows these results.

water interventions. On the other hand, political economy considerations could have led to the omission of heavily foreign municipalities (or foreign enclaves within municipalities).[42]

Our findings, presented in Table 5, demonstrate that the combined effects of water and sewerage had a significant effect on the mortality of infants born in municipalities with a greater percentage of the Irish foreign-born population and with a greater percentage of females who were illiterate (cols. 1 and 5 versus cols. 2 and 6).[43] When we decompose the foreign population by major ethnic groups, we find that sewerage and water combined led to a 50.5 log point decline in infant mortality for municipalities with more Irish-born inhabitants.[44] These effects are nearly twice as large as those for the British (cols. 3 and 4) and suggest that the Irish—a socially and economically marginalized group in the Boston metropolitan area during this time period—gained significantly from the public health investments.[45]

4. *Composition*

Despite the evidence we have presented about the role of the clean water and sewerage interventions, a possibility exists that the interventions did not directly reduce infant mortality. Instead, the composition of the population could have changed. Higher income and more health conscious individuals could have been attracted to places that had cleaner water and a lesser stench from sewage.

To examine the hypothesis we modify eq. (1) and replace the log infant mortality rate with the percent of the population that meets a given demographic criteria. The analysis, in Table 6, should be interpreted with some caution since the number of observations is limited by the availability of the dependent variable in the quinquennial state and federal censuses. Nevertheless, the results are broadly consistent with the notion that compositional changes are not a major explanation for our findings that safe water and sewerage had beneficial impacts on IMR. The only exceptions are that there is a positive correlation between the variation in the water intervention and female illiteracy and between the sewerage intervention and Irish.

We next explore whether there were other demographic variables that responded to the mortality decline—in particular, whether changes in infant mortality led to a decline in fertility or to migration. There does not appear to have been an immediate fertility response to the interventions (Table 6, cols. 7 and 8), consistent with the fairly stable fertility rate cited by

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[42] It is still possible that foreign enclaves were not direct recipients of the intervention but benefitted from the overall reduction in the burden of communicable disease.

[43] The total effect for places that were above the median Irish is statistically significant with a coefficient of -0.466 (standard error = 0.167).

[44] The fiftieth percentile is approximately 12.5 percent.

[45] These results tie into a recent body of work demonstrating that maternal disadvantage leads to worse health at birth and the intergenerational transmission of inequality (for a recent review see Aizer and Currie, 2014).

Haines for this time period (Haines 1998b).[46] Parental expectations about child survival, and thus a fertility response, need time to adjust. In addition, there was no immediate migration reaction.

5. *Robustness*

We next test the robustness of our results to various specifications. We control for the percent of females who are illiterate since maternal education is a strong predictor of child survival today.[47] Inclusion of the variables in Table 7, col. (1) does not change the point estimates on the interaction of safe water and sewerage and the main effects. In col. (2) we add a proxy for the quality of the milk supply at the county level. Milk quality is measured imprecisely and does not reach statistical significance. Milk inspections and nurse home-visits began later in Massachusetts than the water and sewerage infrastructure improvements that are the focus here.

In Table 7, col. (3) we check that our results are not driven by functional form assumptions and are robust to including zeroes on the left hand side by substituting infant mortality as the outcome variable instead of its log. The results are similar to our preferred specification. In col. (4) we weight our regression by births. We find that our results are weakened by this weighting, suggesting that more populous municipalities in our sample did not benefit as much as less populous ones. This may be because less populous areas were growing faster and rapid growth within urban areas extenuates problems related to sanitation and water.[48] In col. (6) we use county-year fixed effects.

In Appendix Table B2, we expand the sample across space (by including Boston) and time (by including the 1870s and ending in 1920, thus including the Spanish Flu period), and drop municipalities that had slightly different water interventions (for example, Lawrence had a filter installed instead of mains from protected watershed areas). Again, the conclusions reached are similar to our preferred estimates in Table 2. We find that controlling for spillover effects by including the share of surrounding municipalities with a given infrastructure has no meaningful impact on the main results concerning the impact of pure water and sewerage for a given municipality.

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[46] Infant survival and fertility are negatively correlated in developing countries today. Haines (1998b) notes that fertility in Massachusetts "had leveled off by the 1870s whereas the infant mortality rate did not commence its decline until the 1890s. One interpretation is that further fertility declines awaited declines in the infant mortality rate, but the birth rate then remained quite stable from the 1890s until the early 1920s, at which point fertility recommenced its decline until 1960" (p. 238)

[47] Literacy is a poor predictor since the vast majority had basic literacy in some language. Education, if it were available, would be a better variable.

[48] Moreover, it is not clear why one would want to give more weight to municipalities with a larger number of births since the treatment was at the municipality level.

IV. Concluding Remarks

We find robust evidence that the pure water and sewerage treatments pioneered by far-sighted public servants and engineers in the Commonwealth saved many babies. It must also have enhanced the quality of life for the citizens of the Greater Boston area even if it did not reduce the non-child death rate by much.[49]

The infant mortality rate declined by 59.3 log points between 1880 and 1915 for the 15 fully treated municipalities in our sample.[50] We estimate that the infant mortality rate decreased by 22 log points during that period because of both treatments. Thus water and sewerage treatments can account for 37 percent of the total change in log infant mortality in the treatment cities and towns. The figure is close to the 47 percent computed from the estimation of Cutler and Miller (2005) in their study of filtration and chlorination for a somewhat later period in a sample of 13 U.S. cities.

The answer we have offered differs from that of contemporary observers in the early twentieth century and many who have contributed to the literature on the historical decline in infant mortality for the United States and Europe.[51] Yet a spate of research in economics has focused on clean water technologies and their influence on public health and typhoid mortality in particular. We build on that literature by incorporating a focus on sewerage and explicitly testing its interaction effect with clean water on age-specific and cause-specific mortality. The interpretation of our results is intuitive yet important.

Without proper disposal of fecal material, the benefits of clean water technologies for the health of children are likely limited. Such a result has relevance for today's low-and middle-income countries. The Millennium Development Goal Target 7 (to halve by 2015 the proportion of the population without sustainable access to safe drinking water and basic sanitation), will be

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[49] These benefits came at a high future environmental cost. The dumping of generally raw sewage into the Boston Harbor led it, by the 1970s, to be known as the "dirtiest harbor in America." A massive cleanup and the installation of a multi-billion dollar sewage treatment facility on Deer Island changed its designation to the cleanest Harbor in America and a "great American jewel." http://www.mwra.state.ma.us/01news/2008/bhpenvironentalsuccess/bhpenvsuccess.htm

[50] The 59.3 figure is the difference between the log (IMR) for the 15 cities (unweighted) average for the five-years from 1880 to 1884 and that for the five-years from 1911 to 1915.

[51] It is our sense that contemporary U.S. observers writing around 1915 correctly deduced that many babies were dying because of impure milk, and that their written works influenced a more recent literature. By the early twentieth century the initial decline in infant mortality we describe, that was largely due to clean water and effective sewerage systems, had already taken place. Lee (2007), for example, stresses the role of clean milk but not clean water and sanitation. Condran and Lentzner (2004) conclude that many factors were at work and Cheney (1984) puts the greatest weight on clean milk and the work of the Child Hygiene Bureau. Woods, Watterson and Woodward (1988, 1989) in their informative work on Britain mention clean water but emphasize clean milk. On the prominence of milk in the contemporary literature see the various U.S. Department of Labor, Children's Bureau reports from the 1910s and 1920s and Whipple (1917, p. 58), who discusses infant mortality causes in the 1870s.

met only for safe water, and not sanitation. One-third of the world does not use an improved sanitation facility and one billion people are estimated to habitually defecate in the open (UNICEF 2014). The problem of waste disposal will likely be compounded by rapid urbanization occurring in the developing world.

There are several important caveats to our study. First, the clean water technology we investigate was primitive. It consisted of protecting watersheds rather than employing the more modern technology of chlorination. Thus, the water lacked the persistent microbicidal effect characteristic of water treated with chlorine. The evidence suggests that the piped water that did reach the consumer (as tested by the Board of Health) was relatively high quality (*JAMA* 1903; Sprague 1900). Yet, without effective sewerage—through a variety of channels—water can be re-contaminated as can food, allowing fecal-oral transmission of pathogens to occur (UN Water 2008).[52]

Second, we are using as our treatment of interest when the main water and sewerage lines were completed for a given municipality rather than when particular homes and areas were linked to the system. The strategy is preferred because it circumvents endogeneity arising from groups having privileged access to sewerage/water infrastructure within a municipality. Third, there are important unanswered questions about the role of other factors, such as the purification of the milk supply, increased street cleaning, baby health stations and nurse home visits, on infant mortality.[53] For the most part, these changes occurred later in the Progressive Era and were more gradual than the water and sewerage interventions we explore.

We have identified that safe water *and* sewerage interventions were responsible for much of the first decrease in infant mortality in the U.S. Other factors led to further declines in infant deaths in the early twentieth century and, closer to the present, the use of neonatal intensive care units has saved many premature babies.[54] Yet saving infants who are just beyond the neonatal period and young toddlers is still a pressing issue in developing countries.

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[52] The aptly named "F-diagram" of fecal-oral disease transmission and control (after Wagner and Lanoix 1958) demonstrates how feces can lead to disease transmission through the "5 F's" fingers, fluids (water supply), flies, fields/floor and food (occasionally flooding is included). The idea is that even if one has clean water, without removing feces—it can seep to the surface (after flooding), contaminate crops, and be transmitted to food/water via flies and/or lack of hand washing—water can be re-contaminated.

[53] See also Phelps (1910). In the modern literature see Cheney (1984) and Condran and Lentzner (2004), who conclude that there are many factors that could have led to the decrease in IMR but that "no single one of them is sufficient to understand either the poor life chances of infants in nineteenth-century cities or the improvements in those chances that were in evidence by the last quarter of the century" (p. 352).

[54] The funding of public health interventions in the 1920s has been identified as a factor reducing IMR. Moehling and Thomasson (2012) show that in the 1922 to 1929 period better public health, caused by the Sheppard-Towner Act matching grants to states, can account for 9 to 21 percent of the decrease in infant mortality.

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Table 1: Baseline Sample Municipality Characteristics in 1880, by Treatment Group

		Relative to No Intervention					
Characteristic	All	Safe Water Only	Sewerage Only	Both Interventions	Difference (2 – 3)	Difference (2 – 4)	Difference (3 – 4)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Percent Foreign Born	27.58	0.87	0.28	-2.15	0.60	3.02	2.43
	[7.75]	(5.65)	(2.89)	(2.53)	(5.47)	(5.29)	(2.10)
Percent Male	48.11	-0.76	-1.50	0.47	0.74	-1.23	-1.97
	[2.79]	(1.25)	(1.20)	(0.64)	(1.63)	(1.28)	(1.23)
Percent Working Age	43.92	2.06*	-0.47	0.76	2.53**	1.31	-1.23
	[2.31]	(1.11)	(0.88)	(0.74)	(1.15)	(1.05)	(0.79)
Log Population Density	0.61	0.67	0.38	0.49	0.29	0.17	-0.12
	[1.14]	(0.53)	(0.36)	(0.38)	(0.55)	(0.56)	(0.39)
Percent Female in Mfg.	9.20	-1.15	-5.46**	-8.13***	4.31	6.98	2.67*
	[6.60]	(5.12)	(2.18)	(2.04)	(4.96)	(4.90)	(1.58)
Log Infant Mortality Rate	4.88	-0.46	-0.16	-0.04	-0.30	-0.42	-0.11
	[0.43]	(0.29)	(0.12)	(0.11)	(0.28)	(0.28)	(0.10)

Notes: Col. (1) reports average values for 54 municipalities with standard deviation in brackets. Cols. (2) and (3) report coefficients from a single regression of the indicated characteristic in the leftmost column on an indicator variable for eventual participation in sewerage, safe water or both interventions simultaneously. Note this categorization of the treatment is different from the regression analysis because the regression exploits variation across space and time, whereas this table gives the ex post treatment. Standard deviations are in brackets. Robust standard errors are in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Table 2: The Effect of Safe Water and Sanitation on the (log) Infant Mortality Rate

	(1) Log (IMR)	(2) Log (IMR)	(3) Log (IMR)	(4) Log (IMR)	(5) Log (IMR)
Safe Water	-0.124		-0.114		0.038
	(0.078)		(0.078)		(0.064)
Sewerage		-0.072	-0.057		-0.027
		(0.051)	(0.050)		(0.052)
Interaction of Safe Water and Sewerage				-0.207**	-0.231**
				(0.093)	(0.101)
Observations	1,873	1,873	1,873	1,873	1,873
R-squared	0.521	0.520	0.521	0.523	0.523
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes
Demographics	Yes	Yes	Yes	Yes	Yes
Municipality-Linear Trends	Yes	Yes	Yes	Yes	Yes
Number of Clusters	54	54	54	54	54
Safe Water + Sewerage + Interaction					-0.220**
Sum Standard Errors					(0.105)

Notes: OLS estimates of eq. (1). The sample is unbalanced spanning the years 1880 to 1915 and includes the 54 sample municipalities. The dependent variable is log of Infant Mortality Rate per 1000 births where the infant death counts are based on data from FamilySearch.org. Safe water is an indicator variable equal to one during the year in which municipal water or a water filter (in the case of Lawrence) was introduced. Sewerage is an indicator variable that equals one in the year a municipality was connected to the metropolitan sewerage district. The interaction represents an indicator variable that equals one in the first year both interventions are provided to a municipality simultaneously. Demographic controls include percent of the city population that is foreign-born, percent male, percent females in manufacturing and log population density. Standard errors are clustered at the municipality level.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3: The Effect of Safe Water and Sanitation on Infant Mortality (Treated Only)

	(1) Log (IMR)	(2) Log (IMR)	(3) Log (IMR)	(4) Log (IMR)	(5) Log (IMR)
Safe Water	-0.107		-0.101		0.042
	(0.073)		(0.074)		(0.067)
Sewerage		-0.089	-0.082		-0.047
		(0.060)	(0.059)		(0.065)
Interaction of Safe Water and				-0.199**	-0.220**
Sewerage				(0.087)	(0.104)
Observations	1,074	1,074	1,074	1,074	1,074
R-squared	0.517	0.517	0.518	0.520	0.520
Year FE	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes
Demographics	Yes	Yes	Yes	Yes	Yes
Municipality-Linear Trends	Yes	Yes	Yes	Yes	Yes
Number of Clusters	31	31	31	31	31
Safe Water + Sewerage +					
Interaction					-0.225**
Sum Standard Errors					(0.109)

Notes: OLS estimates of eq. (1). The sample is unbalanced spanning the years 1880 to 1915 and includes the 31 treated municipalities. The dependent variable is log of Infant Mortality Rate per 1000 births where the infant death counts are based on data from FamilySearch.org. Safe water is an indicator variable equal to one during the year in which municipal water or a water filter (in the case of Lawrence) was introduced. Sewerage is an indicator variable that equals one in the year a municipality was connected to the metropolitan sewerage district. The interaction represents an indicator variable that equals one in the first year both interventions are provided to a municipality simultaneously. Demographic controls include percent of the city population that is foreign-born, percent male, percent females in manufacturing and log population density. Standard errors are clustered at the municipality level.

*** p<0.01, ** p<0.05, * p<0.1

Table 4: Different Ages and Causes of Death

	Age-Specific Mortality Rates			Cause-Specific Mortality Rates				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Log (IMR)	Log (CMR)	Log (NCMR)	Log (GI)	Log (PNA)	Log (OV)	Log (PREM)	Log (CV)
Safe Water	0.038	0.162	-0.002	0.138	-0.014	0.071	-0.005	-0.015
	(0.064)	(0.098)	(0.023)	(0.098)	(0.085)	(0.100)	(0.092)	(0.114)
Sewerage	-0.027	0.068	0.007	0.051	0.141	0.100	-0.084	0.151
	(0.052)	(0.085)	(0.028)	(0.084)	(0.126)	(0.141)	(0.112)	(0.116)
Interaction of Safe Water and Sewerage	-0.231**	-0.403***	-0.011	-0.309**	-0.177	-0.387**	-0.016	-0.079
	(0.101)	(0.136)	(0.040)	(0.132)	(0.139)	(0.147)	(0.154)	(0.176)
Observations	1,873	1,771	1,803	1,805	1,583	1,121	1,566	882
R-squared	0.523	0.514	0.531	0.623	0.440	0.583	0.409	0.787
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality-Linear Trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Clusters	54	53	53	54	54	53	53	52
Safe Water + Sewerage + Interaction	-0.220**	-0.173	-0.005	-0.120	-0.051	-0.216	-0.106	0.058
Sum Standard Errors	(0.105)	(0.122)	(0.055)	(0.109)	(0.133)	(0.172)	(0.123)	(0.184)

Notes: OLS estimates of eq. (1). The sample is unbalanced spanning the years 1880 to 1915 and includes the 54 sample municipalities. The dependent variables for the first three columns are age-specific mortality rates: col. (1) Log (IMR) = log infant mortality rate; col. (2) Log (CMR) = log child mortality rate, that is for individuals one year to less than five years old; and col. (3) Log (NCMR) = the log non-child mortality rate, that is for individuals older than four years. The dependent variables for the last five columns are cause-specific mortality rates: col. (4) Log (GI) = log mortality rate from diarrhea and associated diseases; col. (5) Log (PNA) = log pneumonia mortality rate; col. (6) Log (OV) = log mortality rate from other vaccine preventable diseases; col. (7) Log (PREM) = log mortality rate from prematurity; and col. (8) Log (CV) = log mortality rate from cardiovascular disease. For precise definitions and data sources see the Appendix. Safe water is an indicator variable equal to one during the year in which municipal water or a water filter (in the case of Lawrence) was introduced. Sewerage is an indicator variable that equals one in the year a municipality was connected to the metropolitan sewerage district. The interaction represents an indicator variable that equals one in the first year both interventions are provided to a municipality simultaneously. Demographic controls include percent of the city population that is foreign-born, percent male, percent females in manufacturing and log population density. Year and municipality fixed effects are included in every specification. Standard errors are clustered at the municipality level.

*** p<0.01, ** p<0.05, * p<0.1

Table 5: Heterogeneous Effects

	Irish ≥ 50th Percentile	Irish < 50th Percentile	British ≥ 50th Percentile	British < 50th Percentile	Female Illiterate ≥ 50th Percentile	Female Illiterate < 50th Percentile
	(1) Log (IMR)	(2) Log (IMR)	(3) Log (IMR)	(4) Log (IMR)	(5) Log (IMR)	(6) Log (IMR)
Safe Water	0.117	0.055	-0.031	0.164***	0.013	0.065
	(0.076)	(0.081)	(0.078)	(0.049)	(0.085)	(0.103)
Sewerage	-0.079	0.044	-0.029	-0.015	-0.077	0.004
	(0.077)	(0.066)	(0.070)	(0.080)	(0.082)	(0.068)
Interaction of Safe Water and	-0.505**	-0.142	-0.224	-0.296**	-0.323*	-0.150
Sewerage	(0.190)	(0.092)	(0.146)	(0.121)	(0.165)	(0.130)
Observations	945	928	943	930	945	928
R-squared	0.587	0.473	0.541	0.507	0.588	0.456
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes
Demographics	Yes	Yes	Yes	Yes	Yes	Yes
Municipality Linear Trends	Yes	Yes	Yes	Yes	Yes	Yes
Number of Clusters	28	26	28	26	28	26
Safe Water + Sewerage + Interaction	-0.466***	-0.043	-0.284*	-0.146	-0.386**	-0.080
Sum Standard Errors	(0.167)	(0.104)	(0.143)	(0.147)	(0.162)	(0.107)

Notes: OLS estimates of eq. (1). The sample is unbalanced spanning the years 1880 to 1915 and includes the 54 sample municipalities. The dependent variable is log of Infant Mortality Rate per 1000 births where the infant death counts are based on data from FamilySearch.org. Safe water is an indicator variable equal to one during the year in which municipal water or a water filter (in the case of Lawrence) was introduced. Sewerage is an indicator variable that equals one in the year a municipality was connected to the metropolitan sewerage district. The interaction represents an indicator variable that equals one in the first year both interventions are provided to a municipality simultaneously. Demographic controls include percent of the city population that is foreign-born, percent male, percent females in manufacturing and log population density. The sample is described at the top of the column heading, with Irish>50th percentile, denoting municipalities in the top 50th percentile of percent Irish-born population at the beginning of the analysis period. Other columns are defined similarly. Standard errors are clustered at the municipality level.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 6: The Effect of Safe Water and Sanitation on the Composition and Demographic Features of Municipalities

	(1) Percent Male	(2) Female in Mfg.	(3) Female Illiterate	(4) British	(5) Irish	(6) Log (Total Pop.)	(7) Log (Native Births)	(8) Log (Foreign Births)
Safe Water	-0.650	0.184	0.299*	-0.140	0.032	0.052	0.032	0.008
	(0.813)	(0.413)	(0.164)	(0.167)	(0.248)	(0.041)	(0.071)	(0.038)
Sewerage	-0.462	0.036	-0.124	-0.019	0.139**	-0.028	0.029	0.011
	(0.723)	(0.165)	(0.196)	(0.040)	(0.062)	(0.025)	(0.028)	(0.045)
Interaction of Safe Water	-0.003	-0.457	0.219	0.217	0.018	-0.043	-0.036	-0.024
and Sewerage	(0.938)	(0.491)	(0.352)	(0.181)	(0.270)	(0.045)	(0.074)	(0.057)
Log Total Population							0.584***	0.848***
							(0.108)	(0.137)
Observations	432	432	425	424	420	428	1,920	1,921
R-squared	0.771	0.993	0.966	0.995	0.995	0.996	0.980	0.987
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Demographics	No	No	No	No	No	No	No	No
Municipality Linear Trends	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Clusters	54	54	54	53	53	54	54	54

Notes: OLS estimates of eq. (1). The sample is unbalanced spanning the years 1880 to 1915 and includes the 54 sample municipalities. Each column is a separate regression with a different outcome variable. The outcome variables listed under the column numbers are derived from the State and Federal Censuses as described in Appendix A. Safe water is an indicator variable equal to one during the year in which municipal water or a water filter (in the case of Lawrence) was introduced. Sewerage is an indicator variable that equals one in the year a municipality was connected to the metropolitan sewerage district. The interaction represents an indicator variable that equals one in the first year both interventions are provided to a municipality simultaneously. The last two columns include log population as an additional control variable. Standard errors are clustered at the municipality level.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

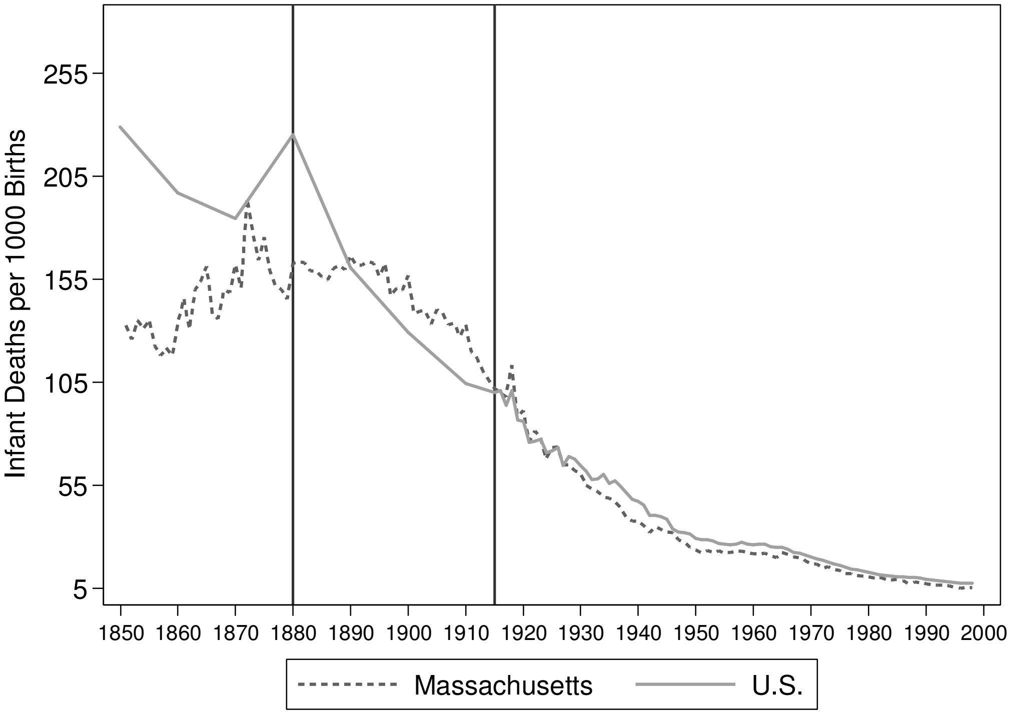
Table 7: Robustness Checks

	(1) Controls for Female Illiteracy	(2) Controls for Milk Supply Quality	(3) Level of Infant Mortality as Outcome	(4) Weight by Births	(5) Sample of Municipalities w/35+ years IMR data	(6) County-Year FE
Safe Water	0.038	0.038	13.997	0.032*	0.006	0.025
	(0.064)	(0.065)	(10.399)	(0.017)	(0.060)	(0.093)
Sewerage	-0.026	-0.027	-6.785	0.036	-0.018	-0.023
	(0.052)	(0.051)	(8.072)	(0.049)	(0.053)	(0.065)
Interaction of Safe Water and	-0.232**	-0.231**	-30.363**	-0.102	-0.204**	-0.147
Sewerage	(0.101)	(0.101)	(13.262)	(0.100)	(0.097)	(0.107)
Percent females illiterate	0.010					
	(0.018)					
Percent dairy milk high quality		-0.0003				
		(0.169)				
Observations	1,858	1,873	1,876	1,873	1,792	1,873
R-squared	0.535	0.523	0.493	0.716	0.540	0.452
Year FE	Yes	Yes	Yes	Yes	Yes	No
Municipality FE	Yes	Yes	Yes	Yes	Yes	No
Demographics	Yes	Yes	Yes	Yes	Yes	Yes
Municipality-Linear Trends	Yes	Yes	Yes	Yes	Yes	No
Number of Clusters	54	54	54	54	50	54

Notes: OLS estimates of eq. (1). Each column represents a separate regression. The sample specification, and sometimes outcome variable, varies across columns. Col. (1) adds the percent of females illiterate as an additional control; col. (2) adds the percent of dairy milk at the county level that is high quality (see Appendix A); col. (3) replaces the (log) Infant Mortality Rate with the level of infant mortality as the outcome variable; col. (4) weights the regression by total births in the municipality; col. (5) is a panel sample of 50 municipalities with at least 35 years of IMR data; col. (6) adds county-state fixed effects (and drops municipality linear trends, municipality fixed effects and year fixed effects). Safe water represents an indicator variable equal to one during the year in which municipal water or a water filter (in the case of Lawrence) was introduced. Sewerage is an indicator variable that equals one in the year a municipality was connected to the metropolitan sewerage district. The interaction represents an indicator variable that equals one in the first year both interventions are provided to a municipality simultaneously. Year and Municipality fixed effects are included in every specification as are demographic variables (percent of the city population that is foreign-born, percent male, percent females in manufacturing and log population density). Standard errors are clustered at the municipality level.

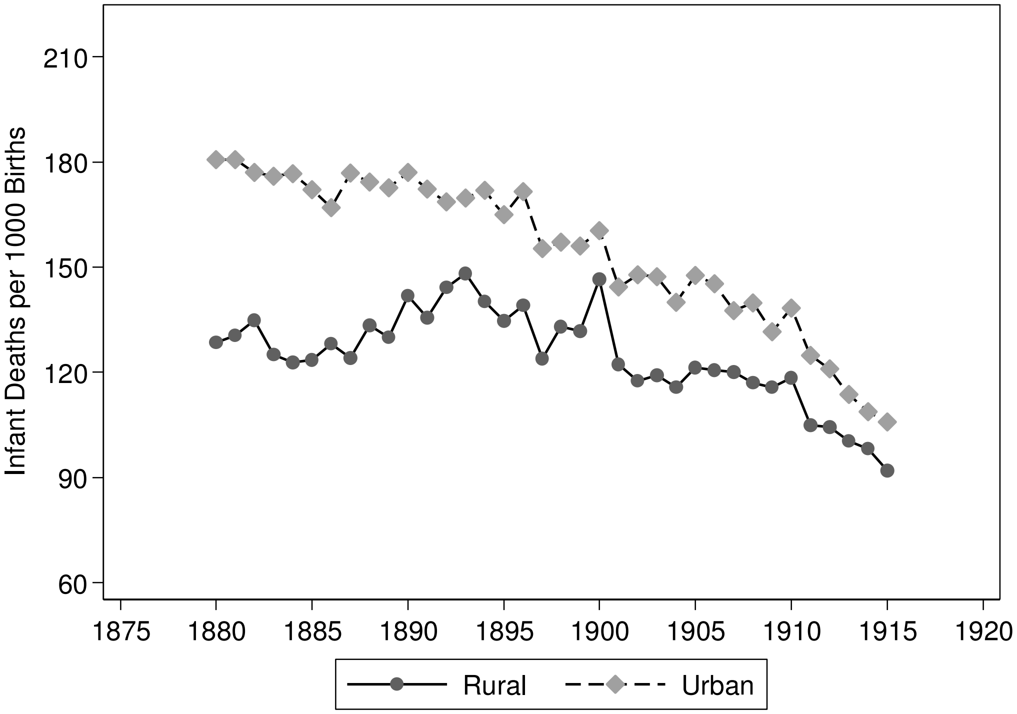
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Figure 1: Infant Mortality in the United States and Massachusetts: 1850 to 1998



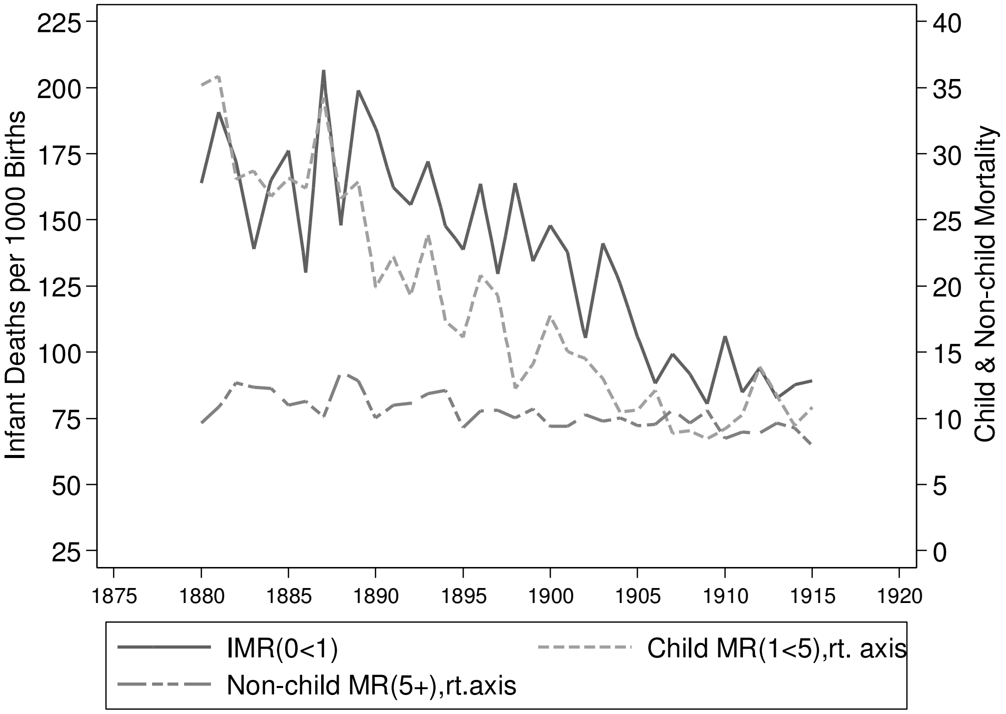
Notes: The U.S. aggregate series for 1850 to 1910 was estimated and, for those years, is probably less accurate than the Massachusetts series, which is at an annual frequency and from actual vital statistics data. See Haines (1998a) and *Historical Statistics* (2006, 1-461). The lines drawn give the boundaries of the period we examine.

Figure 2: Urban and Rural Infant Mortality Rates: Massachusetts, 1880 to 1915



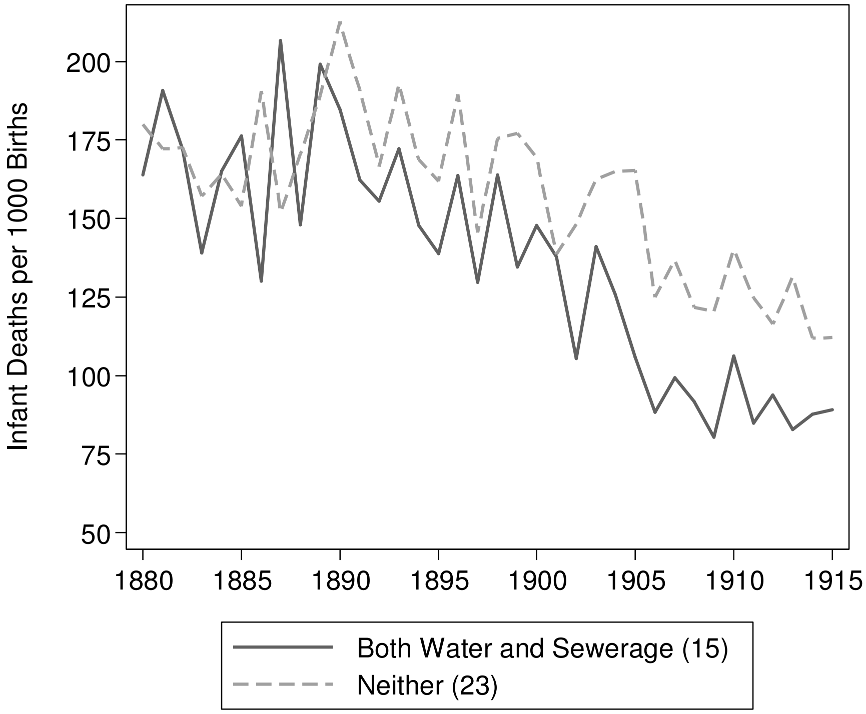
Sources and Notes: See Data Appendix. Urban is defined as the 32 largest municipalities in Massachusetts in the Registration Report of 1898. Rural is defined as all other populations in each of the counties. The minimum urban population in 1880 is 4,159 and is 15,250 in 1915. The data are from the Annual Registration Reports and mortality rates are aggregates within the urban and rural designations.

Figure 3: Infant, Child and Non-Child Mortality Trends among Massachusetts Towns: 1880 to 1915



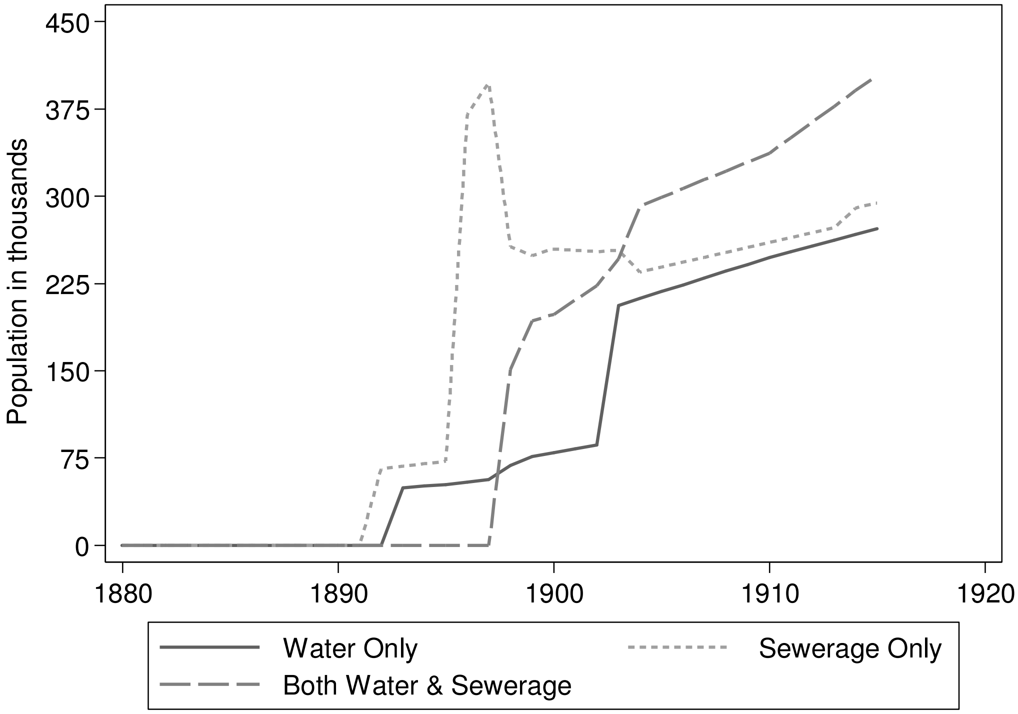
Sources and Notes: The child and non-child mortality rates are graphed on the right axis; the infant mortality rate is graphed on the left axis. The plotted mortality rates are averages across municipalities.

Figure 4: IMR in Analysis Sample by Treatment



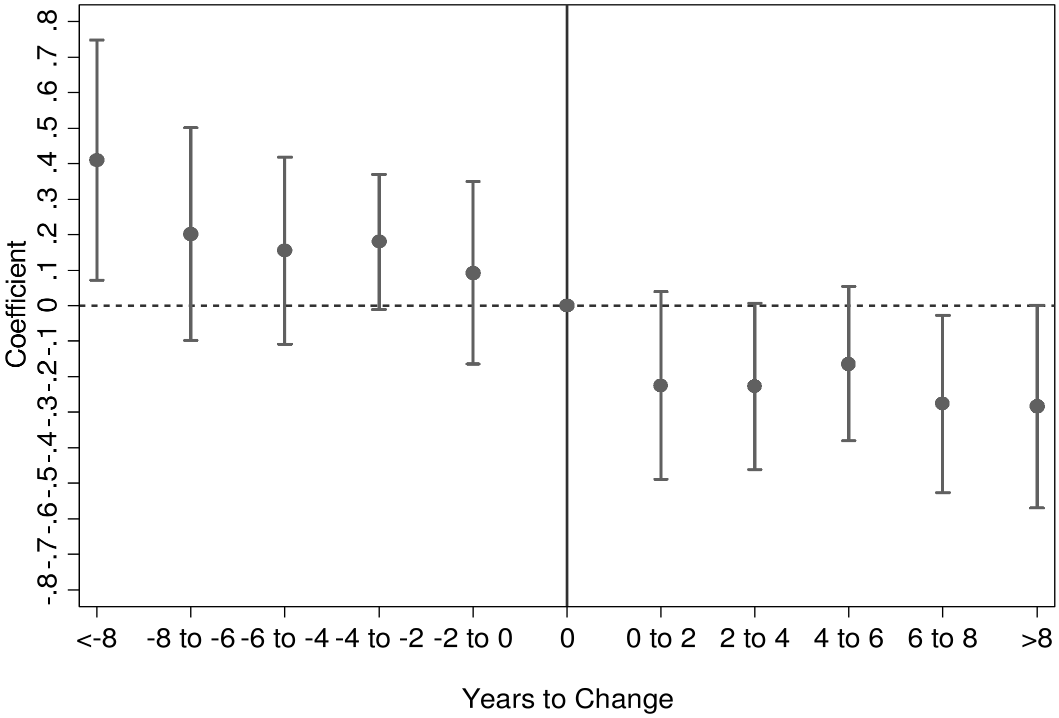
Sources and Notes: Of the 54 sample cities and towns (see text), 15 received both water and sewerage treatments ("Both Water and Sewerage"), 23 received neither treatment ("Neither"). The plotted mortality rates are averages across municipalities.

Figure 5: Total Population Affected by the Sewerage and Water Interventions, 1880 to 1915



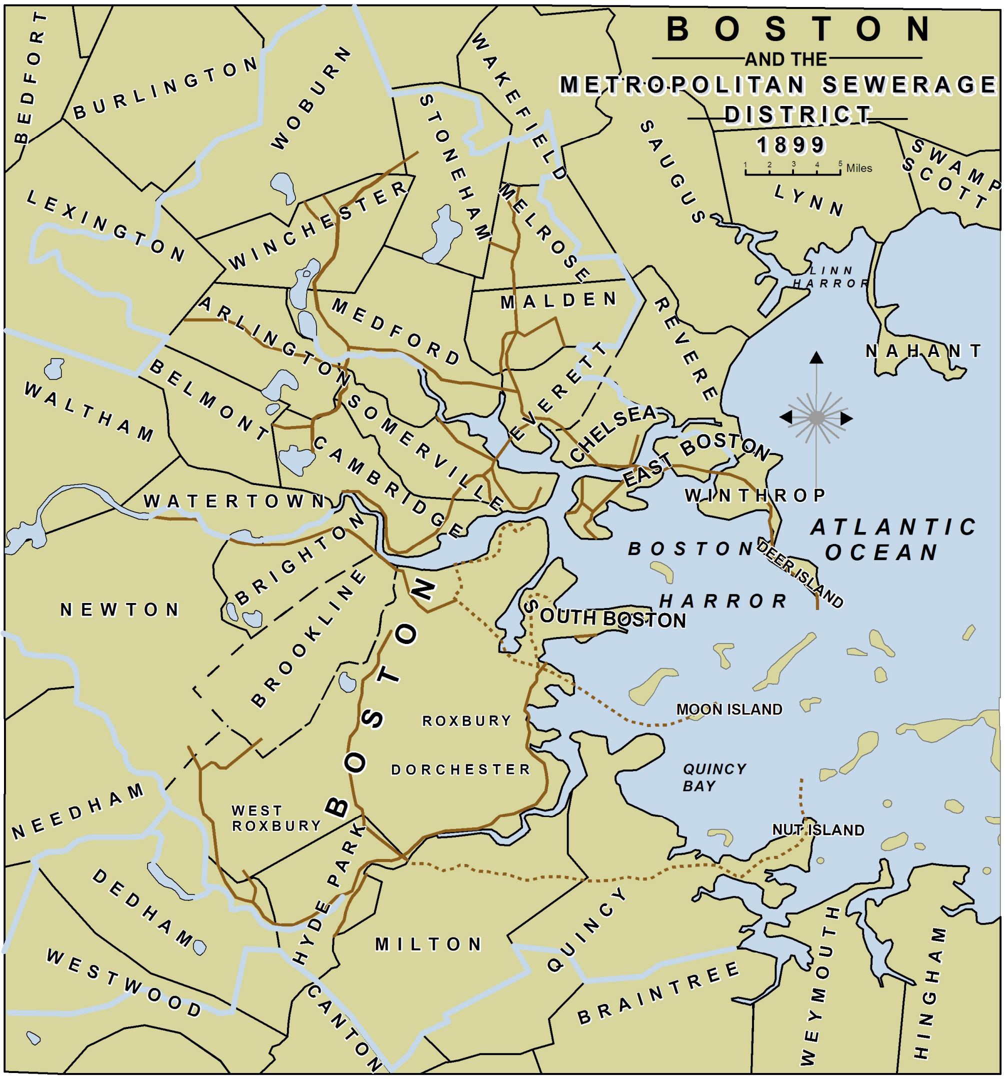
Notes: Municipalities are characterized by their contemporaneous interventions. Total population is summed in each category for each year.

Figure 6: Impact on (Log) IMR of Time Before and After Both Safe Water and Sewerage



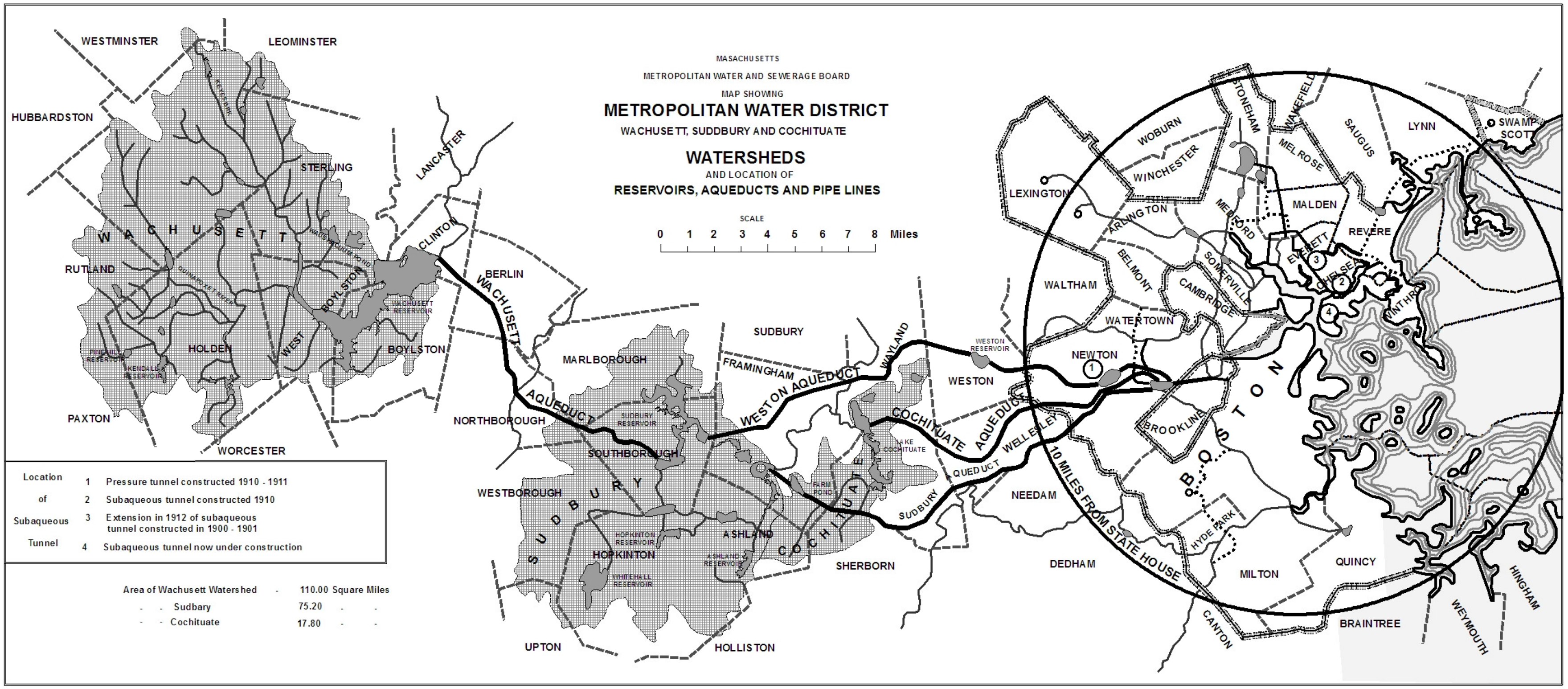
Notes: Computed values of γ_k from eq. (2) are graphed for the 15 cities and towns, among those in the 54 city and town sample, that received both water and sewerage treatments in the 1880 to 1915 period. The line at 0 gives the moment of both water and sewerage treatments by town.

Map 1: Metropolitan Sewerage District (circa 1899)

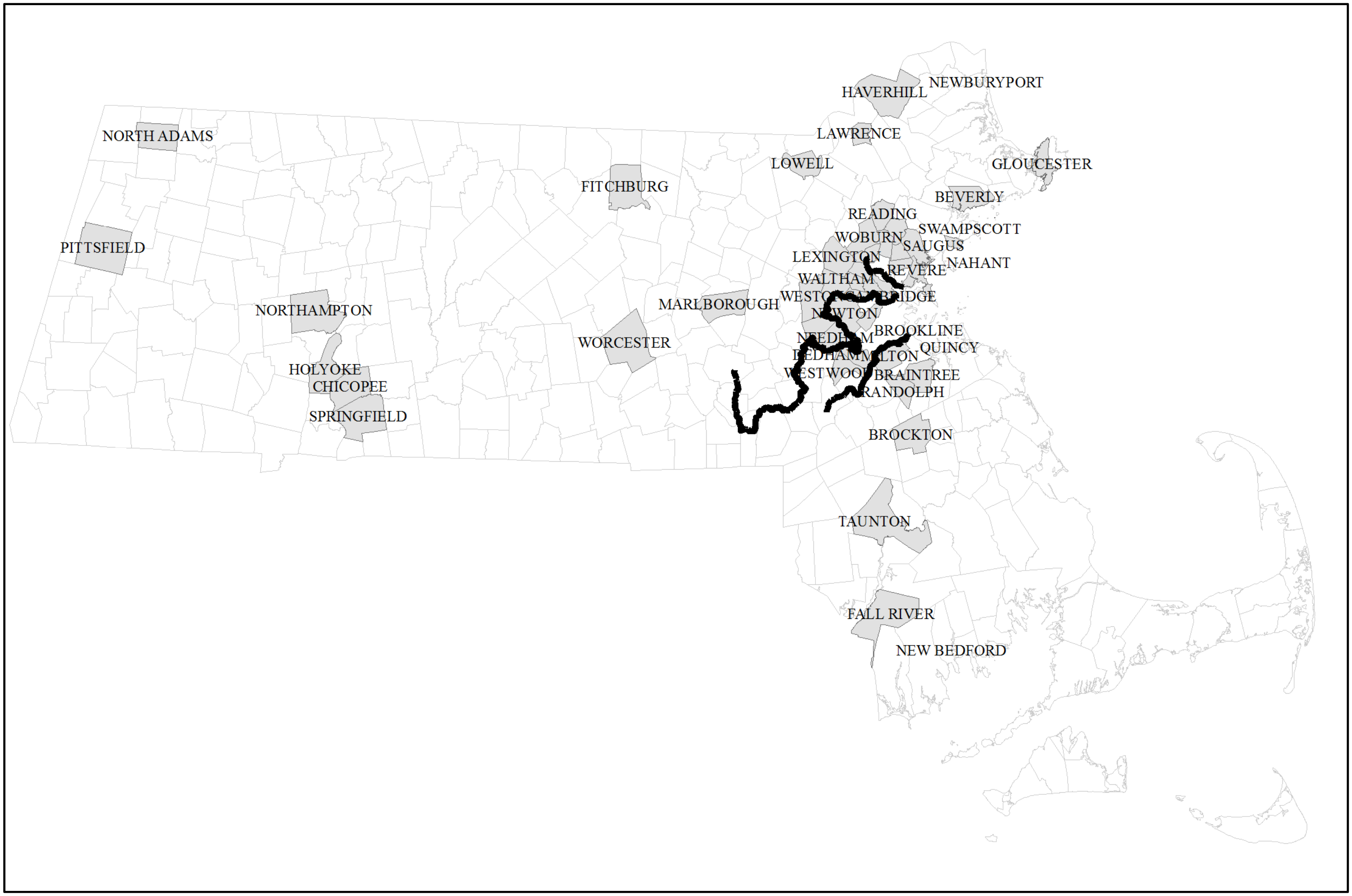


Source: Metropolitan Sewerage Commissioners of Boston, MA (1899).

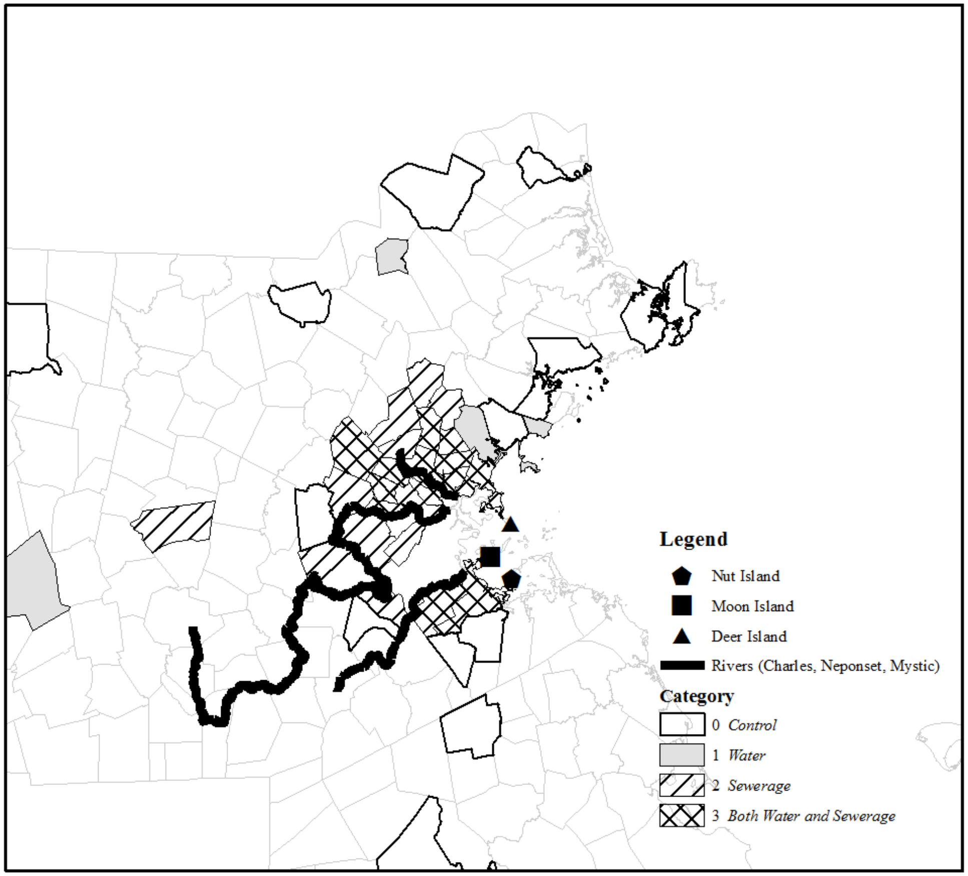
Map 2: Metropolitan Water District (circa 1910)



Map 3: Analysis Sample of 54 Cities and Towns (dark lines are major rivers)



Map 4: Safe Water and Sewerage Treatments in the Boston Metropolitan Area



Appendix A: Data Sources and Dates of Interventions

Data Sources

A. *Vital Statistics*

Information on births, total deaths and deaths under one year of age (infant deaths) are from Secretary of the Commonwealth of Massachusetts, *Annual Massachusetts Registration Reports on Births, Marriages, and Deaths*. Total deaths and total births are available annually for each municipality from 1870 to 1920. From 1870 to 1891, data on infant deaths are available for each municipality but starting in 1891 and continuing through 1897, the *Registration Reports* give infant deaths by county but not municipality. From 1897 to 1920 infant deaths are available for counties and only larger municipalities. For this reason, we obtained data on infant deaths from the original death registry, put into a searchable form by FamilySearch.org. The data were collected using an algorithm described in Appendix C. We also extracted cause, exact age (to the day) and sex of infant that died as well as their parentage.

B. *Demographic Variables*

From the *Massachusetts State and Federal Census*: 1875, 1880, 1885, 1890, 1895, 1900, 1905, 1910, 1915, and 1920.

C. *Water*

The dates are mainly taken from the Appendix number 1 of the 1909 *Metropolitan Water and Sewerage Board Report*.

D. *Sewerage*

Similar to the water district, a Metropolitan Sewerage system was constructed to remove effluent from municipalities into various outfall locations, described further in the text. The dates for the completion of the sewerage system are mainly taken from two texts: *The Main Drainage Works of Boston and its Metropolitan Sewerage District 1899* and *Metropolitan Water Board. Legislation 1895-1900. Metropolitan Sewerage Board. Legislation 1889-1900. Metropolitan Water and Sewerage Board. Legislation 1901-1914*.

E. *Service Pipe Material*

Baker, Moses Nelson. *The Manual of American Water-works* (1897).

F. *Dairy Quality*

Annual State Board of Health Reports (1905-1914) and *City of Boston Board of Health Reports* for 1905 to 1907 and 1909 to 1916.

Variable Definitions

Total Registered Births. Number of live births per municipality as recorded in the *Annual Massachusetts Registration Reports on Births, Marriages, and Deaths*; available at the state, county and municipality level 1870 to 1920.

Total Deaths. Number of deaths as recorded in the *Annual Massachusetts Registration Reports on Births, Marriages, and Deaths*; available at the state, county and municipality level 1870 to 1920.

Total Infant Deaths. Infant death counts at the municipality level are compiled from FamilySearch.org and include all children less than one year of age.

Infant Mortality Rate (IMR). Deaths of individuals less than one year of age in a calendar year per 1,000 registered births in that year. Both the numerator and denominator include stillbirths in the main specification.

Child Mortality Rate (CMR): Deaths of those at least one year to four years of age in a calendar year per 1,000 population one-to-four in the same calendar year. Data for the numerator was obtained via the FamilySearch website with a search algorithm similar to that described in Appendix C except modified to include deaths among those one- to four years of age. The denominator (population of those one- to four-years of age) for each municipality-year was calculated as the difference between lagged total births minus lagged infant deaths:

$$Pop_{1to4,k} = \sum_{k=-1}^{k=-4} (Births_k - Infant\ Deaths_k)$$

Non-Child Mortality Rate Non-infant mortality is calculated as total deaths in the population minus deaths of those under five years old divided by the non-child population. The non-child population is calculated as the total population minus contemporaneous infant births net of deaths and the one- to four-year old population as calculated above.

Log Total Births: Log of total registered births including stillbirths, subgroups by parentage.

Cause-specific mortality: Cause-specific mortality was calculated as deaths of infants from specific causes divided by total births multiplied by 100,000. For diarrhea related deaths we included cause of death from enteritis, colitis, cholera, summer fever, and other various gastrointestinal complaints. Vaccine preventable diseases included diphtheria, measles, pertussis/whooping cough, tetanus, croup and tetanus. Prematurity included death from prematurity, immaturity, debility/exhaustion, cyanosis and atrophy within one day of age. Cardiovascular disease included heart failure/trouble, diseases of the heart, and valvular disease.

Water. Indicator variable that takes a value of 1 in the year a municipality was supplied with water from the Metropolitan Water District of Boston or, if Lawrence MA, installed a filter.

Sewerage. Indicator variable that takes a value of 1 in the year the municipality was linked to the Metropolitan Sewer District of Boston, or, if Marlborough, had a sewerage system built by the Commonwealth for it.

Dairy Quality. The proportion of dairies in the county (except Suffolk) that do not contain "objectionable features". The number for Suffolk County is reported as the proportion of milk sold at stores with bacterial counts < 500,000 bacteria per cubic centimeter. The years prior to 1905 are assigned the 1905 percentage and the years after 1916 are assigned the 1916 proportion.

Demographic and Economic Data. Percentage Female, Foreign-Born, Working Age (18 to 44), Share of Females Working in Manufacturing, Share of Females Illiterate, Percentage Irish, Percentage British. Linearly interpolated between censuses.

Log Population Density. Population per square acre.

Appendix A

Table A1: Analysis Sample of 54 Municipalities and Dates of Water and Sewerage Interventions

Municipality	Sewerage	Water	Municipality	Sewerage	Water
Arlington	1896	1899	New Bedford		
Belmont	1896	1898	Newburyport		
Beverly			Newton	1892	
Braintree			North Adams		
Brockton			Northampton		
Brookline	1892		Pittsfield		
Cambridge	1896		Quincy	1899	1899
Chelsea	1896	1898	Randolph		
Chicopee			Reading	1914	
Dedham	1897*		Revere	1903	1898
Everett	1896	1898	Salem		
Fall River			Saugus		1903
Fitchburg			Somerville	1896	1898
Gloucester			Springfield		
Haverhill			Stoneham	1896	1901
Holyoke			Swampscott		1899
Lawrence		1893	Taunton		
Lexington	1897*	1903	Wakefield	1896*	
Lowell			Waltham	1892	
Lynn			Watertown	1892	1898
Malden	1896	1904	Wellesley	1914	
Marlborough	1904		Weston		
Medford	1896	1898	Westwood		
Melrose	1896	1898	Winchester	1896	
Milton	1897	1902	Winthrop	1896	1899
Nahant		1899	Woburn	1896	
Needham			Worcester		1903

Sources: Massachusetts State Board of Health (1880 to 1915), Metropolitan Sewerage Commissioners (1899) and Commonwealth of Massachusetts (1914).

* Only part of the town.

Appendix B: Additional Tables and Figures

Table B1: Cox Hazard Model of Time to Receive Interventions

	(1) Water	(2) Sewerage
Geographic Features		
Distance to Wachusetts Reservoir	0.983	
	[0.525]	
Within Metropolitan Water District (=1)	5.123**	
	[0.028]	
Adjacent to Boston (=1)		3.792***
		[0.006]
Elevation (meters)	0.992	0.995
	[0.561]	[0.348]
Pretreatment Demographics		
Log Population Density	1.272	1.288
	[0.331]	[0.207]
Percent Male	1.172	1.000
	[0.190]	[0.997]
Percent Foreign	0.968	0.969
	[0.465]	[0.296]
Observations	54	54

Sample includes all municipalities. Within Metropolitan Water District is a binary variable =1 if the municipality is within 10.5 miles of the State House. Adjacent to Boston =1 if municipality borders Boston. Pretreatment characteristics are from the 1880 census. Hazard ratios are reported with p-values in brackets. The period covered is 1880 to 1915.
*** p<0.01, ** p<0.05, * p<0.1

Appendix Table B2: Additional Robustness Checks

	(1) Externalities	(2) 1870-1920	(3) 1880-1915, Include Boston	(4) Drop Lawrence Marlborough Worcester and Malden
Safe Water	0.038	0.102*	0.042	0.062
	(0.075)	(0.055)	(0.067)	(0.102)
Sewerage	-0.100	-0.044	-0.040	-0.031
	(0.073)	(0.045)	(0.050)	(0.059)
Interaction of Safe Water and	-0.273**	-0.273***	-0.224**	-0.230*
Sewerage	(0.118)	(0.093)	(0.101)	(0.123)
Share Neighbors Water	0.424			
	(0.280)			
Share Neighbors Sewerage	0.155			
	(0.117)			
Share Neighbors Both	-0.388			
	(0.278)			
Observations	1,873	2,593	1,909	1,731
R-squared	0.518	0.474	0.517	0.519
Year FE	Yes	Yes	Yes	Yes
Municipality FE	Yes	Yes	Yes	Yes
Demographics	Yes	Yes	Yes	Yes
Municipality-Linear Trends	Yes	Yes	Yes	Yes
Number of Clusters	54	54	55	50

Notes: OLS estimates of eq. (1). Each column represents a separate regression. The sample specification, and sometimes outcome variable, varies across columns. Col. (1) controls for share neighbors with a given infrastructure intervention; col. (2) expands the sample to include the years 1870-1920; col. (3) also includes the city of Boston; col. (4) drops four municipalities that had somewhat special circumstances surrounding the safe water or sewerage intervention (see text for details). Safe water represents an indicator variable equal to one during the year in which municipal water or a water filter (in the case of Lawrence) was introduced. Sewerage is an indicator variable that equals one in the year a municipality was connected to the metropolitan sewerage district. The interaction represents an indicator variable that equals one in the first year both interventions are provided to a municipality simultaneously. Year and Municipality fixed effects are included in every specification as are demographic variables (percent of the city population that is foreign-born, percent male, percent females in manufacturing and log population density). Standard errors are clustered at the municipality level.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Figure B1. Cause of Infant Deaths by Categories (1880-1915)

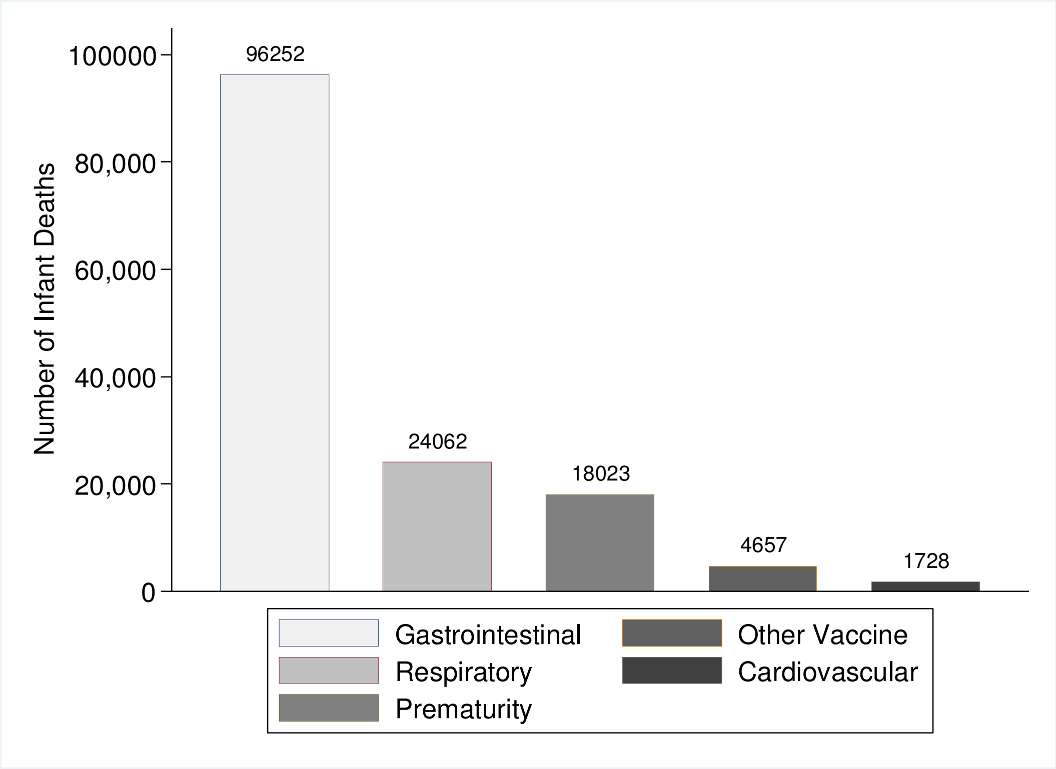


Figure B2: Log of GI-related infant deaths by Intervention

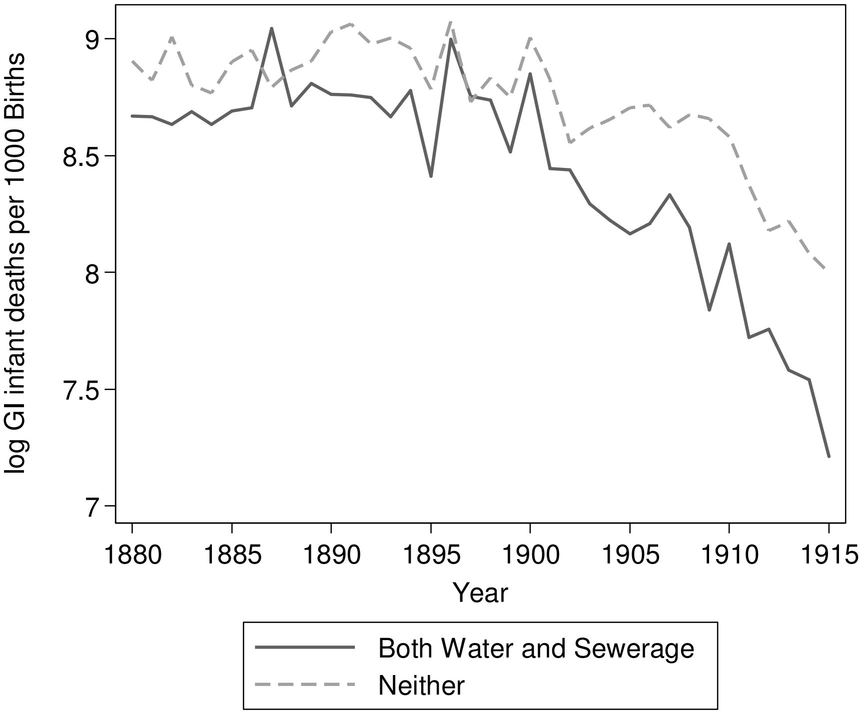
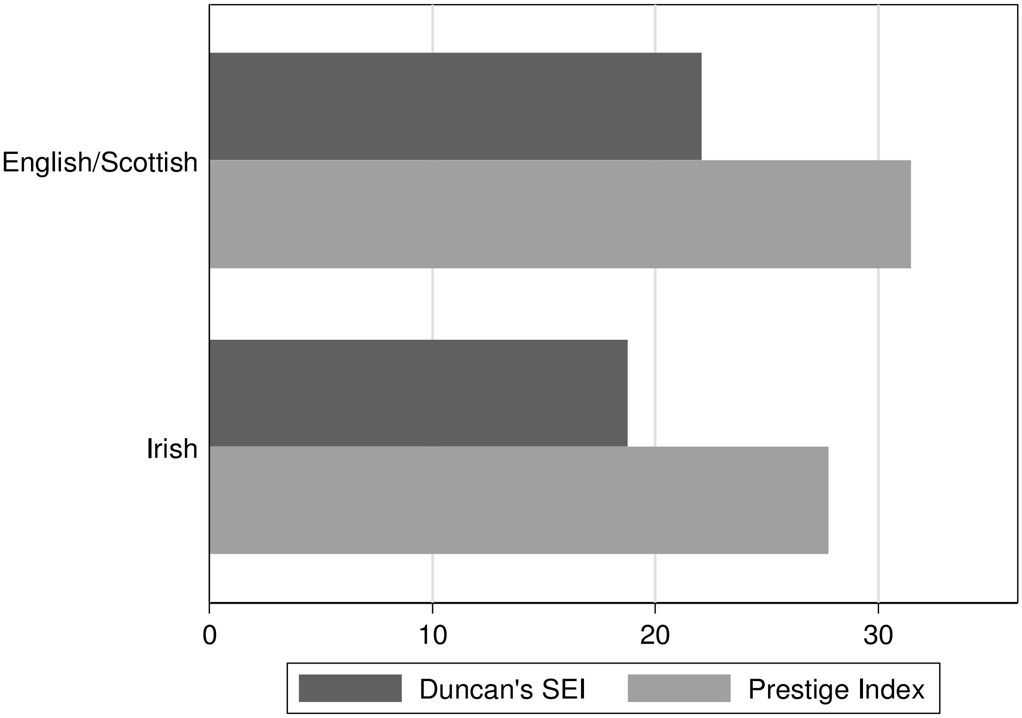


Figure B3: Socioeconomic Status of Irish versus British Immigrants (1880)



Notes: This figure was created using data from the IPUMS-USA 1880 10% census extract. We limited the data to Massachusetts men ages 15-25 and further restricted it to those ages 15-45 (“working age”). We then plotted the appropriate weighted average of Duncan’s Socioeconomic Index and the Siegel Prestige Score. Further details on the indices can be found on the IPUMS website.

Appendix C: Use of the FamilySearch.Org Data for Infant Deaths

FamilySearch.Org Algorithm and Data Cleaning Procedure

We developed the following algorithm for generating a count of infant deaths using data from FamilySearch.org. For each municipality, we isolated each death report where the estimated birth year matched the recorded death year. It became apparent to us, after checking FamilySearch.org against the actual death records that the birth year recorded in FamilySearch.org was generally the death year for infants dying under one year of age.

Two potential limitations exist to our use of the FamilySearch.org website. The website data are inputted based on the actual death records, leaving the potential for data entry errors. FamilySearch.org has redundancy in record entry and we have found, and corrected, instances of duplicate observations.

To systematically minimize the impact of duplicates, we create a flag indicator when multiple observations shared the same date of death and the first two letters of first and last names. Each flagged observation was then more closely examined. If all the following fields were identical or nearly so if a name was typed slightly differently (event date, decedent name, event place, father names and birthplace), we considered the entry a duplicate and removed it from the file. An example of a duplicate is:

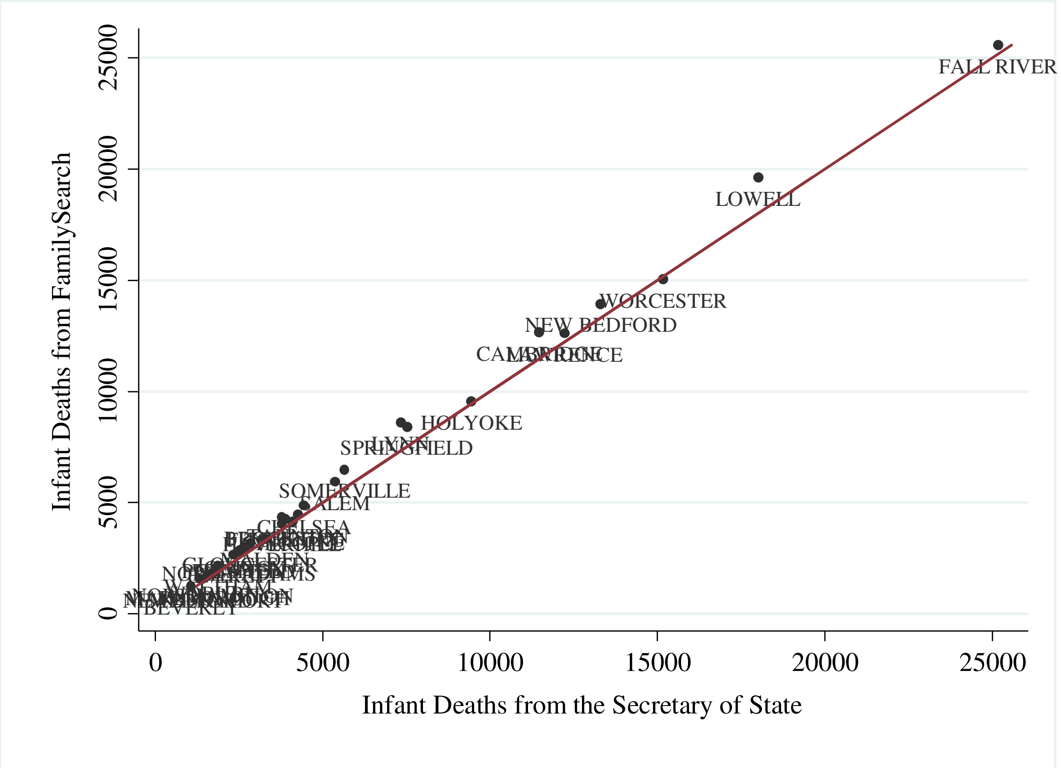
unique_id	eventdate	name	first_name	last_name	eventplace	fathername	birthplace
2837	04 Feb 1880	Thomas Reely	th	ly	Boston, Massachusetts	Cornelius	Boston
1911	04 Feb 1880	Thomas Reely Or Keely	th	ly	Boston, Massachusetts	Cornelius	Boston

In total, we eliminated between 2 and 47 records per year with this methodology.

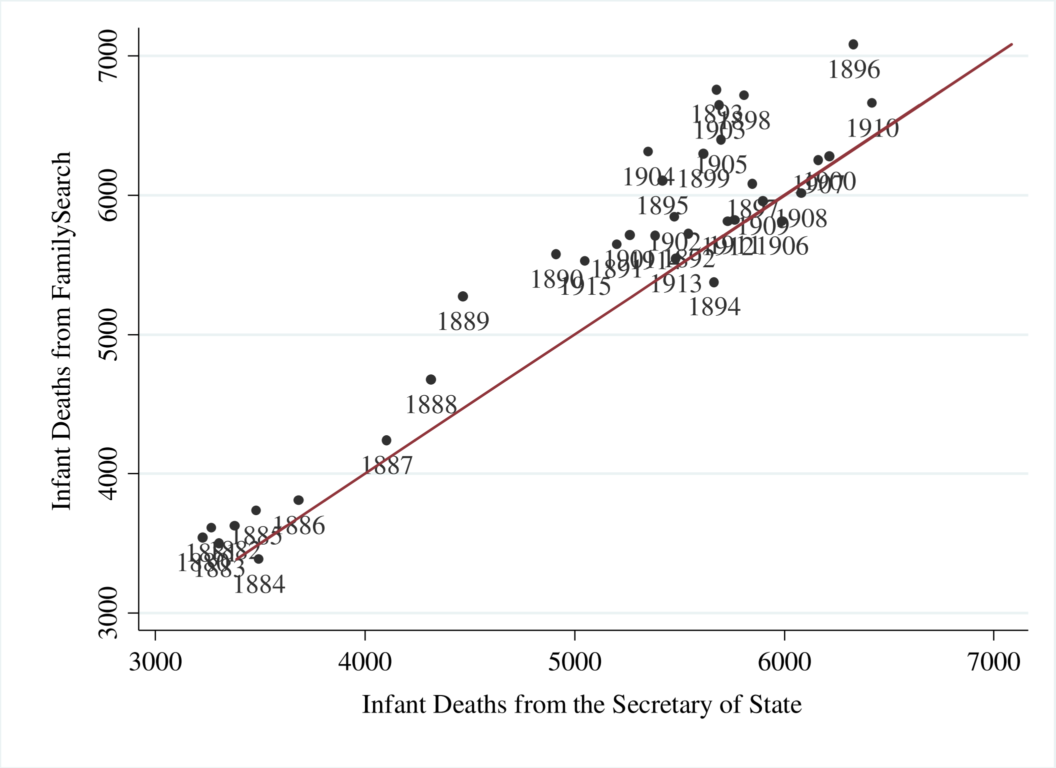
We identified other potential data errors during its original entry by the Municipal authorities or onto the FamilySearch.org website by dropping all entries identified as infant deaths that included an occupation or for which marital status was entered as married, divorced or widowed. These were cases in which the death date was incorrectly entered as the birth date.

FamilySearch.Org versus Secretary of State Counts of Infant Deaths: Goodness of Fit Graphs

A. Infant Deaths by Town, 1880 to 1920: FamilySearch.Org versus the Secretary of State



B. Infant Deaths by Year, 1880 to 1920: FamilySearch.Org versus the Secretary of State



Notes: These figures give the relationship between infant deaths in the FamilySearch.org and Secretary of State data for the 32 towns and cities for which we have reasonably complete data from the Secretary of State data. From 1891 to 1897 infant deaths for these 32 cities are counted from FamilySearch.org to fill in missing data from the Secretary of State.

Appendix References:

Ruggles Steven J., Trent Alexander, Katie Genadek, Ronald Goeken, Matthew B. Schroeder, and Matthew Sobek. Integrated Public Use Microdata Series: Version 5.0 [Machine-readable database]. Minneapolis: University of Minnesota, 2010.