Public Health Efforts and the Decline in Urban Mortality

D. Mark Anderson*

Kerwin Kofi Charles†

Daniel I. Rees‡

September 2018

Abstract. Using data on 25 major American cities for the period 1900-1940, we explore the effects of municipal-level public health efforts that were viewed as critical in the fight against food- and water-borne diseases. In addition to studying interventions such as treating sewage and setting strict bacteriological standards for milk, which have received little attention in the literature, we provide new evidence on the effects of water filtration and chlorination, extending the work of previous scholars. Contrary to the consensus view, we find that none of the interventions under study contributed substantially to the observed declines in total and infant mortality.

* Department of Agricultural Economics and Economics, Montana State University, IZA and NBER. E-mail: dwight.anderson@montana.edu.

† Harris School of Public Policy, University of Chicago and NBER. Email: kcharles@uchicago.edu.

‡ Department of Economics, University of Colorado Denver. E-mail: daniel.rees@ucdenver.edu.

We thank Dora Costa, Claudia Goldin, Adriana Lleras-Muney, Matt Notowidigdo, Elyce Rotella, Werner Troesken, and participants at the 2017 Southern Economic Association and the 2018 Economic History Association annual meetings for comments and suggestions. We would also like to thank David Cutler and Grant Miller for several productive exchanges and for providing us with their data and do-file. Michael McKelligott served as an outstanding research assistant. Partial support for this research came from a *Eunice Kennedy Shriver* National Institute of Child Health and Human Development research infrastructure grant, R24 HD04282, to the Center for Studies in Demography and Ecology at the University of Washington.

1. INTRODUCTION

Since the mid-19th century, mortality rates in the Western world have plummeted and life expectancy has risen dramatically. Sometimes referred to as the mortality transition, this development is widely recognized as one of the most significant in the history of human welfare (Fogel 2004). Two features characterize the mortality transition. First, it was driven by reductions in infectious diseases and diseases of infancy and childhood (Omran 2005; Costa 2015). Second, it was concentrated in urban areas: at the turn of the 20th century, major cities were unsanitary havens of pestilence; by 1940, urban mortality rates were comparable to those of rural areas (Haines 2001; Cain and Hong 2009).

Traditionally, economists have attributed the mortality transition to rising incomes, better nutrition and the onset of modern economic growth (McKeown and Record 1962; McKeown 1976; Fogel 1997, 2004). More recent reviews of the literature emphasize the role of public health efforts, especially those aimed at purifying the water supply. For instance, Cutler et al. (2006) argue that public health efforts drove the dramatic reductions in food- and water-borne diseases at the turn of the 20th century. Similarly, Costa (2015) argues that clean-water technologies such as filtration and chlorination were "the biggest contributor[s] to the decline in infant mortality" (p. 559), but acknowledges that the effects of other public health interventions "remain understudied" (p. 546).

Using data on 25 major American cities for the years 1900-1940, the current study revisits the causes of the urban mortality decline at the turn of the 20th century. Specifically, we conduct a statistical horse race that attempts to distinguish the effects of ambitious, often extraordinarily expensive (Costa 2015, p. 554), public health interventions aimed at controlling mortality from food- and water-borne diseases. Following previous researchers (Troesken 2004; Cutler and Miller 2005; Beach et al. 2016; Knutsson 2018), we explore the extent to which filtering and chlorinating drinking water contributed to the decline in typhoid mortality observed during the period under study and,

more generally, to the observed declines in total and infant mortality. In addition, we explore the effects several other municipal-level efforts that were, at the time, viewed as critical in the fight against typhoid and other food- and water-borne diseases (Meckel 1990; Levitt et al. 2007; Melosi 2008) but have not received nearly as much attention from modern-day researchers. These interventions include: the treatment of sewage before its discharge into lakes, rivers and streams; projects designed to deliver clean water from further afield such as aqueducts and water cribs; requirements that milk sold within city limits meet strict bacteriological standards; and requirements that milk come from tuberculin-tested cows. Because the urban mortality transition was characterized by substantial reductions in infant and childhood mortality (Omran 2005) and because exclusive breastfeeding was not the norm during the period under study (Wolf 2001, 2003), improvements in milk quality seem a particularly promising avenue to explore.

Consistent with the results of Troesken (2004), Cutler and Miller (2005) and Beach et al. (2016), we find that filtering the municipal water supply sharply reduced typhoid mortality. In fact, our results suggest that the building of a water filtration plant cut the typhoid mortality rate by nearly 40 percent. More generally, however, our results are not consistent with the argument that public health interventions drove the extraordinary reductions in infant and total mortality observed between 1900 and 1940. Specifically, we find that efforts to purify milk had no appreciable effect on infant mortality and no effect on mortality from non-pulmonary tuberculosis (TB), which was often transmitted through infected milk. Likewise, neither chlorinating the water supply nor constructing sewage treatment plants appears to have been effective. Although water filtration is associated with a (statistically insignificant) 1-3 percent decrease in total mortality and an 11-13 percent decrease in infant mortality, these estimates are considerably smaller than those found by previous researchers, including Cutler and Miller (2005), the authors of the most influential study in this literature. Finally, we find that filtration is associated with decreased diarrhea and enteritis mortality, but, given their

magnitude, our estimates fall well short of explaining the dramatic decline in mortality from these causes during the period under study.

The remainder of the paper is organized as follows. We begin with an overview of the mortality transition and public health efforts to control food- and water-borne diseases. In Section 3, we describe our data and empirical strategy; in Section 4, we report our principal estimates; and in Section 5 we explore their robustness and consider extensions to our baseline regression model. In Section 6, we directly compare our filtration estimates to those of Cutler and Miller (2005) and document why they are so different. Using their original data and specification, we find that the estimated effect of filtration on infant mortality shrinks by more than two-thirds when a series of transcription errors are corrected. Section 7 concludes.

2. BACKGROUND

Americans experienced an unprecedented improvement in health and longevity in the late 19th and early 20th centuries (Haines 2001; Riley 2005; Troesken 2015). During the period 1850-1950, life expectancy at birth among whites increased by 75 percent from 39.5 to 69 years; among non-whites, life expectancy more than doubled from 23 to 60.8 years (Troesken 2015, p. 10).

This improvement in health and longevity was accompanied by radical changes in the U.S. disease profile (Jones et al. 2012). Before 1900, the leading causes of death were food- and water-borne diseases (e.g., diarrhea, enteritis and typhoid) and respiratory diseases (e.g., influenza and pulmonary TB). By 1940, deaths from these diseases were on the wane; chronic conditions such as heart disease and cancer had become the leading causes of death (Jones et al. 2012).

Ferrie and Troesken (2008) use data from Chicago to illustrate mortality trends in major U.S. cities. Between 1850 and 1925, the Chicago mortality rate fell by 60 percent, driven by the near eradication of food- and water-borne diseases (which disproportionately affected infants and

children) and reductions in mortality from respiratory diseases. In other words, as Chicago transitioned from a high- to low-mortality environment, so-called "modern diseases" replaced food-borne, water-borne and respiratory diseases as the primary causes of death.[1] Boston, Philadelphia, New York and other large American cities experienced their mortality/epidemiological transitions over the same period, while similar transitions occurred roughly one-decade later in smaller American cities (Haines 2001; Ferrie and Troesken 2008).

2.1. Efforts to supply clean water

Many experts believe that, after 1900, the mortality transition in Chicago and other U.S. cities was primarily driven by a series of public health interventions aimed at reducing food- and water-borne illnesses (Cutler et al. 2006; Ferrie and Troesken 2008).[2] Yet, it is far from clear which interventions were most effective, in part because the same city would often implement several of them within a few years of each other, making it difficult to isolate the effect of any single intervention, especially when researchers take a case-study approach.[3] Below, we describe the various water-related public health efforts undertaken by U.S. cities during the period under study:

[1] The phrase "modern diseases" suggests that other countries have experienced (or will experience) the equivalent of the U.S. epidemiological transition (Jones and Greene 2013). This, of course, is an oversimplification. Perhaps because economic development has been uneven, the epidemiological/mortality transition has not been universal (Frenk et al. 1989).

[2] There is an argument to be made that these same public health interventions reduced the within-city (i.e., across neighborhood) variation in mortality (Costa and Kahn 2015).

[3] For instance, Chicago built 5 separate tunnels under Lake Michigan during the period 1867-1892 in an effort to draw water from beyond its heavily polluted shoreline (Reynolds 1894); in 1871, Chicago effectively reversed the current of the Chicago River, which had previously carried sewage into Lake Michigan (Ferrie and Troesken 2008); in 1900, it completed the Sanitary and Ship Canal guaranteeing that, even in the worst weather, the river flowed away from the lake (Hering and Fuller. 1907; Ferrie and Troesken 2008); the North Shore Channel, designed to flush the sewage down the Sanitary and Ship Canal, was completed in 1910 (Gustaitis 2013); in 1912, the city began treating its water with chlorine before delivery to homes and businesses but the process of chlorination was not completed until 1917 (Jennings 1923); and, in 1908, the city passed an ordinance requiring that milk sold within its limits meet a strict bacteriological standard and come from tuberculin-tested cows. As described below, this ordinance had the effect of encouraging pasteurization.

Water filtration. Chicago did not begin filtering its water supply until 1947 (Baylis 1949), but filtration plants were built by most other major U.S. cities during the period under study. Of the 25 cities in our sample, all but 8 had built filtration plants by 1940 (Table 1). Originally developed to reduce discoloration and turbidity, water filtration gained support as the field of bacteriology advanced and city governments came under increasing political pressure to protect their citizens from infectious diseases (McCarthy 1987; Melosi 2008, pp. 90-94).[4] Public health experts, armed with studies showing dramatic decreases in typhoid mortality after filtration systems were put in place (Clark 1907; Johnson 1907; Sedgwick and MacNutt. 1910; McLaughlin 1912a; Johnson 1913), convinced skeptical policymakers that filtering water was a sound investment (Foss-Mollan 2001, pp. 80-116; Melosi 2008, p. 94).

Chlorination. In 1908, Jersey City famously became the first municipality in the United states to disinfect its water supply by treating it with chlorine (Allen 1918). The process of chlorination was simple and inexpensive: water was added to bleaching powder (calcium hypochlorite) to make a thick paste, which was then mixed with the water supply before delivery (Hooker 1913).[5] In part because it was so inexpensive, chlorination quickly gained popularity (Hill 1911). By 1928, every city in our sample was chlorinating its water supply (Table 1), although issues with taste and odor discouraged many smaller communities from adopting the technology.[6]

---

[4] The simplest method of water filtration (i.e., slow water filtration) consisted of "a body of sand of sufficient thickness, underlaid or supported by a few inches of course and fine gravel or broken stone, with a proper number of pipe underdrains to collect the water that passes through the sand…" (Clark 1907, p. 765). Mechanical filter plants, which used coagulants and smaller filter beds, proved less expensive to build and maintain than slow water filtration plants and eventually supplanted the latter (Johnson 1914a, 1914b).

[5] Between 8 and 16 pounds of bleaching powder per million gallons of water were typically used (Hooker 1913, p. 65). Within a decade of it being used to disinfect the Jersey City water supply, bleaching powder (also known as "chloride of lime") had been supplanted by liquid chlorine, which was less expensive and did not have "the disagreeable odor and corrosive influences of chloride of lime" (Bowles 1919, p. 22).

[6] According to Melosi (2008, p. 139), as late as 1939, only one-third of all U.S. waterworks used chlorine because of "taste and odor problems."

Clean water projects. Chicago drew its water from Lake Michigan, but the city also dumped its sewage, which carried disease-causing pathogens, directly into the lake (or into the Chicago River, which flowed into the lake). In 1867, Chicago constructed a two-mile tunnel under Lake Michigan, enabling it to extend its water crib well beyond its heavily polluted shoreline; in 1892, a four-mile tunnel was constructed (Reynolds 1894; Sells 2017).[7] Several other American cities went to even greater lengths to deliver clean water, building aqueducts and tunnels that connected distant reservoirs with their water distribution systems (Table 2). For instance, in 1914 San Francisco began constructing a system of dams, conduits, hydroelectric plants and aqueducts designed to deliver clean water from the Hetch Hetchy Reservoir to the Bay Area, a distance of over 150 miles (Hanson 2005).[8]

Sewage treatment plants. At the turn of the 20th century, dilution (i.e., discharge into lakes, rivers, streams, or the ocean) was the standard method of sewage disposal. Experts argued that the "natural power of self-purification" would render waste water clean and, ultimately, drinkable (Whipple 1914, p. 638).[9] Evolving attitudes, coupled with new technologies and regulatory efforts,

[7] Water cribs are structures designed to collect water from near the bottom of a lake, which is then carried to an onshore pumping station. After the completion of these projects, typhoid deaths fell precipitously, as did deaths from respiratory diseases such as pneumonia and TB, leading Ferrie and Troesken (2008, p. 15) to conclude that water purification efforts reduced mortality "from diseases that other[wise] would not have been classified as waterborne or even water-related..." In fact, Ferrie and Troesken (2008, p. 15) conclude that 35-56 percent of the total mortality decline in Chicago is attributable to water purification efforts.

[8] During the period 1900-1940, Boston, Jersey City, New York City, Newark and Providence also built aqueducts to transport clean water from reservoirs located in protected watersheds. According to Melosi (2008, p. 57), "distant sources of supply received great attention because they offered large and dependable quantities of water, but also because they provided alternatives to polluted or infected sources in the local area." Smaller cities, however, were "hard-pressed to seek distant sources" and were therefore more likely to build filtration plants (Melosi 2008, p. 57).

[9] Despite this argument, several cities (including Chicago and Detroit) went to great lengths to ensure that their sewage was disposed of downstream from the system intake (Hering and Fuller 1907; Cain 1977; Detroit Water and Sewerage Department 2002).

prompted the construction of sewage treatment plants across the country (Tarr et al. 1984).[10] By the end of 1940, 15 of the 25 cities in our sample were treating their sewage (Table 3).[11]

Previous studies in this literature have focused on estimating the effects of building and extending sewer systems (i.e., providing sewerage) as distinct from treating sewage (i.e., using chemical or biological processes to remove contaminants from waste water) before its discharge into lakes, rivers and streams. For instance, using data from Paris for the period 1880–1914, Kesztenbaum and Rosenthal (2017) show that the provision of sewerage to a neighborhood added several years to the life expectancy of its residents. Using data on 60 municipalities in Massachusetts for the period 1880-1920, Alsan and Goldin (2018) examine the effects of clean water and access to a regional sewerage system on infant and child mortality. Instead of filtration or chlorination, Massachusetts opted to provide clean water through a system of "impounding reservoirs in which spring floodwaters were stored" (Alsan and Goldin 2018, p. 10). These authors find that the interaction of clean water and sewerage accounted for approximately one-third of the observed decline in child mortality (i.e., mortality among children under the age of 5) from 1880 to 1920 and nearly one-half of the observed decline in infant mortality.[12] By the early 1900s, every major U.S.

[10] During the period under study, the use of chemical precipitation (which involved the addition of coagulants to separate sludge from water) waned and more efficient methods of treating sewage, including the activated sludge process, were gradually adopted (Ardern and Lockett 1914; Reynolds 1933). Providence, Rhode Island was the first city in our sample to treat its sewage. The Providence plant, built in 1901, used chemical precipitation (Nixon 1995). None of the other cities in our sample adopted this technology and the Providence plant converted to using an activated sludge process in the mid-1930s.

[11] Philadelphia and San Francisco are not counted among these 15 cities because they were treating less than 25 percent of their effluent by the end of the period under study (Mohlman 1940). We code our sewage treatment indicator as equal to 0 for cities that were treating less than 25 percent of the effluent. If we apply a higher threshold (e.g., a city must have been treating at least 50 percent of their effluent), our results are qualitatively similar. Appendix Figure 1 illustrates the rollout of the water-related interventions during the period 1900-1940 for our sample of cities.

[12] Cutler and Miller (2005) control for sewage treatment plants and the chlorination of sewage but only three out of 13 cities in their sample period constructed sewage treatment plants (Baltimore in 1911, Cleveland in 1922 and Milwaukee in 1925) and only one city chlorinated its sewage (Cleveland in 1922).

city had installed sewers (Cain and Rotella 2001; Melosi 2008; Hoagland 2018), precluding us from using the same regressors as were used by Alsan and Goldin (2018).[13]

2.2. Efforts to supply clean milk

Diarrheal diseases were important contributors to infant mortality in the early 1900s and experts at the time were convinced that cleaning up the milk supply was key to combatting them (Brosco 1999). Yet, aside from Olmstead and Rhode (2004a) and Komisarow (2017), modern-day researchers have not paid a great deal of attention to milk-related public health efforts undertaken during this period.[14] Below, we describe two milk-related municipal-level public health interventions, the effects of which have not been adequately explored by previous researchers:

Bacteriological standards for milk. Boston was the first U.S. city to require that milk sold within its limits meet a bacteriological standard (specifically, a maximum of 500,000 bacteria per cubic centimeter). Adopted by the Boston Board of Health in 1905, the rule was initially "the subject of scoffing", but ultimately served as a model for cities across the United States (Rosenau 1908, p. 434).

Between 1900 and 1940, all but one of the 25 cities in our sample adopted a bacteriological standard for milk (Table 4).[15] Although such standards were not always enforced with vigor

[13] Baltimore was the last major U.S. city to construct a sewer system. The first house was connected to the Baltimore system in 1911 but the project was not completed until 1915 (Hoagland 2018).

[14] Olmstead and Rhode (2004a) attribute the decline in bovine tuberculosis to a U.S. federal program that began in 1917 and was designed to eradicate the disease. See Olmstead and Rhode (2004b) for an excellent description of efforts to control bovine TB that preceded the federal program. Using data from 40 U.S. cities, Komisarow (2017) explores the effect of dairy farm inspections covering a "broad range of areas and practices, including the monitoring of animal health, farmworkers' sanitation practices, and farm worker health and hygiene" (p. 129) on mortality. She finds that the introduction of dairy farm inspections reduced mortality from diarrhea and enteritis among one-year-olds by 14 percent, but finds no effect among infants nor among children ages 2-4. In a robustness check, Alsan and Goldin (2015, p. 47) include the proportion of dairies in the county that did not contain "objectionable features" as a control.

[15] Komisarow (2017, p. 131) asserts that only 5 major U.S. cities adopted a bacteriological standard for milk after 1901 (Kansas City, Missouri in 1902, Cleveland in 1906, Milwaukee in 1906, Omaha in 1906 and St. Paul in 1907). This

(Olmstead and Rhode 2004a), many cities went to great lengths to ensure that they were adhered to by dairy farmers and milk vendors. For instance, Milwaukee employed 6 full-time inspectors to ensure that its milk supply was clean (Milwaukee Common Council 1918); Baltimore hired 6 new dairy-farm inspectors, two bacteriologists and two lab assistants shortly after its 1913 milk ordinance was passed (Carey 1913).[16]

Ordinances requiring milk meet a bacteriological standard were (and are) sometimes referred to by historians and public health experts as "pasteurization ordinances" (Harding 1917, p. 57; Troesken 2015, pp. 33-34; Swinford 2016, p. 254; Komisarow 2017, p. 131) because they were difficult to meet without resorting to pasteurization and, in fact, had the effect of encouraging all but a handful of producers to pasteurize their milk (Meckel 1990, pp. 88-89).[17] Suggestive evidence of their effectiveness comes from the fact that diarrheal deaths in the summer, when bacteria counts in milk were highest, declined markedly between 1910 and 1930 (Cheney 1984; Condran 1988). Nonetheless, this was a period during which "many municipalities were also making significant

assertion, which is incorrect, appears to be based on a misinterpretation of the "Collection of Milk" dates reported in Table 114 of Parker (1917, p. 371).

[16] In general, enforcement was strictest in the largest cities. Fuchs and Frank (1939) surveyed municipal health departments across the country regarding their milk purification efforts in 1936. Cities with a population greater than 500,000 employed an average of 27.6 full-time milk inspectors; cities with a population between 100,000 and 500,000 employed an average of 3.7 full-time milk inspectors.

[17] By the mid-1920s, the majority of American cities with a population greater than 100,000 reported that more than 90 percent of their milk supply was pasteurized (Ayers 1932). Many ordinances explicitly exempted pasteurized milk from having to meet the bacteriological standard or allowed higher levels of bacteria in raw milk that was to be pasteurized before being sold. Cities that required milk sold within their limits to meet a bacteriological standard but exempted pasteurized milk include: Chicago, Cincinnati, Indianapolis, Milwaukee, Minneapolis, New York, Philadelphia, Providence and St Louis. During the period 1900-1940, only three cities in our sample (Detroit, Chicago and San Francisco), required that all milk sold within their limits be pasteurized. Detroit passed its pasteurization ordinance in 1915 without first requiring that milk meet a bacteriological standard and that it come from tuberculin-tested cows (Kiefer 1911; Clement and Warber 1918). One year later, the Chicago commissioner of health, worried about an outbreak of Polio, ordered that all milk sold in the city be pasteurized (Czaplicki 2007). This emergency measure, which was never rescinded, was viewed as necessary despite an ordinance requiring that unpasteurized milk sold within city limits meet strict a strict bacteriological standard and that it come from tuberculin-tested cows. The San Francisco pasteurization ordinance came into effect in 1939 (Skelly 1944). Boston, New York and Pittsburg banned the sale of raw milk between 1940 and 1946.

strides in improving their water supply, sewerage, and refuse removal systems" (Meckel 1990, p. 89), and disentangling the effects of these various public-health interventions requires a more careful, comprehensive empirical approach than heretofore undertaken.

TB testing of dairy cows. Approximately 10 percent of dairy cows in the United States were infected with bovine TB in 1917, the year in which federal efforts to control the disease were begun (Olmstead and Rhode 2004a). Bovine TB can be transmitted to humans through the consumption of raw milk and represented a particularly serious threat to the health of children and infants because they had lower resistance to the disease (Olmstead and Rhode 2004a). Minneapolis was the first city in our sample to require that milk sold within its limits come from tuberculin-tested cows but the ordinance was not popular among dairy farmers and, at least initially, was not well enforced (Keyes 1901; Baker 1910). Despite often bitter opposition from dairy farmers (Olmstead and Rhode 2007), 22 of the 25 cities in our sample required that milk come from tuberculin-tested cows by 1940.[18]

3. DATA AND EMPIRICAL FRAMEWORK

Our focus is on major U.S. cities, defined as having a population greater than 150,000 in 1900. This criterion is met by 24 cities. In addition to these 24 cities, we included data from Memphis, Tennessee in our analyses. Although its population was less than 150,000 in 1900,

[18] For instance, due to opposition, the city of Cleveland did not initially require that dairy farmers comply with a tuberculin-testing ordinance that was passed in 1906 (Lane and Weld 1908). A Chicago tuberculin-testing ordinance, passed in 1908, faced so much resistance from dairy farmers that the Illinois legislature, under pressure from rural constituents, passed a law prohibiting any city or town in the state from requiring that dairy cattle be tested for TB (Wolf 2001, pp. 59-63; Czaplicki 2007). Many ordinances explicitly exempted pasteurized milk from having to come from tuberculin-tested cows. Cities that required milk sold within their limits to come from tuberculin-tested cows but exempted pasteurized milk include: Baltimore, Boston, Chicago, Cleveland, Indianapolis, Minneapolis, New York and Rochester. Appendix Figure 2 illustrates the roll-out of the milk-related interventions during the period 1900-1940 for our sample of cities.

Memphis was among the 13 cities examined by Cutler and Miller (2005). All of our principal results, discussed below, are robust to excluding Memphis.

Municipal-level mortality data come from *Mortality Statistics* and *Vital Statistics of the United States*, both of which were published annually by the U.S. Census Bureau.[19] From 1900 to 1940, annual mortality rates in major American cities fell from 1,840 to 1,164 per 100,000 population, or 37 percent (Figure 1). The reduction in the infant mortality rate was even more dramatic, falling from 383 to 80 per 100,000 population, or 79 percent (Figure 2).

Typhoid deaths have been used as a proxy for water quality and to track diarrheal deaths (Cutler and Miller 2005; Ferrie and Troesken 2008; Clay et al. 2014), but it is worth noting that they represented only a small proportion of total deaths and never amounted to more than half of mortality from diarrhea/enteritis.[20] In 1900, there were 39 typhoid deaths per 100,000 population and 130 diarrhea/enteritis deaths per 100,000 population (Figures 3 and 4); by the 1920s, the typhoid mortality rate was approaching zero (Figure 3) and diarrhea/enteritis mortality rate was not far behind (Figure 4). Mortality from non-pulmonary TB also plunged during the period under study (Figure 5). In fact, by the mid-1930s non-pulmonary TB mortality among children under the

[19] Specifically, mortality data come from *Mortality Statistics* for the period 1900-1936 (U.S. Bureau of the Census 1906-1938) and from *Vital Statistics of the United States* for the period 1937-1940 (U.S. Bureau of the Census 1939-1941, 1943). Cause of death was obtained from the death certificate and coded using the *International Classification of Diseases*. When more than one medical condition was listed on the death certificate, cause of death was based on a standardized algorithm (Armstrong et al. 1999).

[20] See Appendix Figures 3 and 4 for more information. Cutler and Miller (2005) assume a three-to-one ratio of diarrhea/enteritis deaths to typhoid deaths. Based on this assumption, they conclude that "reductions in all waterborne diseases account for about 8% of the reduction in total mortality…." (Cutler and Miller 2005, p. 14). In our data, the ratio of diarrhea/enteritis to typhoid deaths ranges from 3.3 (in 1900) to 15.6 (in 1920). During the period under study, diarrhea and enteritis deaths at the municipal level were reported in one category ("diarrhea and enteritis") by *Mortality Statistics* and *Vital Statistics of the United States*. Total mortality from diarrhea/enteritis is not available for the years 1939 or 1940. Enteritis is inflammation of the small intestine but can also include inflammation of the large intestine and stomach (Pietrangelo 2016).

age of 2 had essentially been eradicated and non-pulmonary TB morality in other age groups was approaching zero.[21]

We begin our exploration of which municipal-level public health efforts, if any, were responsible for the trends shown in Figures 1-5 by estimating the following baseline regression:

$$(1) \qquad \ln(\textit{Mortality Rate}_{ct}) = \beta_0 + \boldsymbol{Z}_{ct}\boldsymbol{\beta_1} + \boldsymbol{X}_{ct}\boldsymbol{\beta_2} + v_c + w_t + \Theta_c \cdot t + \varepsilon_{ct},$$

where c indexes cities and t indexes years. Our primary interest is in the variables that compose the vector $\boldsymbol{Z}_{ct}$, which were constructed using information available from a wide variety of primary and secondary sources. Specifically, the vector $\boldsymbol{Z}_{ct}$ includes separate indicators for whether city c filtered its water supply in year t, whether it treated its water with chlorine and whether it had completed a clean water project.[22]

The vector of controls, $\boldsymbol{X}_{ct}$, is composed of city characteristics taken from the 1900-1940 Censuses (and linearly interpolated for intercensal years). Specifically, it includes the percent of the population that was female, nonwhite, foreign born, under 15 years of age, 15-44 years of age and 45 years of age or older. The terms v_c and w_t represent city and year fixed effects, respectively. The city fixed effects control for city-level determinants of mortality that were constant over time, and the year fixed effects control for common shocks. In addition to these fixed effects, we include city-specific linear time trends ($\Theta_c \cdot t$) to account for the possibility that mortality rates evolved differently

[21] Our data do not distinguish between bovine TB mortality (caused by *M. bovis*), which was often transmitted through milk, and non-bovine TB mortality (caused by *M. tuberculosis*), which was much more common and typically spread through airborne particles (Anderson et al. forthcoming). Price (1939) estimates that *M. bovis* accounted for 12 percent of total TB infections in the United States and there is evidence that approximately half of adult bovine TB sufferers exhibited pulmonary infections (Olmstead and Rhode 2004a). By contrast, only 10 percent of bovine TB infections were pulmonary among young children (Olmstead and Rhode 2004a).

[22] Tables 1 and 2 detail the water purification efforts of the cities in our sample. The references used to construct Tables 1 and 2 are given in Appendix B.

in cities that adopted certain technologies versus those that did not. Standard errors are corrected for clustering at the city level (Bertrand et al. 2004).

After estimating the baseline regression described above, we augment the vector $\boldsymbol{Z}_{ct}$ with an indicator for whether city c treated or diverted its sewage in year t. Finally, our fully specified model includes an indicator for whether city c required that milk sold within its limits meet a bacteriological standard and an indicator for whether it required that milk come from tuberculin-tested cows.[23] Descriptive statistics and variable definitions are reported in Table 5.

4. BASELINE RESULTS

We report estimates from the baseline model, which focuses on the relationship between total mortality and water purification efforts, in the first column of Table 6. While the estimated coefficient of the filtration indicator is negative, it is small and not statistically significant at conventional levels. Taken at face value, it would suggest that filtering the municipal water supply reduced the total mortality rate by .025 log points, or 2.5 percent ($e^{-.025}$ -1 = -.025). By contrast, Cutler and Miller (2005), whose empirical strategy and data are closest to ours, find that filtration is associated with a 15 percent reduction in total mortality.[24] The estimated coefficients of the chlorination and clean-water-project indicators are also small and statistically indistinguishable from zero.

[23] Detroit passed its pasteurization ordinance in 1915 without first requiring that milk meet a bacteriological standard and that it come from tuberculin-tested cows (Kiefer 1911; Clement and Warber 1918). The bacteriological standard and tuberculin-testing indicators are set equal to .67 for Detroit in 1915 (the ordinance same into effect on May 1) and 1 in subsequent years. We experimented with including a mandatory pasteurization ordinance indicator on the right-hand side of our regressions. The results were qualitatively similar to those reported and discussed below.

[24] Cutler and Miller (2005) report that water filtration is associated with a reduction in total mortality of .16 log points ($e^{-.16} - 1 = -.148$). These authors estimate a regression model similar to equation (1) using data from 13 major American cities for the period 1900-1936. In Section 6, we directly compare our filtration estimates to those of Cutler and Miller (2005) and document why they are so different, at least with regard to infant and total mortality.

The remaining columns of Table 6 report estimates from regression models in which the sewage treatment/diversion and milk-related indicators are included on the right-hand side. The estimated effect of treating/diverting sewage is small, positive and never statistically significant at conventional levels. Likewise, the coefficients of the milk-related intervention indicators are small, consistently positive, but imprecisely estimated. The combined (i.e., joint) effects of the water- and milk-related public health interventions are given at the bottom of Table 6. There is little evidence that the effects of these interventions, even when summed together, were related to total mortality.

We turn our attention to infant mortality in Table 7. Across specifications, there is strong evidence of a negative relationship between water filtration and infant mortality. For instance, filtration is association with a 13 percent reduction in the infant mortality rate if we do not include the sewage- and milk-related intervention indicators; with these indicators on the right-hand side of the regression model, it is associated with an 11 percent reduction. By contrast, Cutler and Miller (2005) find that filtration was associated with a 35 percent reduction in the infant mortality rate.[25]

The results reported in Table 7 provide little evidence that the other interventions under study contributed to the decline in infant mortality between 1900 and 1940. In fact, the estimated effects of treating/diverting sewage, setting a bacteriological standard for milk and requiring dairy cows to be tested for TB are consistently positive but statistically insignificant, and chlorination is actually associated with a statistically significant 8-10 percent increase in the infant mortality rate.[26]

[25] Cutler and Miller (2005) report that water filtration is associated with a reduction in the infant mortality rate of .43 log points ($e^{-.43} - 1 = -.349$).

[26] Cutler and Miller (2005) find a negative, but insignificant, relationship between chlorination and infant mortality, although the coefficient of the interaction between chlorination and filtration is positive. These authors ascribe this pattern of results to the fact that only a handful of cities in their sample adopted chlorination technology before building a filtration plant. We, however, observe 9 cities that added chlorine to their water supply before the construction of a filtration plant (Table 1).

Finally, the estimated effects of completing a clean water project, although negative, are not statistically significant at conventional levels.

5. Robustness Checks and Extensions

In Table 8, we explore the robustness of the infant mortality estimates described in the previous section. We begin by controlling for the manufacturing wage in city *c* and year *t*, which can be thought of as measuring the purchasing power of urban workers. The estimated coefficient of the filtration indicator retains its magnitude and significance, suggesting that the effect of filtration cannot be explained by changes in the purchasing power of urban workers.[27]

Additional robustness checks include controlling for region-by-year fixed effects, not weighting by population, dropping New York City (the most populous city in the sample), dropping the years 1917-1920 to avoid potential confounding from the effects of the 1918 influenza pandemic and specifying the dependent variable in levels (as opposed to taking its log). The results of these robustness checks provide evidence that the estimated effect of water filtration on infant mortality is not an artifact of specification or sample choice. The positive (and admittedly counterintuitive), association between chlorination and infant mortality, however, appears to be quite sensitive to small changes in specification and sample composition. For instance, it shrinks and loses significance when we include region-by-year fixed effects, do not weight by population, or run the regression in levels as opposed to using the semi-log specification.

[27] Data on the manufacturing wage come from the *Biennial Census of Manufactures*. The manufacturing wage is linearly imputed for missing years and deflated using price indices in Rees and Jacobs (1961) and the Bureau of Labor Statistics (1973). Rapid industrialization after 1900 led to substantial increases in the purchasing power of workers as measured by the manufacturing wage (Bry 1960; Rees and Jacobs 1961). With the stock market crash in October of 1929 and the onset of the Great Depression, the ranks of the unemployed swelled but real wages continued to increase (Margo 1993). Evidence that the typical American diet underwent profound changes during the period under study is provided by Bente and Gerrior (2002). Because of the *Census of Manufactures* was discontinued after 1937, the column (1) regression is based on the years 1900-1937. If we do not control for the manufacturing wage and restrict our attention to the period 1900-1937, the coefficient of the filtration indicator is equal to -.105 and is statistically significant at the 5 percent level.

Next, we estimate a modified version of equation (1) in which the filtration indicator is decomposed into a series of mutually exclusive lags. The results, which are reported in Table 9, suggest that the effect of constructing a water filtration plant gradually became stronger over time. Specifically, filtration is associated with a 6-7 percent decrease in the infant mortality in the year of implementation (*Year 0*); two years after implementation, filtration is associated with an 8-9 percent decrease; and, after 5 or more years, filtration is associated with a 17 percent decrease in the infant mortality rate.[28] Replacing the filtration indicator with a series of its leads and lags produces a similar pattern of results (Figure 6). Again, the effect of filtration increases after *Year 0* and there is no evidence that infant mortality rates began trending downwards prior to the adoption of filtration, suggesting the parallel trends assumption is satisfied.[29]

5.1. Interactive effects

In the early 20th century, public health experts often disagreed as to whether it was necessary to chemically treat water that had already been filtered and vice versa (Hill 1911; Orchard 1917; Race 1918; Kienle 1919; Stein 1919; Clark 1921).[30] There was also debate surrounding whether the

[28] Even after a filtration plant came online, it could be some time before filtered water was delivered throughout the city. For instance, during its first 6 months of operation, the Cleveland filtration plant mixed its output with "raw" (i.e., unfiltered) water before delivery (Unknown Author 1918). The effort to provide filtered water to every neighborhood in Philadelphia took more than three years (McCarthy 1987). Cutler and Miller (2005) find that the effects of water purification efforts on total mortality and typhoid mortality grew over time. These authors argue that "[g]rowing effects over time could be due to…increases in complementary private health behaviors (like hand washing, boiling milk, and appropriate food storage) as the expected return to health investments rises" (pp. 14-15).

[29] Event studies for chlorination, clean water projects and sewage treatment/diversion are shown in Appendix Figure 5. Consistent with the parallel trends assumption, there is little evidence of an association between these interventions and infant mortality prior to year 0. Event studies for requiring that milk meet a bacteriological standard and that it come from tuberculin-tested cows are shown in Appendix Figure 6. Again, there is little evidence of pre-treatment differences in infant mortality rates.

[30] Modern-day researchers have also come to different conclusions with regard to the direction and importance of these interactive effects. For instance, Cutler and Miller (2005) find evidence that "filtration and chlorination were substitute technologies" (p. 11). By contrast, Troesken (2004, p. 139-143) finds that typhoid mortality in Washington D.C. fell by 29 percent when its filtration plant opened and that filtration and chlorination combined reduced typhoid mortality in Washington D.C. by 57 percent.

treatment of sewage was necessary if the downstream water supply was chlorinated and/or filtered (McLaughlin 1912b; Eddy 1913; Whipple 1913, 1914; Phelps 1918). We begin an exploration of these questions by introducing interactions between filtration and the other efforts to purify municipal water supplies.

The results, which are reported in Table 10, provide evidence, albeit tentative, that these interactions had negative effects on infant mortality. For instance, the estimated coefficient of the filtration-sewage treatment/diversion interaction is negative and quite large, but statistically insignificant. Taken at face value, it suggests that the combination of filtration and treating sewage led to an 8 percent reduction in infant mortality. The estimated coefficients of the *Filtration*Chlorination* and *Filtration*Clean Water Project* interactions are also negative, but imprecisely measured.[31]

5.2. Estimates by cause of death

Municipal water purification efforts were often undertaken with the explicit goal of reducing (or even eradicating) typhoid infections (Foss-Mollan 2001; Melosi 2008) and, more often than not, public health officials could point to fewer typhoid deaths after these efforts came to fruition (Eddy 1913; Elms 1914; Jennings 1918; Morse and Hall 1919).[32] Nonetheless, it was widely recognized that typhoid mortality could be used as a gauge of overall water quality and that mortality from other

[31] Interacting *Chlorination* with *Clean Water Project* or with *Sewage Treatment/Diversion* produced coefficient estimates that were negative in sign, small in magnitude and nowhere near statistically significant. Using data on 60 municipalities in the Boston Harbor watershed area for the period 1880-1920, Alsan and Goldin (2018) examine the interaction between access to a regional sewerage system and the provision of clean water. Municipalities in their sample began receiving sewerage as early as 1892.

[32] Interestingly, there was much consternation and complaint when typhoid mortality did not fall immediately after the Washington D.C. filtration plant was put into operation (Horton 1906; Woodword 1907) and blame was placed on infected dairy products and other sources (Horton 1906; Sedgwick 1906).

water-borne diseases should, at least in theory, decline with the adoption of filtration and/or chlorination technology (Sedgwick and MacNutt. 1910; Hill 1911; Jordan 1916).

In the first column of Table 11, we report estimates from a modified version of equation (1) where the dependent variable is the typhoid mortality rate per 100,000 population. Because there were zero typhoid deaths for 20 city-year combinations, we used the quartic root of the typhoid mortality rate instead of taking its natural log.[33] The marginal effects of the various interventions on the typhoid mortality rate are reported in brackets directly under the standard errors. We find that the adoption of water filtration technology substantially reduced typhoid mortality. Specifically, filtration is associated with 4.6 fewer deaths from typhoid per 100,000 population, or a 36 percent reduction relative to the mean.[34] However, there is little evidence that the other public health interventions under study were related to typhoid mortality.

In the remaining columns of Table 11, we turn our attention to diarrhea/enteritis mortality and mortality from non-pulmonary TB.[35] Although previous researchers have investigated the effects of filtration and chlorination on typhoid mortality (Troesken 2004; Cutler and Miller 2005; Beach et al. 2016), this is the first study that uses historical data to examine the effects of these

[33] This method of dealing with zeros has been used by Thomas et al. (2006), Tarozzi et al. (2014), Ashraf et al. (2015) and Anderson et al. (2016), among others. Taking the natural log of the rate or taking the natural log of the rate plus 1 produced similar results.

[34] Cutler and Miller (2005) find that filtration is associated with a reduction in the typhoid mortality rate of .46 log points, or 37 percent ($e^{-.46} - 1 = -.369$).

[35] Specifically, we report estimates of equation (1) using the natural log of total diarrhea/enteritis deaths per 100,000 population as the dependent variable and the natural log of diarrhea/enteritis deaths among children under the age of two per 100,000 population. We also report estimates of equation (1) using the natural log of total non-pulmonary TB deaths per 100,000 population as the dependent variable and the quartic root of non-pulmonary TB deaths among children under the age of two per 100,000 population. Although half of adult bovine TB sufferers exhibited pulmonary infections, only 10 percent of bovine TB infections were pulmonary among young children (Olmstead and Rhode 2004a). Because there were zero non-pulmonary TB deaths among children under the age of two for 12 city-year combinations, we used the quartic root function instead of the natural log. Marginal effects are reported in brackets below the standard errors.

interventions on diarrheal mortality.[36] It is also the first study to test whether turn-of-the-20th century efforts to purify the milk supply at the municipal level led to reductions in mortality from non-pulmonary TB mortality.

As noted above, diarrheal deaths fell to near-zero levels during the period under study, at least in major American cities (Figure 4). The results reported in Table 11 provide evidence that filtration contributed to this phenomenon. Specifically, filtration is associated with a statistically significant 15 percent reduction in the diarrhea/enteritis mortality rate. The estimated effects of the milk-related interventions are, by contrast, consistently positive and imprecise. In fact, aside from filtration, there is little evidence that any of the public health interventions under study contributed to the falling rates of diarrhea/enteritis mortality.[37] Similarly, the public health interventions under study seem to have been essentially unrelated to the non-pulmonary TB mortality rate.[38] Even municipal ordinances requiring that milk meet strict bacteriological standards and that dairy cows be tested for TB seem to have been ineffective at reducing the non-pulmonary TB mortality rate.

[36] Cutler and Miller (2005) have mortality data on diarrhea/enteritis mortality for one year, 1900. Based on these data, they assume a three-to-one ratio of diarrhea/enteritis deaths to typhoid deaths. Using data on 60 municipalities in Massachusetts for the period 1880-1920, Alsan and Goldin (2018) find that the interaction of sewerage and clean water is associated with a reduction in gastrointestinal mortality among children. Ferrie and Troesken (2008) use typhoid mortality to proxy for water quality in Chicago. These authors find a strong negative association between typhoid mortality and mortality due to other causes (including diarrhea/enteritis), which they interpret as evidence of a Mills–Reincke effect. Using data from 15 American cities for 1908, Troesken (2004, pp. 179-183) examines the relationship between miles of water mains per 100,000 population (a measure of "extensiveness of local water systems") and mortality from water-borne diseases, defined as the sum of typhoid and diarrheal mortality. Several studies in the economics literature use more recent data to examine the effect of water purification efforts on diarrheal mortality among children in the developing world. For instance, Bhalotra et al. (2017) estimate that a Mexican program that increased the share of the population receiving chlorinated water by 30 percentage points led to a substantial reduction in diarrheal mortality among children. Galiani et al. (2005) find that the privatization of municipal water companies in Argentina is associated with substantial reductions in mortality from infectious and parasitic diseases among children. Related studies in the medical literature include Arnold et al. (2007) and Gruber et al. (2013).

[37] The completion of a clean water project is associated with a 15 percent reduction in diarrhea/enteritis mortality and a 14 percent reduction in diarrhea/enteritis mortality among children under the age of two. Neither of these estimates, however, are statistically significant at conventional levels.

[38] Non-pulmonary TB mortality counts by age are unavailable at the municipal level for the years 1937-1940.

5.3. A closer look at filtration and typhoid mortality

In this subsection, we take a closer look at the estimated effect of filtration on typhoid mortality. Specifically, we show results from the same checks that were used to explore the robustness of the infant mortality estimates in Table 7.

The relationship between filtration and typhoid mortality is reasonably robust to specification and sample choice (Table 12). For instance, controlling for the manufacturing wage, filtration is associated with 5 fewer typhoid deaths per 100,000 population, or a 36 percent reduction relative to the mean; controlling for region-by-year fixed effects, filtration is associated with 5.2 fewer typhoid deaths per 100,000 population, or a 41 percent reduction relative to the mean. Estimating equation (1) in levels (as opposed to taking the quartic root of the typhoid mortality rate) produces an estimated effect of filtration on the typhoid mortality rate that is less precise than the other estimates in Table 12 but about twice their size: in this specification, filtration is associated with 10.3 fewer typhoid deaths per 100,000 population, or an 80 percent reduction relative to the sample mean.

In Table 13, we decompose the filtration indicator into a series of mutually exclusive lags. Similar to the results for infant mortality, the effect of filtration on typhoid mortality gradually becomes stronger over time. Replacing the filtration indicator with a series of its leads and lags produces a similar pattern of results (Figure 7). The filtration effect steadily becomes stronger after *Year 0* and there is no evidence that typhoid mortality was trending downwards during the years leading up to the adoption of filtration technology.[39]

[39] In Appendix Table 1, we explore the robustness of the diarrhea/enteritis results originally reported in Table 11. The estimated effect of filtration on the diarrhea/enteritis mortality rate is consistently negative, although it loses significance when we drop the years 1917-1920 or specify the dependent variable in levels. Controlling for region-by-year fixed effects produces evidence that the construction of a clean water project led to a substantial reduction in diarrhea/enteritis mortality. Results reported in Appendix Table 2 and Appendix Figure 7 indicate that the effect of filtration on diarrhea/enteritis mortality gradually became stronger over time. Finally, we experimented with the wild cluster bootstrap method for inference suggested by Cameron et al. (2008) and Cameron and Miller (2015). Appendix

6. COMPARING OUR ESTIMATES TO THOSE OF CUTLER AND MILLER

Using data from 13 major American cities for the period 1900-1936, Cutler and Miller (2005), hereafter C&M, investigate the effects of water filtration and chlorination on mortality. C&M's empirical strategy is similar to ours and their mortality data also come from *Mortality Statistics*. They find that water filtration is associated with a reduction in total mortality of .16 log points (= -15 percent) and a reduction in infant mortality of .43 log points (= -35 percent). C&M's estimate of the effect of filtration on typhoid mortality is almost exactly equal to our estimate (reported in the first column of Table 11). However, C&M's infant and total mortality estimates are considerably larger. In this section, we explore why.

We begin by successfully reproducing C&M's estimates of the effects of filtration and chlorination on total mortality using their specification and original data. These estimates are reported in column (1) of Table 14.[40] While C&M's specification is similar to ours, they control for 5 lags of the total mortality rate. Because the inaugural issue of *Mortality Statistics* was published in 1900, including these lags effectively restricted their analysis to the period 1905-1936. In Appendix Table 4, we compare their specification and sample to ours.[41]

In column (2) of Table 14, we correct their standard errors for clustering at the municipal level (Bertrand et al. 2004). With this correction, the filtration coefficient is still significant at the 5 percent level, but the coefficient of the interaction between chlorination and filtration is no longer statistically significant. C&M interpreted the positive and significant coefficient of the interaction between chlorination and filtration as evidence that these were "substitute technologies" (p. 11).

Table 3 reports our preferred filtration estimates for infant, typhoid, diarrhea/enteritis and diarrhea/enteritis (under age 2) mortality but also includes a row of p-values calculated from the wild bootstrap procedure for comparison.

[40] We are grateful to Cutler and Miller for graciously providing us with their data and do-file. These estimates correspond to those reported by C&M in the second column of Table 5.

[41] In Appendix Table 5, we list and describe the controls used by C&M.

In the third column of Table 14, we correct a minor transcription error. Memphis did not provide mortality data to the U.S. Census Bureau in 1916, so C&M assigned Memphis a total mortality rate of zero for this year. Because they used a semi-log specification, the 1916 Memphis observation was dropped from their regression, but the 5 lags of the 1916 Memphis total mortality rate were incorrectly coded as zeros. Dropping these 5 observations with missing lagged mortality rates reduces the estimated effect of filtration from -.16 log points to -.13 log points.

In the fourth column of Table 14, we correct transcription errors in C&M's total mortality counts for the period 1910-1917[42]; in the fifth column, we correct their chlorination and filtration dates.[43] Combined, these corrections reduce the filtration estimate still further, to -.051 log points. In the last column of Table 14, we switch from C&M's specification to ours but restrict the sample to their years (i.e., 1905-1936) and cities. Filtration is associated with a statistically insignificant reduction in total mortality of .046 log points, which is less than a third the size of C&M's original estimate, although still much larger than the estimate we report in the last column of Table 6, which suggests that the effect of filtration on total mortality in the 13 cities analyzed by C&M may have been larger than its effect in our expanded sample of 25 cities.

[42] C&M make systematic transcription errors for the years 1910-1917. In these city-year combinations, total mortality counts are reported with decimal values. In Appendix Table 6a, we list the correct counts from *Mortality Statistics* alongside the incorrect values recorded by C&M. With a few exceptions, the differences between their counts and the correct counts are not large. However, their counts for Detroit are up to 35 percent larger than the correct counts from *Mortality Statistics*. Likewise, their counts for Jersey City are up to 8 percent smaller than the correct counts.

[43] The majority of these corrections were trivial. For instance, according to C&M, Baltimore began filtering its water supply in 1914, but the Montebello Water Filtration Plant did not begin operations until September 13, 1915 (Hendrickson 2012). However, the chlorination dates provided by C&M for Memphis, Milwaukee and St. Louis are off by at least 5 years. Memphis began chlorinating its water supply in 1920, not after 1936 (Typhoid in the Large Cities 1921, 1922); Milwaukee began chlorinating its water supply in 1910, not 1915 (Jennings 1918); and St. Louis began chlorinating its water supply in 1913, not 1919 (Wall 1920). Chicago began experimenting with chlorinating its water supply in 1912, but full chlorination was not achieved until 1917 (Jennings 1923). We chose to use 1912 as the start date for Chicago chlorination but using 1917 does not appreciably change our results or those of C&M. Likewise, the process of delivering filtered water to all the neighborhoods of Philadelphia began before 1906 and was not completed until 1909 (Philadelphia 1909). We chose to use 1906 as the start date for Philadelphia filtration but using 1909 does not appreciably change our results or those of C&M.

We turn our attention to C&M's infant mortality estimates in Table 15. Again, we begin by reproducing C&M's estimates of the effects of chlorination and filtration on infant mortality using their original data.[44] In the second column of Table 15, we show that the estimated relationship between filtration and infant mortality is still significant at the one percent level after correcting their standard errors for clustering at the municipal level. In the third column, we drop the 5 Memphis observations with missing lagged total mortality, which reduces the estimated effect of filtration on infant mortality from -.43 to -.37 log points. In the fourth column, we correct transcription errors in C&M's infant mortality counts. These errors are detailed in Appendix Table 6b.[45] Correcting them reduces the estimated effect of filtration on infant mortality by almost two-thirds, from -.37 log points to -.13 log points. Correcting C&M's chlorination and filtration dates reduces the filtration estimate still further, to a statistically insignificant -.067 log points. Finally, when we switch from C&M's specification to ours (but restrict the sample to their years and cities), filtration is associated with a reduction in infant mortality of .10 log points, which is similar in magnitude to our estimates reported in Table 7.[46]

[44] These estimates correspond to those reported by C&M in the third column of Table 5.

[45] In 9 out of the 13 cities in their sample, C&M make systematic transcription errors for the years 1910-1917. In these city-year combinations, infant mortality counts are reported with decimal values. In Appendix Table 6b, we list the correct counts from *Mortality Statistics* alongside the incorrect values recorded by C&M. The differences between their recorded values and the correct counts are not large for some cities, such as Chicago and St. Louis. For other cities, however, the differences are substantial. For instance, the values recorded by C&M for Memphis and New Orleans are roughly 50 percent smaller than the correct counts from *Mortality Statistics*. In all cases, the values recorded by C&M are less than the true values. In addition to the systematic errors for the period 1910-1917, C&M make several other transcription mistakes, some of which can easily be explained. For example, for Pittsburgh in 1901, C&M appear to have incorrectly recorded the overall mortality count (6,578 deaths) instead of the infant mortality count (1,580 deaths). For Pittsburgh in 1904, they appear to have incorrectly recorded 1,771 infant deaths as "771" infant deaths.

[46] A final difference between C&M's specification and ours is that they divide infant mortality by infant population rather than overall population when calculating the infant mortality rate. If we do this, the filtration estimate reported in column (6) in Table 15 becomes smaller in magnitude and loses precision (*Filtration* estimate = -.065, with a standard error = .045).

7. GAUGING THE OVERALL IMPACT OF FILTRATION

By 1940, 17 out of the 25 cities in our sample were filtering their water supply. To gauge the extent to which the infant mortality decline documented in Figure 2 can be explained by filtration, we calculated a predicted infant mortality rate for every year *t* (and its 90 percent confidence interval) under the assumption that no filtration plants were constructed during the period 1900-1940. Predicted mortality infant rates are from a regression model that controls for the variables listed in Table 5, city fixed effects, year fixed effects and city-specific linear trends. The results from this exercise are shown in Figure 8 and actual infant mortality rates for the cities in our sample are also plotted for reference.

The actual and predicted mortality rates are not far apart throughout the period under study, suggesting that filtration did not contribute substantially to the observed decline in infant mortality. For instance, the actual infant mortality rate among the 25 cities in our sample was 80 per 100,000 population in 1940. In the absence filtration plants, we predict that it would have been 97 per 100,000 population. Even using the upper bound of the 90 percent confidence interval, we predict that the infant mortality rate would have fallen by 71 percent (from 383 to 110 per 100,000 population) had no filtration plants been built by the 25 municipalities in our sample during the period 1900-1940.

To gauge whether the typhoid mortality decline documented in Figure 3 can be explained by filtration, we calculated a predicted typhoid mortality rate for every year *t* (and its 90 percent confidence interval) under the assumption that no water filtration plants were built (Figure 9). The actual typhoid mortality rate among the 25 cities in our sample was 0.44 per 100,000 population in 1940. In the absence of filtration plants, we predict that it would have been 8.3 per 100,000 population. Using the upper bound of the 90 percent confidence interval, we predict that the

typhoid mortality rate would have fallen by 59 percent (from 39 to 16 per 100,000 population) had no filtration plants been built during the period 1900-1940.[47]

8. CONCLUSION

The mortality transition is of obvious importance to policymakers and economic historians, but its causes are not well understood. Prominent economists such Fogle and McKeown have argued that rising incomes and better nutrition were the primary drivers of the morality transition (McKeown and Record 1962; McKeown 1976; Fogel 1997, 2004). More recently, however, economists have emphasized the role of municipal-level public health interventions. For instance, Costa (2015) argues that filtration and chlorination were the primary drivers of the reduction in infant mortality; citing Cutler and Miller (2005), Cutler et al. (2006) argue that public health interventions such filtration and chlorination were responsible for the dramatic reductions in food- and water-borne diseases at the turn of the 20th century.

In this study, we reevaluate the impact of public health interventions on the urban mortality decline in the United States at the turn of the 20th century. Specifically, using data on 25 major American cities for the years 1900-1940, we attempt to distinguish the effects of municipal-level efforts to purify water and milk supplies. Previous researchers, including Cutler and Miller (2005), Troesken (2004), Beach et al. (2016) and Knutsson (2018) focus on estimating the contributions of filtering and chlorinating drinking water to the urban mortality decline. In addition to these interventions, we examine the treatment of sewage before discharging it into lakes, rivers and

[47] In Appendix Figures 8 and 9, we repeat these exercises for infant and typhoid mortality, respectively, under the assumption that no water-related interventions had been implemented by the 25 municipalities in our sample during the period 1900-1940. These results are similar to those shown in Figures 8 and 9. In Appendix Figures 10 and 11, we gauge the extent to which the observed diarrhea/enteritis mortality decline can be explained by filtration and, more generally, by water-related interventions, respectively. In both figures, the actual and predicted rates are never far apart throughout the period under study, suggesting that water-related technologies did not contribute substantially to the decline in diarrhea/enteritis mortality.

streams, the construction of large-scale projects designed to deliver clean water from further afield, requirements that milk sold within city limits meet strict bacteriological standards and requirements that milk come from tuberculin-tested cows.

Consistent with the results of turn-of-the-20th-century studies (Clark 1907; Johnson 1907; Sedgwick and MacNutt. 1910; Johnson 1913; McLaughlin 1912a), as well as more recent research (Troesken 2004; Cutler and Miller 2005; Beach et al. 2016), we find that filtering the municipal water supply sharply reduced typhoid mortality. For instance, after 5 or more years, filtration is associated with more than a 60 percent reduction in the typhoid mortality rate. More generally, however, our results are not consistent with the argument that municipal public health interventions were important drivers of non-typhoid mortality. Specifically, we find little evidence that the chlorination of water supplies or the milk-related interventions under study affected mortality. Likewise, we find little evidence that treating sewage (i.e., using chemical or biological processes to remove contaminants from waste water) was effective.[48]

By contrast, the building of a water filtration plant is negatively associated with infant mortality. Nonetheless, filtration can explain, at most, only a small fraction of the overall decline in infant mortality observed during the period 1900-1940. Although we find evidence that water filtration led to reductions in diarrheal mortality, our results suggest that filtration alone cannot explain why diarrheal mortality fell so precipitously after 1900.

Leaning on the results of Cuter and Miller (2005), scholars such as Cutler et al. (2006) and Costa (2015) argue that municipal public health efforts were important drivers of the mortality transition at the turn of the 20th century. Because the study by Cutler and Miller (2005) is so influential, it is important to document why our results are different from theirs. Using their original

[48] It is worth reiterating that we cannot examine the effects of providing sewerage (i.e., the building and extending of sewer systems) because, by the early 1900s, every major U.S. city was providing sewerage to its residents (Melosi 2008; Hoagland 2018).

data and specification, we find that the estimated effect of filtration on total mortality shrinks by half, from -.16 log points to -.08 log points, when we correct a series of transcription errors. Correcting transcription errors in their infant mortality counts reduces the estimated effect of filtration on infant mortality by two-thirds, from -.43 log points to -.13 log points.

If public health interventions such as chlorination and filtration cannot explain why mortality fell between 1900 and 1940, what can? Our results point to other factors such as better living conditions and improved nutrition as being responsible for the sharp decline in urban mortality at the turn of the 20th century. However, this is admittedly an educated guess. We hope that readers will embrace the implicit challenge inherent in our results and redouble their efforts to discover the true causes of the urban mortality transition.

REFERENCES

Allen, Kenneth. 1918. "Water Purification and Sewage Treatment." *Municipal Engineering*, 55(1): 244-251.

Alsan, Marcella and Claudia Goldin. 2015. "Watersheds in Infant Mortality: The Role of Effective Water and Sewerage Infrastructure, 1880 to 1915." NBER Working Paper No. 21263

Alsan, Marcella and Claudia Goldin. 2018. "Watersheds in Child Mortality: The Role of Effective Water and Sewerage Infrastructure, 1880 to 1920." NBER Working Paper N. 21263.

Anderson, D. Mark, Ryan Brown, Kerwin Charles, and Daniel Rees. 2016. "The Effect of Occupational Licensing on Consumer Welfare: Early Midwifery Laws and Maternal Mortality." NBER Working Paper No. 22456.

Anderson, D. Mark, Kerwin Charles, Claudio Las Heras Olivares, and Daniel Rees. "Was the First Public Health Campaign Successful? The Tuberculosis Movement and its Effect on Mortality." Forthcoming at *American Economic Journal: Applied Economics*.

Ardern, Edward and William T. Lockett. 1914 "Experiments on the Oxidation of Sewage Without the Aid of Filters." *Journal of the Society of Chemical Industry*, 33(10): 523 – 539.

Armstrong, Gregory L., Laura A. Conn, and Robert W. Pinner. 1999. "Trends in Infectious Disease Mortality in the United States during the 20th Century." *The Journal of the American Medical Association*, 281(1): 61-66.

Arnold, Benjamin F. and John M. Colford. 2007. "Treating Water with Chlorine at Point-of-Use to Improve Water Quality and Reduce Child Diarrhea in Developing Countries: A Systematic Review and Meta-Analysis." *American Journal of Tropical Medicine and Hygiene*, 76(2): 354-364.

Ashraf, Nava, Diego Aycinena, Claudia Martinez and Dean Yang. 2015. "Savings in Transnational Households: A Field Experiment among Migrants from El Salvador." *Review of Economics and Statistics*, 47(2): 332-351.

Ayers, Henry S. 1932. "The Present Status of the Pasteurization of Milk" Bulletin No. 342 (revised). Washington, D.C.: United States Department of Agriculture.

Baker, Moses M. 1910. "The Economic and Sanitary Supervision of City Milk Supplies." *Statistics of Cities Having a Population of Over 25,000: 1907*. Washington, D.C.: Government Printing Office, pp. 36-45.

Baylis, John R. 1949. "Chicago South District Filtration Plant." *Journal of the American Water Works Association*, 41(7): 599-615.

Beach, Brian, Joseph Ferrie, Martin Saavedra, and Werner Troesken. 2016. "Typhoid Fever, Water Quality, and Human Capital Formation." *Journal of Economic History*, 76(1): 41-75.

Bente, Lisa and Shirle Gerrior. 2002. "Selected Food Highlights of the 20th Century: U.S. Food

Supply Series." *Family Economics and Nutrition Review*, 14(1): 43-52.

Bertrand, Marianne, Esther Duflo and Sendhil Mullainathan. 2004. "How Much Should We Trust Difference-In-Difference Estimates?" *Quarterly Journal of Economics*, 119(1): 249-275.

Bhalotra, Sonia R. Alberto Diaz-Cayeros, Grant Miller, Alfonso Miranda, and Atheendar S. Venkataramani. 2017. "Urban Water Disinfection and Mortality Decline in Developing Countries." NBER Working Paper No. 23239.

Bowles, James T.B. 1919. "Chlorination of Water and Sewage" *Water and Gas Review*, 29(10): 22.

Brosco, Jeffrey P. 1999. "The Early History of the Infant Mortality Rate in America: A Reflection Upon the Past and a Prophecy of the Future." *Pediatrics*, 103(2): 478-485.

Bry, Gerhard. 1960. *Wages in Germany, 1871-1945*. Princeton, NJ: Princeton University Press

Bureau of Labor Statistics. 1973. *Handbook of Labor Statistics*, 1973. U.S. Department of Labor, Washington, D.C.: U.S. Government Printing Office.

Cain, Louis P. 1977. *Sanitation Strategy for a Lakefront Metropolis: The Case of Chicago*. Dekalb, IL: Northern Illinois University Press.

Cain, Louis P. and Elyce J. Rotella. 2001. "Death and Spending: Urban Mortality and Municipal Expenditure on Sanitation." *Annales De Demographie Historique*, 1: 139-154.

Cain, Louis P. and Sok Chul Hong. 2009. "Survival in 19th Century Cities: The Larger the City, the Smaller Your Chances." *Explorations in Economic History*, 46(4): 450–463.

Cameron, A. Colin, Jonah Gelbach, and Douglas Miller. 2008. "Bootstrap-Based Improvements for Inference with Clustered Errors." *Review of Economics and Statistics*, 90(3): 414-427.

Cameron, A. Colin and Douglas Miller. 2015. "A Practitioner's Guide to Cluster-Robust Inference." *Journal of Human Resources*, 50(2): 317-372.

Carey, Francis K. 1913. "Report of the Milk Committee." *Civic Courier*, 1(5): 8.

Cheney, Rose A. 1984. "Seasonal Aspects of Infant and Childhood Mortality: Philadelphia, 1865-1920." *Journal of Interdisciplinary History*, 14(3): 561-585.

Clark, Harry W. 1907. "Filtration of Public Water Supplies." *Journal of the American Medical Association*, 46(9): 742-745.

Clark, Harry W. 1921. "Water Supplies and the Typhoid Rate." *The American City*, 24(February): 171-175.

Clay, Karen, Werner Troesken, and Michael Haines. 2014. "Lead and Mortality." *Review of Economics and Statistics*, 96(3): 458-470.

Clement, Clarence Elbert and Gustav Paul Warber. 1918. "The Market Milk Business of Detroit, Mich., in 1915." *United States Department of Agriculture Bulletin No. 639* (February 15).

Condran, Gretchen A. 1988. "Declining Mortality in the United States in the late Nineteenth and Early Twentieth Centuries." *Annales de Démographie Historique*, 1: 119-141.

Costa, Dora. 2015. "Health and the Economy in the United States, from 1750 to the Present." *Journal of Economic Literature*, 53(3): 503–570.

Costa, Dora and Matthew Kahn. 2015. "Declining Mortality Inequality within Cities during the Health Transition." *American Economic Review*, 105(5): 564-569.

Cutler, David M. and Grant Miller. 2005. "The Role of Public Health Improvements in Health Advances: The twentieth-century United States." *Demography*, 42(1): 1–22.

Cutler, David, Angus Deaton, and Adriana Lleras-Muney. 2006. "The Determinants of Mortality." *Journal of Economic Perspectives*, 20(3): 97-120.

Czaplicki, Alan. 2007. "Pure Milk Is Better Than Purified Milk": Pasteurization and Milk Purity in Chicago, 1908-1916." *Social Science History*, 31(3): 411-433

Detroit Water and Sewerage Department. 2002. *Detroit Water and Sewerage Department: The First 300 Years* (Daisy, Michael, editor). Detroit, MI: Detroit Water and Sewerage Department.

Eddy, Harrison P. 1913. "Report upon Necessity and Feasibility of Treating the Sewage of Cincinnati before its Discharge into the Ohio River." *Progress Report on a Plan of Sewerage for the City of Cincinnati*. Cincinnati (Ohio), Cincinnati Department of Public Works, pp. 295-610.

Elms, J.W. 1914. "Relation of Purity of Water-Supply to Typhoid Fever at Cincinnati, Ohio." *Engineering News*, 71(5): 239.

Ferrie, Joseph, and Troesken, Werner. 2008. "Water and Chicago's Mortality Transition, 1850–1925." *Explorations in Economic History*, 45(1): 1-16.

Fogel, Robert W. 1997. "New Findings on Secular Trends in Nutrition and Mortality: Some Implications for Population Theory." *Handbook of Population and Family Economics*, 1, Part A: 433-481.

Fogel, R. 2004. *The Escape from Hunger and Premature Death, 1700–2100: Europe, America and the Third World*, Cambridge, U.K.: Cambridge University Press

Foss-Mollan, Kate. 2001. *Hard Water: Politics and Water Supply in Milwaukee, 1870-1995.* West Lafayaette, IN: Purdue University Press.

Frenk, Julio, José L. Bobadilla, Jaime Sepulveda, and Malaquias López Cervantes. 1989. "Health Transition in Middle-Income Countries: New Challenges for Health Care." *Health Policy and Planning*, 4(1): 29–39.

Fuchs, A.W. and L.C. Frank. 1939. "Milk Supplies and their Control in American Urban Communities of over 1,000 Population in 1936." *Public Health Bulletin 245*. Washington D.C.: Government Printing Office.

Galiani, Sebastian, Paul Gertler, and Ernesto Schargrodsky. 2005. "Water for Life: The Impact of the Privatization of Water Services on Child Mortality." *Journal of Political Economy*, 113(1): 83-120.

Gruber, Joshua S., Fermin Reygadas, Benjamin F. Arnold, Isha Ray, Kara Nelson, and John M. Colford. 2013. "A Stepped Wedge, Cluster-Randomized Trial of a Household UV-Disinfection and Safe Storage Drinking Water Intervention in Rural Baja California Sur, Mexico." *American Journal of Tropical Medicine and Hygiene*, 89(2): 238-245.

Gustaitis, Joseph. 2013. *Chicago's Greatest Year, 1893: The White City and the Birth of a Modern Metropolis*. Carbondale, IL: Southern Illinois University Press.

Haines, Michael R. 2001. "The Urban Mortality Transition in the United States, 1800-1940." *Annales de Démographie Historique*, 1:33–64.

Hanson, Warren D. 2005. *A History of the Municipal Water Department and Hetch Hetchy System.* San Francisco, CA: San Francisco Public Utilities Commission.

Harding, H.A. 1917. "City Milk and the Public Health". *Annual Report of the Illinois Farmers' Institute*, 22: 52-58.

Hendrickson, Martha A. 2012. "The Montebello Water Filtration Plant I: Clean Water for City & Suburb Alike." History Trails, 43(3-4): 1-20.

Hering, Rudolph and George W. Fuller. 1907. "Sewage Disposal at Chicago and Vicinity." *Engineering Record*, 55(5): 130-134.

Hill, Nicholas, S. 1911. "Bleaching Powder as an Agent in the Purification of Water." *Engineering Record*, 63(18): 491-494

Hoagland, Alison K. 2018. *The Bathroom: A Social History of Cleanliness and the Body*. Santa Barbara, CA: ABC-CLIO.

Hooker, Albert H. 1913. *Chloride of Lime in Sanitation*. New York: John Wiley and Sons.

Horton, Theodore. 1906. "The Prevalence and Causation of Typhoid Fever in Washington, D. C." *Engineering News*, 56(19): 484-488.

Jennings, C. A. 1918. "Some Results Secured by Chlorine Compounds in Water Purification and Sewage Treatment." *Municipal Engineering*, 55(1): 249-251.

Jennings, C. A. 1923. "The Disinfection of Public Water Supplies and its Relation to Public Health." *Journal of the American Water Works Association,* 10(1): 127-138.

Johnson, George A. 1914a. "The Filtration of Public Water Supplies." *The American City*, 10(5): 478-483.

Johnson, George A. 1914b. "Present Day Water Filtration Practice." *Fire and Water Engineering*, 56(9): 131-132.

Johnson, George A. 1913. "Typhoid Fever in Large American Cities." *Engineering News*, 70(10): 473-475.

Johnson, William S. 1907. "The Quality of Public Water Supplies." *Journal of the American Medical Association*, 49(9): 762-764.

Jones, David S. and Jeremy A. Greene. 2013. "The Decline and Rise of Coronary Heart Disease: Understanding Public Health Catastrophism." *American Journal of Public Health*, 103(7): 1207–1218.

Jones, David S., Scott H. Podolsky, and Jeremy A. Greene. 2012. "The Burden of Disease and the Changing Task of Medicine." *New England Journal of Medicine*, 366(25): 2333-2338.

Jordan, Edwin O. 1916. "Purification of Water Supplies." *Scientific American Supplement*, 2112: 406-407.

Kesztenbaum, Lionel and Jean-Laurent Rosenthal. 2017. "Sewers' Diffusion and the Decline of Mortality: The Case of Paris, 1880–1914." *Journal of Urban Economics*, 98(March): 174-186.

Keyes, A.A. 1901. "Report of the City Veterinarian." *Annual Reports of the Various City Officers of the City of Minneapolis, Minnesota.* Minneapolis, MN: Harrison and Smith, Co., Printers, pp. 576-577.

Kiefer, Guy L. 1911. "Report of the Milk Inspector." *Thirtieth Annual Report of the Board of Health of the City of Detroit for the Fiscal Year Ending June 30, 1911*. Detroit, MI: Board of Health, pp. 94-106.

Kienle, John A. 1919. "The Relation of the Chemical Industry of Niagara Falls to the Water Works." *Journal of the American Water Works Association*, 6(3): 496-513.

Komisarow, Sarah. 2017. "Public Health Regulation and Mortality: Evidence from Early 20th Century Milk Laws." *Journal of Health Economics*, 56(December): 126-144.

Knutsson, Daniel. 2018. "Urban Water Improvement and Health: Evidence from the Early Stages of Industrialisation." Available at: http://www2.ne.su.se/paper/wp17_02.pdf.

Lane, C.B. and Ivan C. Weld. 1908. "A City Milk and Cream Contest as a Practical Method of Improving the Milk Supply." *Bureau of Animal Industry Circular 117*. Washington D.C.: Government Printing Office.

Levitt, Alexandra M., D. Peter Drotman, and Stephen Ostroff. 2007. "Control of Infectious Diseases: A Twentieth Century Public Health Achievement." In: Ward J.W. and Warren C., editors. *Silent Victories: The History and Practice of Public Health in Twentieth America.* New York, NY: Oxford University Press, pp. 3-17.

Margo, Robert A. 1993. "Employment and Unemployment in the 1930s." *Journal of Economic Perspectives*, 7(2): 41-59.

McCarthy, Michael P. 1987. *Typhoid and the Politics of Public Health in Nineteenth-Century Philadelphia*. Philadelphia, PA: American Philosophical Society.

McKeown, Thomas and R.G. Record. 1962. "Reasons for the Decline of Mortality in England and Wales during the Nineteenth Century." *Population Studies*, 16(2): 94–122.

McKeown, Thomas. 1976. *The Modern Rise of Population*. New York, NY: Academic Press.

McLaughlin, Allan J. 1912a. "The Necessity for Safe Water Supplies in the Control of Typhoid Fever." *Public Health Reports*, 27(12): 421-431.

McLaughlin, Allan J. 1912b. "Sewage Pollution of Interstate and International Waters: With Reference to the Spread of Typhoid Fever." *Hygienic Laboratory--Bulletin* No. 83 (March) Washington D.C.: Government Printing Office.

Meckel, Richard A. 1990. Save the Babies: American Public Health Reform and the Prevention of Infant Mortality, 1850–1929. Baltimore, MD: Johns Hopkins University Press.

Melosi, Martin V. 2008. *The Sanitary City: Urban Infrastructure in America from Colonial Times to the Present*. Pittsburgh: The University of Pittsburgh Press.

Milwaukee (WI), Common Council. 1918. *Proceedings of the Common Council of the City of Milwaukee: For the Year Ending April 16, 1918*. Milwaukee, WI: Phoenix Printing, Co.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

Morse, Robert B. and Harry R. Hall. 1919. "Progress of Water Disinfection in Maryland." *Municipal Journal and Public Works*, 46(23): 405-407.

Nixon, Scott W. 1995. *Metal Inputs to Narragansett Bay: A History and Assessment of Recent Conditions*. Narragansett, RI: Rhode Island Sea Grant Communications Office.

Olmstead, Alan and Paul Rhode. 2004a. "An Impossible Undertaking: The Eradication of Bovine Tuberculosis in the United States." *Journal of Economic History*, 64(3): 734–772.

Olmstead, Alan and Paul Rhode. 2004b. "The 'Tuberculous Cattle Trust': Disease Contagion in an Era of Regulatory Uncertainty." *Journal of Economic History*, 64(4): 929-963.

Olmstead, Alan and Paul Rhode. 2007. "Not on My Farm! Resistance to Bovine Tuberculosis Eradication in the United States." *Journal of Economic History,* 67(3): 768-809.

Omran, Abdel R. 2005. "The Epidemiologic Transition: A Theory of the Epidemiology of Population Change." *Milbank Memorial Fund Quarterly*, 83(4): 731–757.

Orchard, William J. 1917. “Filtration, the First Line of Defense.” *Engineering Record*, 75(13): 516.

Parker, Horatio N. 1917. *City Milk Supply*. New York, NY: McGraw-Hill Book Company, Inc.

Phelps, Earle B. 1918. “The Control of Stream Pollution.—A Problem in Economics.” *Water and Sewage Works*, 55(1): 22-24.

Philadelphia (PA), 1909. *Description of the Filtration Works and Pumping Stations: Also Brief History of the Water Supply.* Philadelphia, PA: Bureau of Water.

Pietrangel, Ann. 2016. “Enteritis.” Available at: https://www.healthline.com/health/enteritis.

Price, R. M. 1939. “The Bovine Tubercle Bacillus in Human Tuberculosis.” *American Journal of the Medical Sciences*, 197: 411–427.

Race, Joseph. 1918. *The Chlorination of Water.* New York, NY: John Wiley and Sons, Inc.

Rees, Albert and Donald P. Jacobs. 1961. *Real Wages in Manufacturing, 1890-1914*. Princeton, NJ: Princeton University Press.

Reynolds, Arthur R. 1894. “The Water Supply of Chicago: Its Source and Sanitary Aspects.” *Annual Report of the Department of Health of the City of Chicago for the Year Ended December 31, 1894*, pp. xxxvii-xlvii.

Reynolds, Leon B. 1933. “History of Chemical Precipitation.” *Sewage Works Journal*, 5(4): 595-599.

Riley, James C. 2005. “Estimates of Regional and Global Life Expectancy, 1800–2001.” *Population and Development Review*, 31(1) 537-543.

Rosenau, Milton J. 1908. “The Number of Bacteria in Milk and the Value of Bacterial Counts.” In *Milk and its Relation to the Public Health*, Washington D.C.: Government Printing Office, pp. 429-453.

Sedgwick, William T. 1906. “Comments upon Mr. Horton’s Report and upon the Typhoid Fever Situation in the District of Columbia.” *Engineering News*, 56(19): 488-489.

Sedgwick, William T. and J. Scott MacNutt. 1910. “On the Mills-Reincke Phenomenon and Hazen's Theorem concerning the Decrease in Mortality from Diseases Other than Typhoid Fever following the Purification of Public Water-Supplies.” *Journal of Infectious Diseases*, 7(4): 489-564.

Sells, Benjamin. 2017. *The Tunnel under the Lake: The Engineering Marvel That Saved Chicago*. Evanston, IL: Northwestern University Press.

Skelly, Al. 1944. “Concerning San Francisco Ordinance Requiring Pasteurization of Milk.” *California and Western Medicine*, 60(6): 355.

Stein, Milton F. 1919. “Features of Present-Day Water Purification Practice.” the *Municipal and County Engineering*, 56(2): 57-69.

Swinford, Michael. 2016. "Urban-Rural Tensions, 1880-1930." In: Pamela Riney-Kehrberg (ed.), *The Routledge History of Rural America*, New York, NY: Routledge, pp. 245-259.

Tarozzi, Alessandro, Aprajit Mahajan, Brian Blackburn, Dan Kopf, Lakshmi Krishnan and Joanne Yoong. 2014. "Micro-loans, Insecticide-Treated Bednets, and Malaria: Evidence from a Randomized Controlled Trial in Orissa, India." *American Economic Review*, 104(7): 1909-1941.

Tarr, Joel A., James McCurley, Francis C. McMichael and Terry Yosie. 1984. "Water and Wastes: A Retrospective Assessment of Wastewater Technology in the United States, 1800-1932." *Technology and Culture*, 25(2): 226-263.

Thomas, Duncan, Elizabeth Frankenberg, Jed Friedman, Jean-Pierre Habicht, Mohammed Hakimi, Nicholas Ingwersen, Jaswadi, Nathan Jones, Christopher McKelvey, Gretel Pelto, Bondan Sikoki, Teresa Seeman, James Smith, Cecep Sumantri, Wayan Suriastini and Siswanto Wilopo. 2006. "Causal Effect of Health on Labor Market Outcomes: Experimental Evidence." CCPR-070-06. Available at: http://escholarship.org/uc/item/0g28k77w.

Troesken, Werner. 2004. *Water, Race, and Disease*. Cambridge, MA: MIT Press.

Troesken, Werner. 2015. *The Pox of Liberty: How the Constitution Left Americans Rich, Free, and Prone to Infection.* Chicago, IL: University of Chicago Press.

"Typhoid in the Large Cities of the United States in 1920." 1921. *JAMA* (editorial), 76(13): 860-863.

"Typhoid in the Large Cities of the United States in 1921." 1922. *JAMA* (editorial), 78(12): 890-893.

Unknown Author. 1918. "Cleveland's New Filtration Plant in Operation." *Municipal Journal*, 44(13): 266-267.

United States Bureau of the Census. 1906-1938. *Mortality Statistics* (annual reports). Washington, D.C.: United States Government Printing Office.

United States Bureau of the Census. 1939-1941, 1943. *Vital Statistics of the United States* (annual reports). Washington, D.C.: United States Government Printing Office.

Wall, Edward E. 1920. "Water Treatment at St. Louis Mo." *American Journal of Public Health*, 10(5): 437-443.

Whipple, George C. 1913. "Sewage Treatment vs. Sewage Purification." *American Journal of Public Health*, 3(6): 513-523.

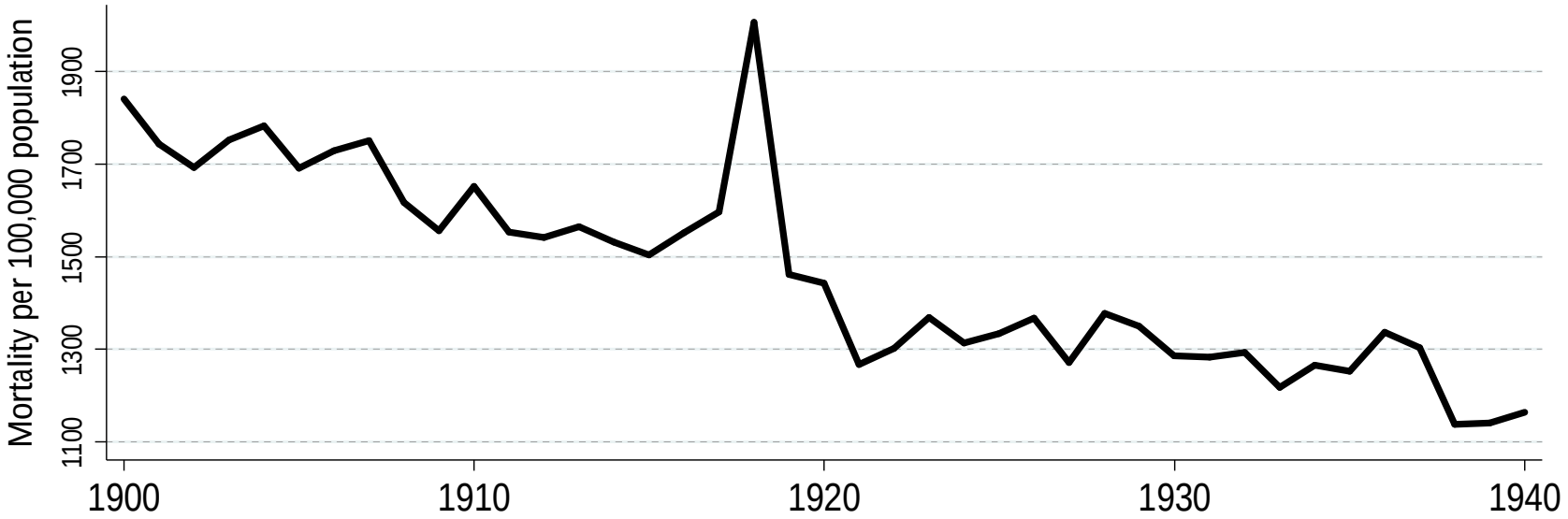
Whipple, George C. 1914. "The Broadening Science of Sanitation." *The Atlantic Monthly*, 113(May): 630-641.

Woodword, William C. 1907. "Report of the Health Officer." *Annual Report of the Commissioners of the District of Colombia.* Washington D.C.: Government Printing Office, pp. 7-34.

Wolf, Jacqueline H. 2001. *Don't Kill Your Baby: Public Health and the Decline of Breastfeeding in the Nineteenth and Twentieth Centuries*. Columbus, OH: Ohio State University Press.

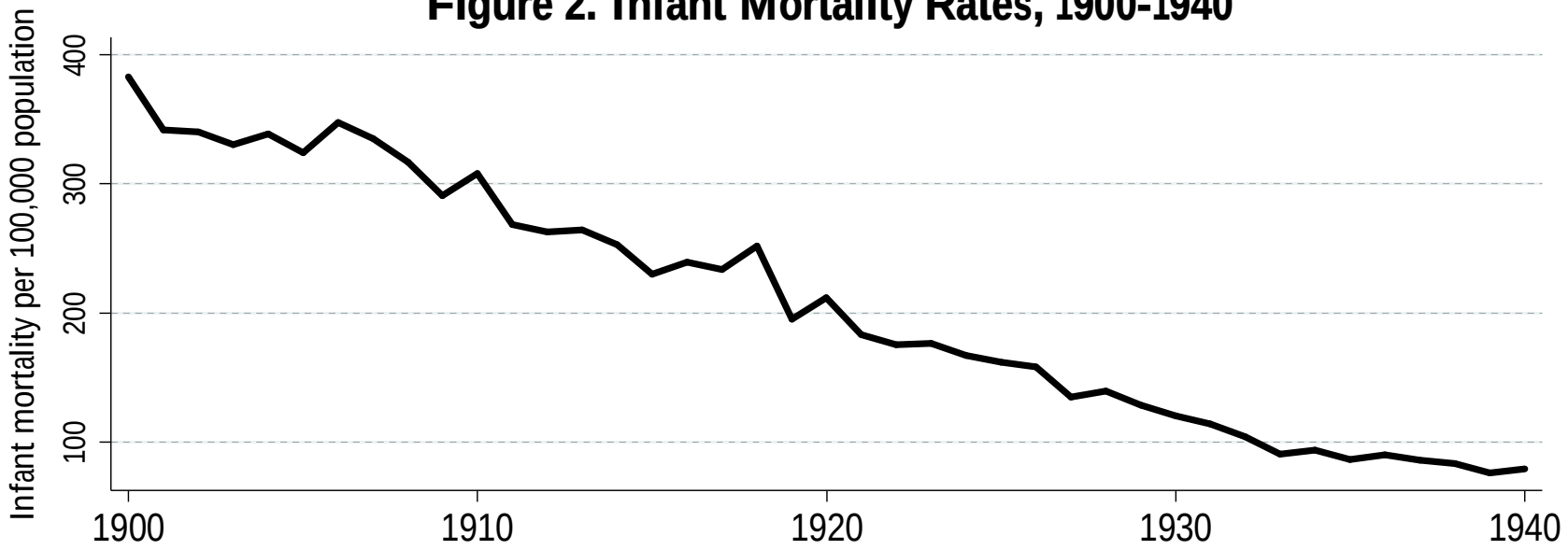
Wolf, Jacqueline H. 2003. "Low Breastfeeding Rates and Public Health in the United States." *American Journal of Public Health*, 93(12): 2000–2010.

Figure 1. Overall Mortality Rates, 1900-1940



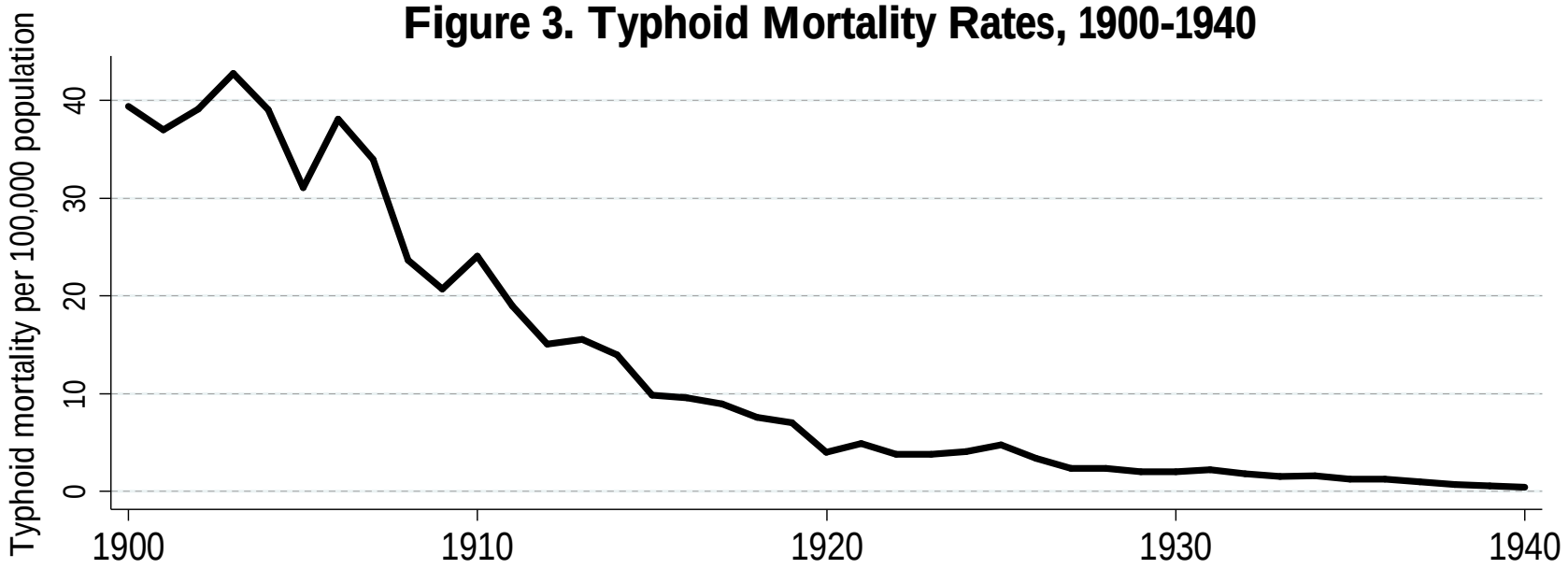
Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1940, published by the U.S. Census Bureau.

Figure 2. Infant Mortality Rates, 1900-1940



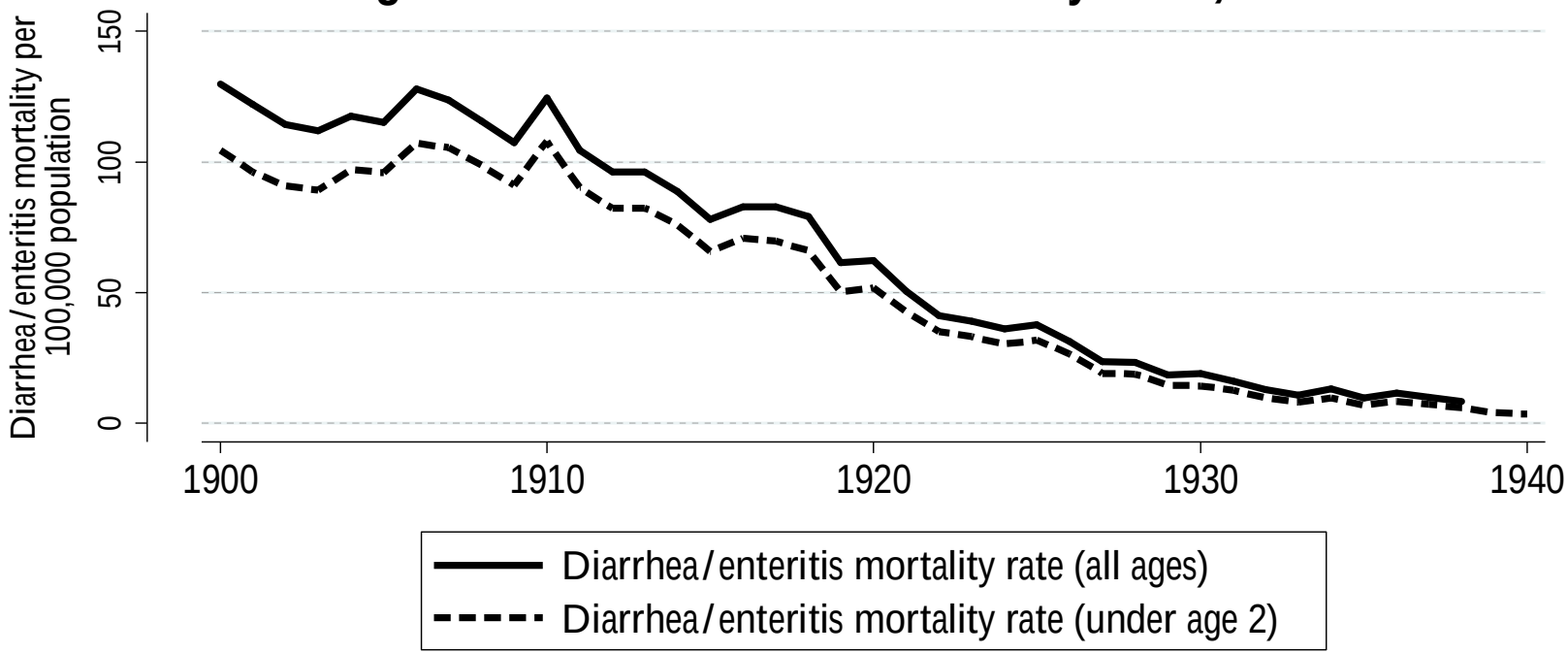
Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1940, published by the U.S. Census Bureau.

Figure 3. Typhoid Mortality Rates, 1900-1940



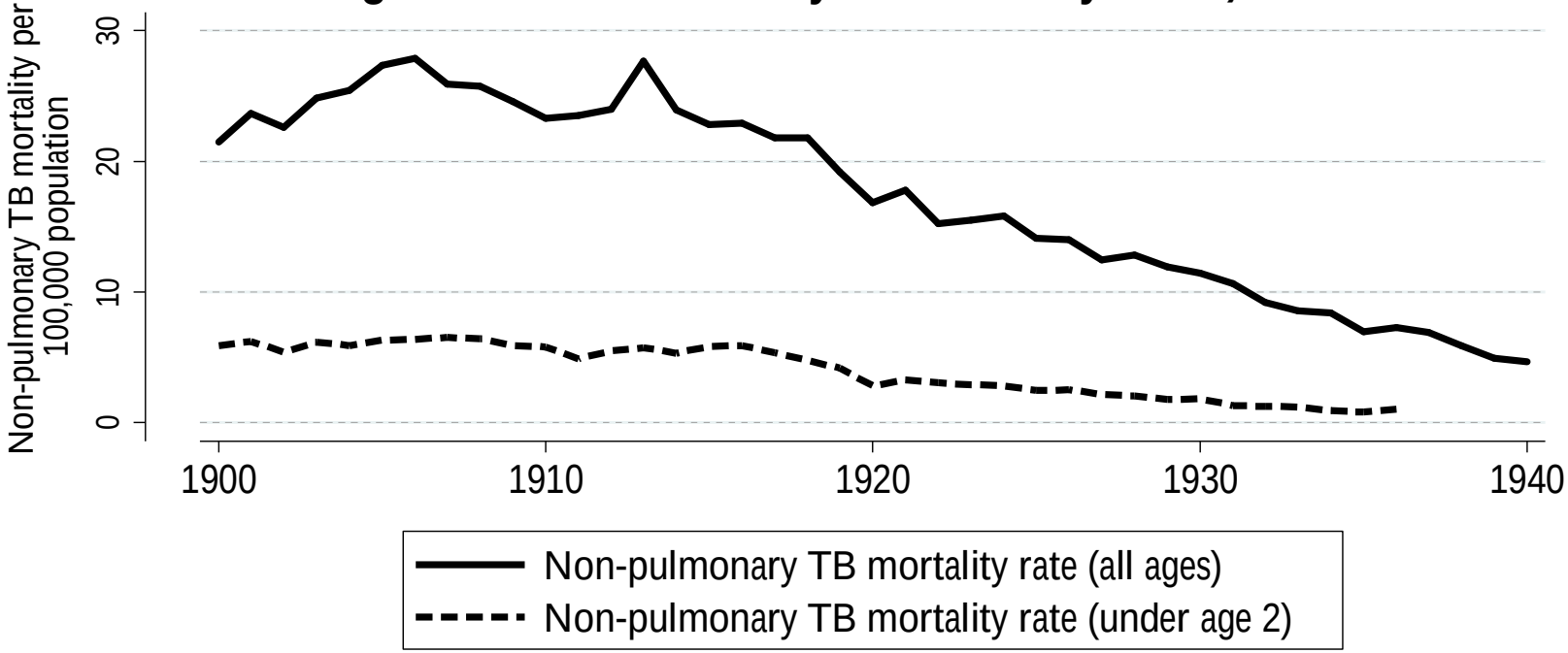
Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1940, published by the U.S. Census Bureau.

Figure 4. Diarrhea/Enteritis Mortality Rates, 1900-1940



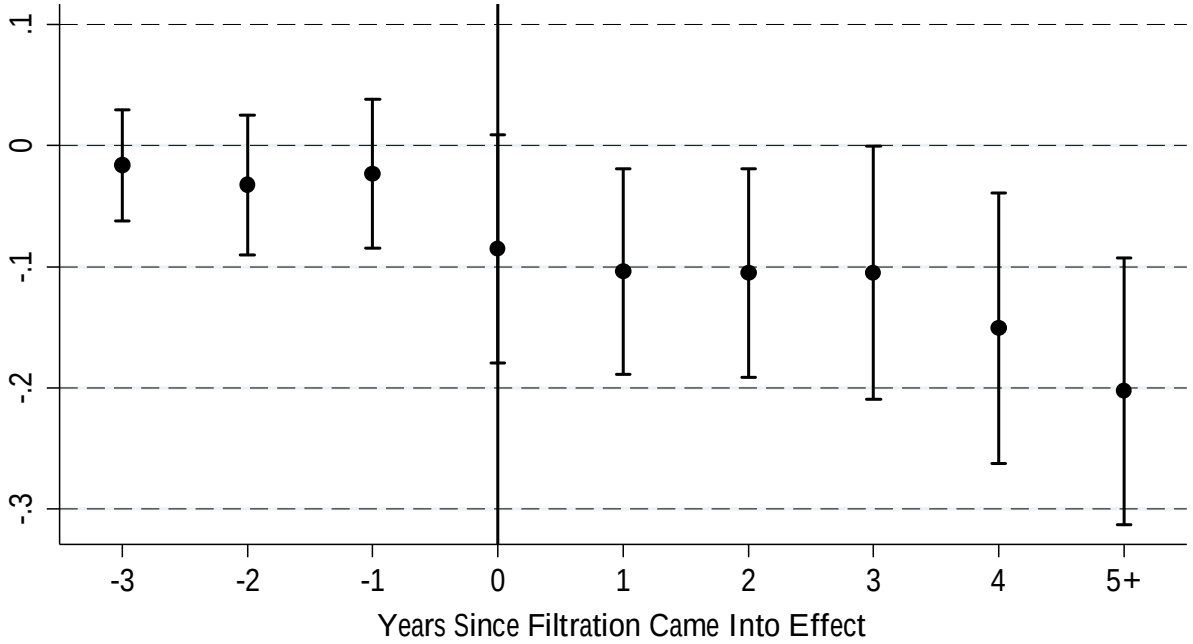
Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1940, published by the U.S. Census Bureau.

Figure 5. Non-Pulmonary TB Mortality Rates, 1900-1940



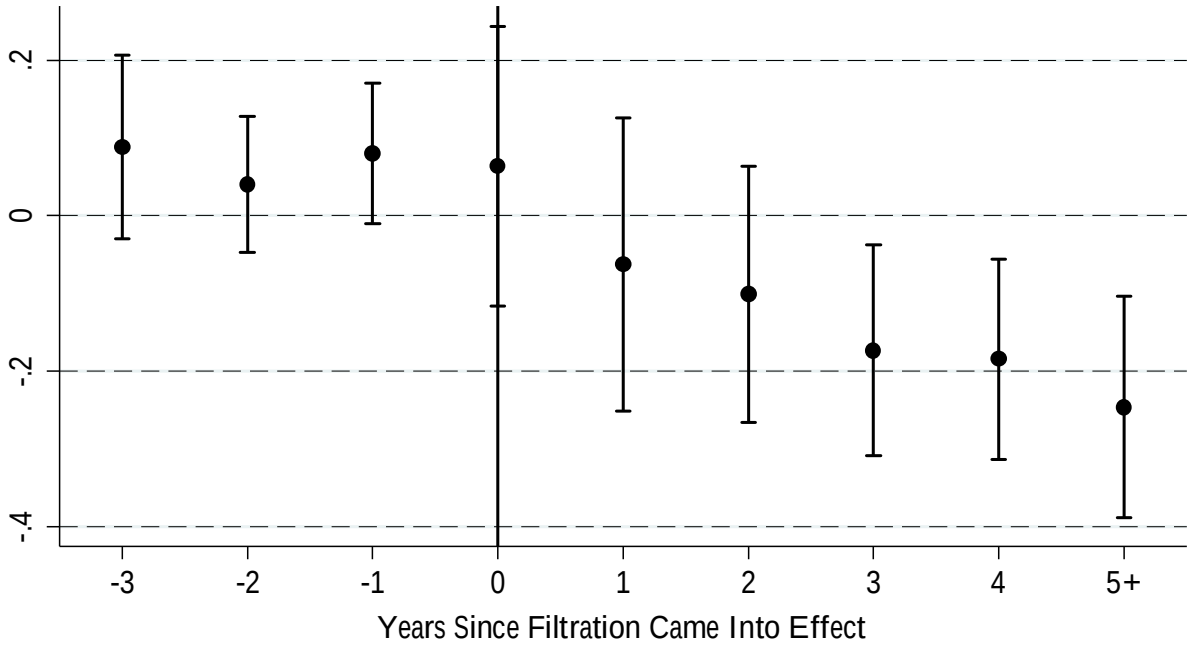
Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1940, published by the U.S. Census Bureau.

Figure 6. Pre- and Post-Filtration Trends in Infant Mortality



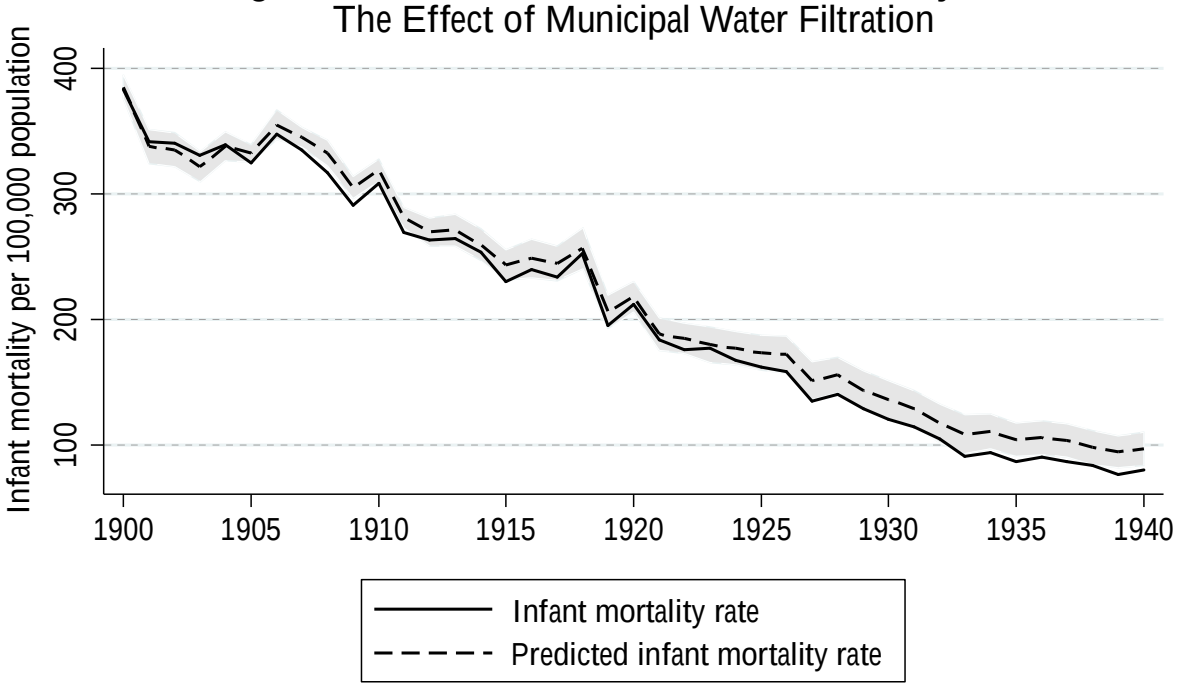
Notes: OLS coefficient estimates (and their 90% confidence intervals) are reported. The dependent variable is equal to the natural log of the number of infant deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects, and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors are corrected for clustering at the municipal level.

Figure 7. Pre- and Post-Filtration Trends in Typhoid Mortality



Notes: OLS coefficient estimates (and their 90% confidence intervals) are reported. The dependent variable is equal to the quartic root of the number of typhoid deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects, and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors are corrected for clustering at the municipal level.

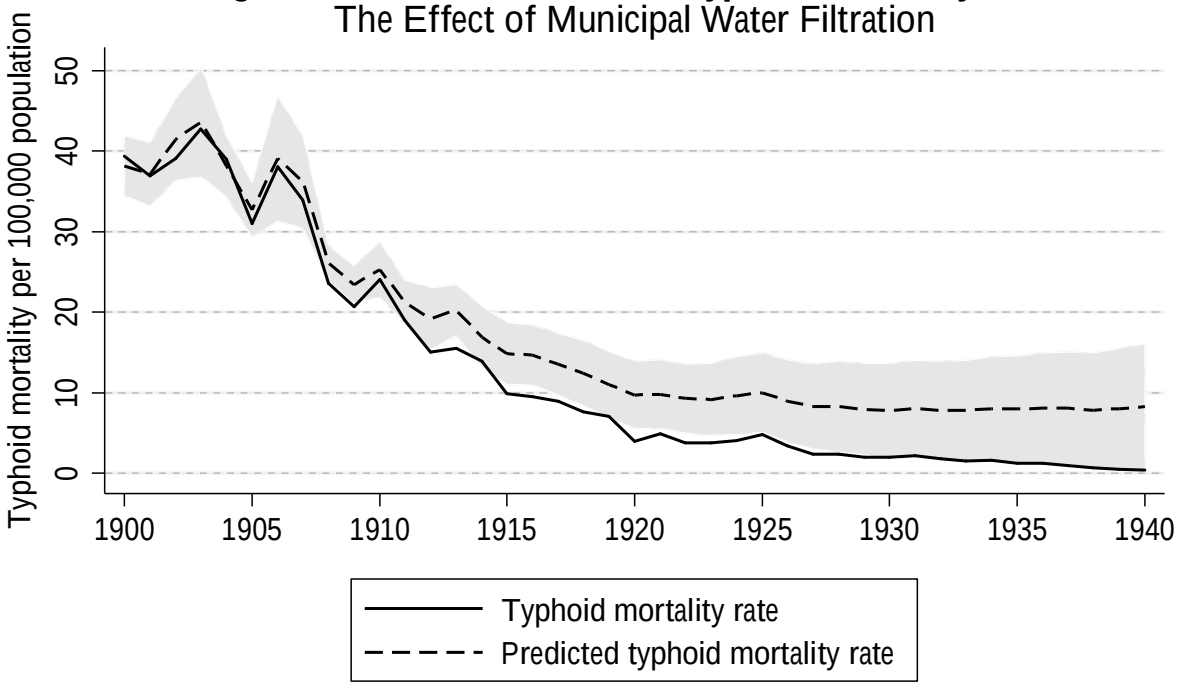
Figure 8. Actual vs. Predicted Infant Mortality Rates
The Effect of Municipal Water Filtration



Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1940, published by the U.S.Census Bureau. Predicted infant mortality rates are calculated under the assumption that municipalities did not filter their water supply. Shaded area represents 90% confidence region around infant mortality rates.

Figure 9. Actual vs. Predicted Typhoid Mortality Rates

The Effect of Municipal Water Filtration



Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1940, published by the U.S. Census Bureau. Predicted typhoid mortality rates are calculated under the assumption that municipalities did not filter their water supply. Shaded area represents 90% confidence region around typhoid mortality rates.

Table 1. Municipal Water Purification, 1900-1940

City and State	Water Filtration Plant[a]	Water Treated with Chlorine[b]
Baltimore, Maryland	1915	1911
Boston, Massachusetts	…	1928
Buffalo, New York	1926	1914
Chicago, Illinois	…	1912
Cincinnati, Ohio	1907	1918
Cleveland, Ohio	1918	1911
Detroit, Michigan	1923	1913
Indianapolis, Indiana	1904	1909
Jersey City, New Jersey	…	1908
Kansas City, Missouri	1928	1911
Louisville, Kentucky	1909	1913
Memphis, Tennessee	…	1920
Milwaukee, Wisconsin	1939	1910
Minneapolis, Minnesota	1913	1910
Newark, New Jersey	…	1921
New Orleans, Louisiana	1909	1915
New York, New York	…	1911
Philadelphia, Pennsylvania	1906	1910
Pittsburgh, Pennsylvania	1908	1910
Providence, Rhode Island	1904	1917
Rochester, New York	…	1925
San Francisco, California	…	1922
St. Louis, Missouri	1915	1913
St. Paul, Minnesota	1923	1920
Washington, D.C.	1905	1923

[a] **Philadelphia, PA**: Filtration began before 1906, but not all parts of the city received filtered water until February, 1909. **Pittsburgh, PA**: By October 1908, the water supply of peninsular Pittsburgh was being filtered. In 1909 and 1914, the Southside and the Northside, respectively, began receiving filtered water.

[b] **Chicago, IL**: Chlorination began in 1912, but full chlorination was not achieved until 1917. **Milwaukee, WI**: Water was chlorinated from June, 1910-December, 1910; February, 1912-March 1912; April, 1912 onwards. **Newark, NJ**: Chlorine was used in rare, emergency-only cases beginning in 1913; continuous use started in 1921. **Philadelphia, PA**: Water was chlorinated from December, 1910-April, 1911; December, 1911-February, 1913; November, 1913 onwards. **Pittsburgh, PA**: Water was chlorinated from January, 1910-March, 1910; November, 1910-April, 1911; August, 1911 onwards.

Table 2. Clean Water Projects, 1900-1940

City and State	Clean Water Project	Description
Boston, Massachusetts	1904	Water was conveyed by the Wachusett/Weston Aqueduct to the Weston Reservoir. Water was first delivered to metropolitan Boston on December 29, 1904.
Buffalo, New York	1913	Water intake, located on Lake Erie's Emerald Channel, was completed on May 12, 1913.
Cleveland, Ohio	1904	Cleveland built the first tunnel (the "Five Mile Crib") to draw water from Lake Erie. It went into operation on April 6, 1904.
Jersey City, New Jersey	1904	The Boonton Reservoir began delivering water to Jersey City on May 23, 1904.
Newark, New Jersey	1930	The Wanaque Reservoir began delivering water to Newark on March 20, 1930.
New York, New York	1907	The New Croton Dam was completed on January 1, 1907 and began delivering water to New York City on November 6, 1907. The Catskills Aqueduct began delivering water to the Bronx on December 27, 1915. By January 22, 1917, all other boroughs were receiving water.
Providence, Rhode Island	1926	The Scituate Reservoir began delivering water to Providence on September 30, 1926.
San Francisco, California	1934	The Hetch Hetchy Reservoir began delivering water to San Francisco on October 28, 1934.
St. Paul, Minnesota	1913	A conduit was built to deliver water from Vadnais Lake to McCarron's pumping station, which supplied water to St. Paul.

Table 3. Sewage Treatment / Diversion, 1900-1940

City and State	Sewage Treatment Plant / Sewage Diversion	Description
Baltimore, Maryland	1911	Operation of the sewage treatment plant was begun "in the latter part of 1911" (Wagenhals et al. 1925).
Buffalo, New York	1938	The sewage treatment plant was completed in June, 1938.
Chicago, Illinois	1907	In 1907, the last sewer outfalls emptying into Lake Michigan were shut off.
Cleveland, Ohio	1922	The first sewage treatment plant was opened in 1922. By 1928, two additional plants were in operation.
Detroit, Michigan	1912	The Detroit River Interceptor was built in 1912. It intercepted sewage and discharged it below the intake for drinking water. Detroit began treating its sewage in February, 1940.
Indianapolis, Indiana	1925	The sewage treatment plant began operations in May, 1925.
Jersey City, New Jersey	1924	The sewage treatment plant was built in 1924 and upgraded in 1937.
Milwaukee, Wisconsin	1925	The sewage treatment plant began operations in June, 1925.
Minneapolis, Minnesota	1938	The sewage treatment plant began operations in June, 1938. It served both Minneapolis and St. Paul.
Newark, New Jersey	1924	The sewage treatment plant began operations in 1924.
New York, New York	1937	The Wards Island sewage treatment plant began operations in October, 1937.
Providence, Rhode Island	1901	The Providence sewage treatment plant, built in 1901, used chemical precipitation. It converted to using an activated sludge process in the mid-1930s.
Rochester, New York	1917	The sewage treatment plant began operations in March, 1917
St. Paul, Minnesota	1938	The sewage treatment plant began operations in June, 1938. It served both Minneapolis and St. Paul
Washington, D.C.	1938	The sewage treatment plant began operations in 1938.

Table 4. Municipal Milk Purification, 1900-1940

City and State	Bacteriological Standard[a]	Tuberculin Testing of Cows[b]
Baltimore, Maryland	1913	1917
Boston, Massachusetts	1905	1924
Buffalo, New York	1918	…
Chicago, Illinois	1909	1909
Cincinnati, Ohio	1914	1907
Cleveland, Ohio	1906	1906
Detroit, Michigan	1915	1915
Indianapolis, Indiana	1916	1916
Jersey City, New Jersey	1915	1915
Kansas City, Missouri	1910	1910
Louisville, Kentucky	1932	1932
Memphis, Tennessee	1917	1910
Milwaukee, Wisconsin	1908	1908
Minneapolis, Minnesota	1907	1895
Newark, New Jersey	1913	1913
New Orleans, Louisiana	1923	1923
New York, New York	1912	1914
Philadelphia, Pennsylvania	1915	1930
Pittsburgh, Pennsylvania	1910	…
Providence, Rhode Island	1915	…
Rochester, New York	1907	1922
San Francisco, California	1909	1909
St. Louis, Missouri	1923	1928
St. Paul, Minnesota	1907	1907
Washington, D.C.	…	1925

[a] **Baltimore, MD**: On October 15, 1912, Baltimore passed an ordinance setting a bacteriological standard, but the first milk inspectors did not start working until January 1, 1913. **Boston, MA**: On March 1, 1905, the Boston Board of Health (in conjunction with the State Board of Health) set a bacteriological standard for health inspectors to follow. On January 8, 1913, Boston passed an ordinance that required licensing of milk producers and set a bacteriological standard. **Buffalo, NY**: The Buffalo Health Commissioner conducted bacteriological tests of milk as early as 1907, but standards were not set by law until October 9, 1918. **Chicago, IL:** The Chicago milk ordinance that came into effect on January 1, 1909 was nullified by the Illinois legislature on June 12, 1911. A new ordinance, passed on August 14, 1912, required that non-pasteurized milk come from tuberculin-tested cows and meet a bacteriological standard. On July 22, 1916, the Chicago Commissioner of Health required that all milk be pasteurized. **Detroit, MI:** An ordinance required that all milk sold in Detroit be pasteurized as of May 1, 1915. **Philadelphia, PA**: As of October 15, 1909, dairy farmers were required to have a license. Although inspections were conducted under rules set by the Board of Health, a bacteriological standard was not enforced until July 1, 1915.

[b] **St. Louis, MO**: Ordinance for tuberculin testing of raw milk was set on March 21, 1928. Ordinance for tuberculin testing of all milk, including pasteurized milk, was set on March 21, 1930.

Table 5. Descriptive Statistics

	Mean (SD)	Description
Filtration	.428 (.493)	= 1 if municipality had a water filtration plant, = 0 otherwise
Chlorination	.625 (.480)	= 1 if municipality chemically treated water supply, = 0 otherwise
Clean Water Project	.263 (.439)	= 1 if municipality had completed a clean water project, = 0 otherwise
Sewage Treatment/Diversion	.248 (.430)	= 1 if municipality had a sewage treatment plant or diverted sewage away from drinking water supply, = 0 otherwise
Bacteriological Standard	.616 (.484)	= 1 if municipality set bacteriological standard for milk supply, = 0 otherwise
TB Test	.515 (.497)	= 1 if municipality required tuberculin testing of cows, = 0 otherwise
% Female	.503 (.016)	Percent of municipal population that was female
% Nonwhite	.090 (.100)	Percent of municipal population that was nonwhite
% Foreign	.193 (.109)	Percent of municipal population that was foreign born
% Under 15	.255 (.032)	Percent of municipal population that was under 15 years of age
% 15 to 44	.529 (.025)	Percent of municipal population that was 15 to 44 years of age
% 45 and Older	.216 (.038)	Percent of municipal population that was 45 years of age or older
N	1,024	

Notes: Unweighted means with standard deviations in parentheses.

Table 6. The Effects of Water Quality, Sewage Treatment/Diversion, and Clean Milk on Total Mortality

	(1)	(2)	(3)	(4)	(5)
			Total Mortality		
Water					
Filtration	-.025	…	…	-.023	-.014
	(.020)			(.020)	(.021)
Chlorination	.020	…	…	.016	.013
	(.016)			(.014)	(.014)
Clean Water Project	-.015	…	…	-.009	-.006
	(.032)			(.030)	(.029)
Sewage					
Sewage Treatment/Diversion	…	.035	…	.031	.028
		(.027)		(.025)	(.022)
Milk					
Bacteriological Standard	…	…	.016	…	.013
			(.016)		(.016)
TB Test	…	…	.025	…	.020
			(.018)		(.015)
Joint effect of water-related interventions	-.020	.035	…	.015	.020
{*F* statistic}	{1.07}	{1.61}		{.984}	{.797}
Joint effect of milk-related interventions	…	…	.041	…	.033
{*F* statistic}			{1.35}		{1.10}
Mean of total mortality rate	1,468	1,468	1,468	1,468	1,468
N	1,024	1,024	1,024	1,024	1,024
R^2	.925	.925	.925	.925	.926

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1900-1940, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the natural log of the number of deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses.

Table 7. The Effects of Water Quality, Sewage Treatment/Diversion and Clean Milk on Infant Mortality

	(1)	(2)	(3)	(4)	(5)
	Infant Mortality (Under Age 1)				
Water					
Filtration	-.137**	…	…	-.133**	-.114**
	(.050)			(.049)	(.045)
Chlorination	.097**	…	…	.090**	.084**
	(.046)			(.040)	(.040)
Clean Water Project	-.064	…	…	-.054	-.047
	(.068)			(.062)	(.058)
Sewage					
Sewage Treatment/Diversion	…	.077	…	.058	.049
		(.070)		(.058)	(.050)
Milk					
Bacteriological Standard	…	…	.040	…	.022
			(.035)		(.035)
TB Test	…	…	.067	…	.045
			(.047)		(.033)
Joint effect of water-related interventions	-.104**	.077	…	-.039**	-.027**
{*F* statistic}	{3.36}	{1.21}		{3.24}	{3.13}
Joint effect of milk-related interventions	…	…	.107	…	.067
{*F* statistic}			{2.25}		{1.40}
Mean of infant mortality rate	207.8	207.8	207.8	207.8	207.8
N	1,024	1,024	1,024	1,024	1,024
R^2	.980	.979	.979	.981	.981

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1900-1940, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the natural log of the number of infant deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses.

Table 8. Robustness Checks: The Effects of Water Quality, Sewage Treatment/Diversion, and Clean Milk on Infant Mortality

	(1)	(2)	(3)	(4)	(5)	(6)
	Control for wages	Control for region-by-year fixed effects	Unweighted	Drop New York City	Drop years 1917-1920	Dependent variable in levels
Water						
Filtration	-.101**	-.108**	-.132***	-.119***	-.104**	-23.2*
	(.042)	(.049)	(.038)	(.038)	(.047)	(11.7)
Chlorination	.073**	.035	.056	.103**	.083**	13.1
	(.035)	(.036)	(.044)	(.039)	(.039)	(9.24)
Clean Water Project	-.053	-.091**	.050	.027	-.028	-20.5*
	(.039)	(.042)	(.046)	(.080)	(.054)	(11.8)
Sewage						
Sewage Treatment/Diversion	.083*	.053	.017	.082	.047	9.96
	(.047)	(.040)	(.039)	(.044)	(.048)	(11.2)
Milk						
Bacteriological Standard	.026	.058	.073*	.035	.002	2.07
	(.033)	(.036)	(.036)	(.042)	(.034)	(8.25)
TB Test	.040	.018	.0002	.059*	.058*	7.46
	(.028)	(.031)	(.040)	(.034)	(.032)	(7.72)
Joint effect of water-related interventions	.002**	-.111**	-.010***	.093***	.002*	-20.7**
{*F* statistic}	{3.68}	{2.89}	{5.62}	{4.41}	{2.59}	{2.91}
Joint effect of milk-related interventions	.067	.076	.073*	.094*	.060	9.53
{*F* statistic}	{1.94}	{1.29}	{2.97}	{3.08}	{1.85}	{.571}
Mean of infant mortality rate	217.9	207.8	207.8	207.3	206.1	207.8
N	949	1,024	1,024	983	924	1,024
R^2	.979	.986	.964	.974	.983	.972

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1900-1940, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. In columns (1)-(5), the dependent variable is equal to the natural log of the number of infant deaths per 100,000 population in municipality *m* and year *t*. In column (6), the dependent variable is equal to the number of infant deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. In columns (1)-(2) and (4)-(6), regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses.

Table 9. Infant Mortality and Lags of *Filtration*

	(1)	(2)	(3)
	Infant Mortality		
Year 0	-.068	-.074*	-.077*
	(.043)	(.043)	(.044)
1 Year After Filtration	-.085**	-.092**	-.096**
	(.037)	(.037)	(.037)
2 Years After Filtration	-.083**	-.093**	-.097**
	(.039)	(.038)	(.039)
3+ Years After Filtration	-.156***	…	…
	(.048)		
3 Years After Filtration	…	-.092*	-.097*
		(.050)	(.050)
4 Years After Filtration	…	-.138**	-.143**
		(.053)	(.054)
5+ Years After Filtration	…	-.186***	…
		(.051)	
5 Years After Filtration	…	…	-.152***
			(.048)
6 Years After Filtration	…	…	-.185***
			(.039)
7+ Years After Filtration	…	…	-.202***
			(.062)
Mean of infant mortality rate	207.8	207.8	207.8
N	1,024	1,024	1,024
R^2	.981	.982	.982

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1900-1940, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the natural log of the number of infant deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses.

Table 10. Exploring Interactive Effects

	(1)	(2)	(3)
		Infant Mortality	
Water			
Filtration	-.093	-.105**	-.092*
	(.060)	(.049)	(.049)
Chlorination	.093*	.085**	.078*
	(.046)	(.040)	(.039)
Clean Water Project	-.046	-.044	-.046
	(.058)	(.058)	(.057)
Sewage			
Sewage Treatment/Diversion	.048	.051	.070
	(.050)	(.049)	(.054)
Interactions			
*Filtration*Chlorination*	-.034	…	…
	(.049)		
*Filtration*Clean Water Project*	…	-.052	…
		(.073)	
*Filtration*Sewage Treatment/Diversion*	…	…	-.088
			(.061)
Joint effect of water-related interventions	-.032**	-.064**	-.078**
{*F* statistic}	{2.86}	{3.01}	{2.85}
Mean of infant mortality rate	207.8	207.8	207.8
N	1,024	1,024	1,024
R^2	.981	.981	.981

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1900-1940, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the natural log of the number of infant deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses.

Table 11. The Effects of Water Quality, Sewage Treatment/Diversion and Clean Milk on Mortality by Cause

	(1)	(2)	(3)	(4)	(5)
	Typhoid Mortality	*Diarrhea/ Enteritis Mortality*	*Diarrhea/ Enteritis Mortality (Under Age 2)*	*Non-Pulmonary TB Mortality*	*Non-Pulmonary TB Mortality (Under Age 2)*
Water					
Filtration	-.171**	-.162*	-.163	.036	.024
	(.073)	(.091)	(.105)	(.059)	(.030)
	[-4.63]				[.275]
Chlorination	.007	.091	.109	.013	-.006
	(.039)	(.081)	(.098)	(.052)	(.032)
	[.177]				[-.064]
Clean Water Project	.058	-.159	-.150	.077	.043
	(.070)	(.140)	(.189)	(.046)	(.031)
	[1.57]				[.486]
Sewage					
Sewage Treatment/Diversion	-.019	.198	.204	-.057	-.022
	(.059)	(.124)	(.151)	(.046)	(.030)
	[-.525]				[-.252]
Milk					
Bacteriological Standard	-.053	.026	.046	.026	.008
	(.040)	(.056)	(.067)	(.040)	(.026)
	[-1.44]				[.087]
TB Test	.041	.165*	.165	.002	.005
	(.064)	(.080)	(.099)	(.038)	(.028)
	[1.10]				[.058]
Joint effect of water-related interventions	-.126	-.033	.001	.070	.039
{*F* statistic}	{1.82}	{1.54}	{1.05}	{1.23}	[.796]
Joint effect of milk-related interventions	-.013	.191*	.211*	.028	.013
{*F* statistic}	{.899}	{3.11}	{2.86}	{.273}	[.068]
Years	1900-1940	1900-1938	1900-1940	1900-1940	1900-1936
Mean of specified mortality rate	12.8	65.5	52.0	17.4	4.01
N	1,024	974	1,024	1,024	924
R^2	.938	.971	.964	.937	.844

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics*, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the natural log (or, in the case of typhoid and non-pulmonary TB for children under the age of 2, the quartic root) of the number of specified deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses and marginal effects are in brackets.

Table 12. Robustness Checks: The Effects of Water Quality, Sewage Treatment/Diversion, and Clean Milk on Typhoid Mortality

	(1)	(2)	(3)	(4)	(5)	(6)
	Control for wages	Control for region-by-year fixed effects	Unweighted	Drop New York City	Drop years 1917-1920	Dependent variable in levels
Water						
Filtration	-.173**	-.193**	-.206***	-.170**	-.186**	-10.3*
	(.075)	(.082)	(.073)	(.073)	(.080)	(5.61)
	[-4.97]	[-5.22]	[-5.59]	[-4.68]	[-5.24]	
Chlorination	.011	.024	.005	-.010	-.001	-.800
	(.038)	(.048)	(.042)	(.042)	(.041)	(2.11)
	[.301]	[.661]	[.143]	[-.266]	[-.018]	
Clean Water Project	.046	.077	-.028	-.036	.057	5.09
	(.070)	(.092)	(.061)	(.107)	(.070)	(5.05)
	[1.32]	[2.08]	[-.759]	[-.984]	[1.59]	
Sewage						
Sewage Treatment/Diversion	-.009	-.048	-.056	-.036	-.008	1.51
	(.063)	(.052)	(.056)	(.065)	(.056)	(1.98)
	[-.259]	[-1.30]	[-1.53]	[-.993]	[-.218]	
Milk						
Bacteriological Standard	-.052	-.069*	-.049	-.061	-.058	-4.07
	(.039)	(.040)	(.049)	(.051)	(.041)	(3.10)
	[-1.49]	[-1.86]	[-1.34]	[-1.67]	[-1.62]	
TB Test	.029	.096*	.034	.046	.048	2.02
	(.062)	(.052)	(.067)	(.073)	(.070)	(2.56)
	[.822]	[2.59]	[.930]	[1.28]	[1.35]	
Joint effect of water-related interventions	-.126	-.140	-.285	-.252	-.138	-4.52
{*F* statistic}	{1.65}	{2.10}	{2.18}	{1.99}	{1.76}	{.413}
Joint effect of milk-related interventions	-.023	.027*	-.015	-.014	-.010	-2.05
{*F* statistic}	{.896}	{2.84}	{.513}	{.695}	{.995}	{1.00}
Mean of typhoid mortality rate	13.8	12.8	12.8	13.1	13.5	12.8
N	949	1,024	1,024	983	924	1,024
R^2	.938	.948	.910	.929	.942	.808

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1900-1940, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. In columns (1)-(5), the dependent variable is equal to the quartic root of the number of typhoid deaths per 100,000 population in municipality *m* and year *t*. In column (6), the dependent variable is equal to the number of typhoid deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. In columns (1)-(2) and (4)-(6), regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses and marginal effects are in brackets.

Table 13. Typhoid Mortality and Lags of *Filtration*

	(1)	(2)	(3)
	Typhoid Mortality		
Year 0	.037	.030	.027
	(.083)	(.083)	(.083)
	[1.01]	[.824]	[.744]
1 Year After Filtration	-.089	-.097	-.100
	(.092)	(.092)	(.091)
	[-2.42]	[-2.62]	[-2.72]
2 Years After Filtration	-.128	-.137*	-.141*
	(.079)	(.079)	(.079)
	[-3.46]	[-3.72]	[-3.83]
3+ Years After Filtration	-261***	…	…
	(.069)		
	[-7.06]		
3 Years After Filtration	…	-.209***	-.213***
		(.069)	(.070)
		[-5.67]	[-5.79]
4 Years After Filtration	…	-.223***	-.228**
		(.076)	(.078)
		[-6.04]	[-6.17]
5+ Years After Filtration	…	-.292***	…
		(.075)	
		[-7.93]	
5 Years After Filtration	…	…	-.275***
			(.068)
			[-7.45]
6 Years After Filtration	…	…	-.274***
			(.073)
			[-7.42]
7+ Years After Filtration	…	…	-.308***
			(.084)
			[-8.34]
Mean of typhoid mortality rate	12.8	12.8	12.8
N	1,024	1,024	1,024
R^2	.941	.941	.941

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1900-1940, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the quartic root of the number of typhoid deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses and marginal effects are in brackets.

Table 14. Comparing our Total Mortality Estimates to those of Cutler and Miller (2005)

	(1)	(2)	(3)	(4)	(5)	(6)
	Replicating C&M's original estimates	Column (1) + clustered standard errors	Column (2) + Memphis, TN correction	Column (3) + corrected total mortality counts	Column (4) + corrected filtration and chlorination dates	Our specification, limited to C&M's city-years
Filtration	-.162***	-.162**	-.134**	-.081**	-.051	-.046
	(.036)	(.064)	(.053)	(.028)	(.034)	(.034)
Chlorination	-.017	-.017	-.010	-.039	-.033*	.004
	(.025)	(.034)	(.024)	(.026)	(.018)	(.031)
*Filtration*Chlorination*	.047**	.047	.032	.054**	.051	.025
	(.022)	(.031)	(.025)	(.024)	(.029)	(.042)
Years	1905-1936	1905-1936	1905-1936	1905-1936	1905-1936	1905-1936
Mean of total mortality rate	1,504	1,504	1,498	1,494	1,494	1,495
N	415	415	410	410	410	415
R^2	.957	.957	.963	.970	.969	.952

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1905-1936, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the natural log of the number of deaths per 100,000 population in municipality *m* and year *t*. Controls for the Cutler and Miller (2005) regressions shown in columns (1)-(5) include those listed in Appendix Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. In column (6), controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. In columns (1)-(5), the regressions are unweighted. In column (6), the regression is weighted by municipality population. In column (1), Huber-White corrected standard errors are in parentheses. In columns (2)-(6), standard errors, corrected for clustering at the municipal level, are in parentheses.

Table 15. Comparing our Infant Mortality Estimates to those of Cutler and Miller (2005)

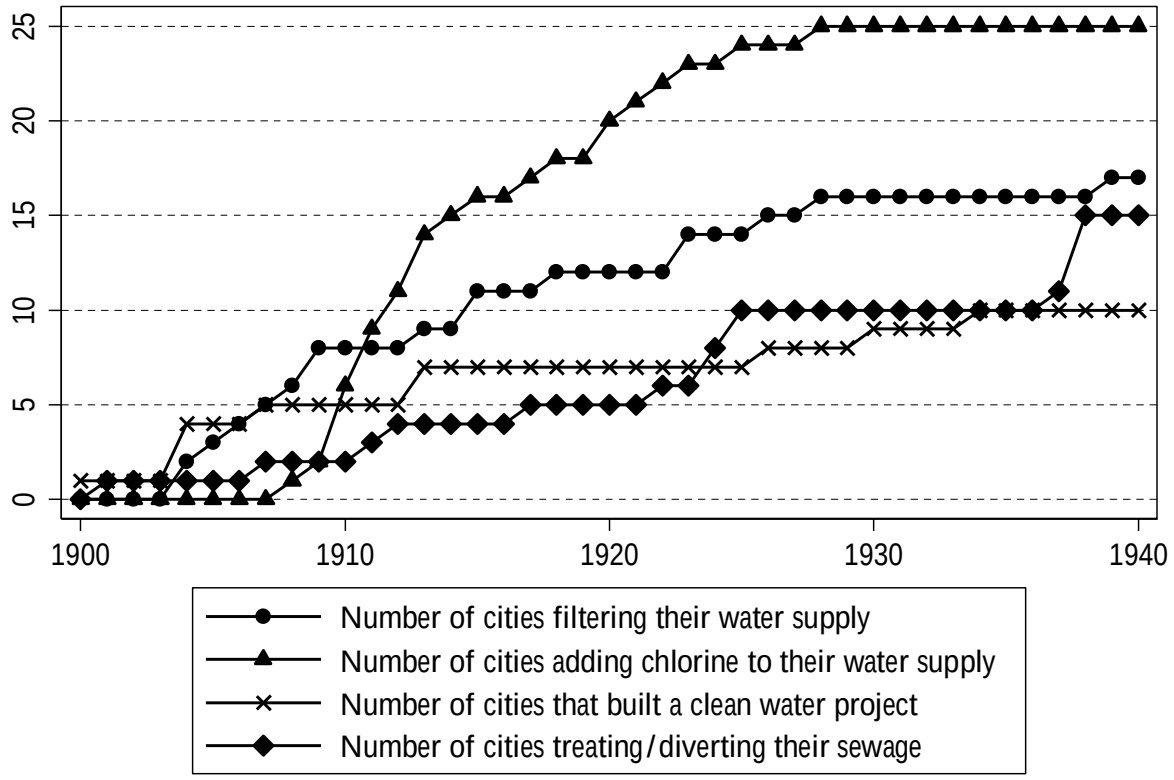
	(1)	(2)	(3)	(4)	(5)	(6)
	Replicating C&M's original estimates	Column (1) + clustered standard errors	Column (2) + Memphis, TN correction	Column (3) + corrected infant mortality counts	Column (4) + corrected filtration and chlorination dates	Our specification, limited to C&M's city-years
Filtration	-.429***	-.429***	-.373***	-.125*	-.067	-.100**
	(.090)	(.138)	(.111)	(.068)	(.057)	(.045)
Chlorination	-.085	-.085	-.072	.017	.072*	.106**
	(.083)	(.104)	(.104)	(.038)	(.034)	(.048)
*Filtration*Chlorination*	.056	.056	.034	.052	.003	-.043
	(.074)	(.083)	(.077)	(.048)	(.042)	(.062)
Years	1905-1936	1905-1936	1905-1936	1905-1936	1905-1936	1905-1936
Mean of infant mortality rate	11,076	11,076	11,057	11,626	11,626	215.6
N	415	415	410	410	410	415
R^2	.828	.828	.835	.955	.955	.983

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

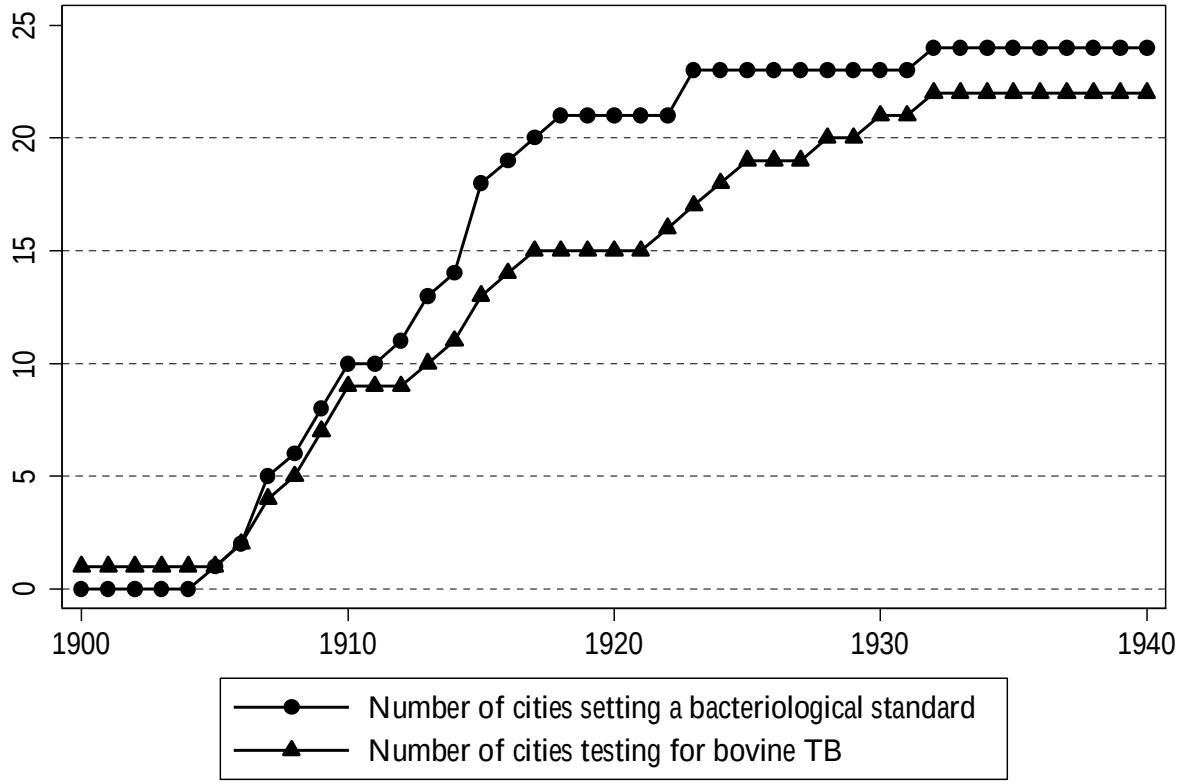
Notes: Based on annual data from *Mortality Statistics* for the period 1905-1936, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. In columns (1)-(5), the dependent variable is equal to the natural log of the number of infant deaths per 100,000 infant population in municipality *m* and year *t*. In column (6), the dependent variable is equal to the natural log of the number of infant deaths per 100,000 population in municipality *m* and year *t*. Controls for the Cutler and Miller (2005) regressions shown in columns (1)-(5) include those listed in Appendix Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. In column (6), controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. In columns (1)-(5), the regressions are unweighted. In column (6), the regression is weighted by municipality population. In column (1), Huber-White corrected standard errors are in parentheses. In columns (2)-(6), standard errors, corrected for clustering at the municipal level, are in parentheses.

Appendix A

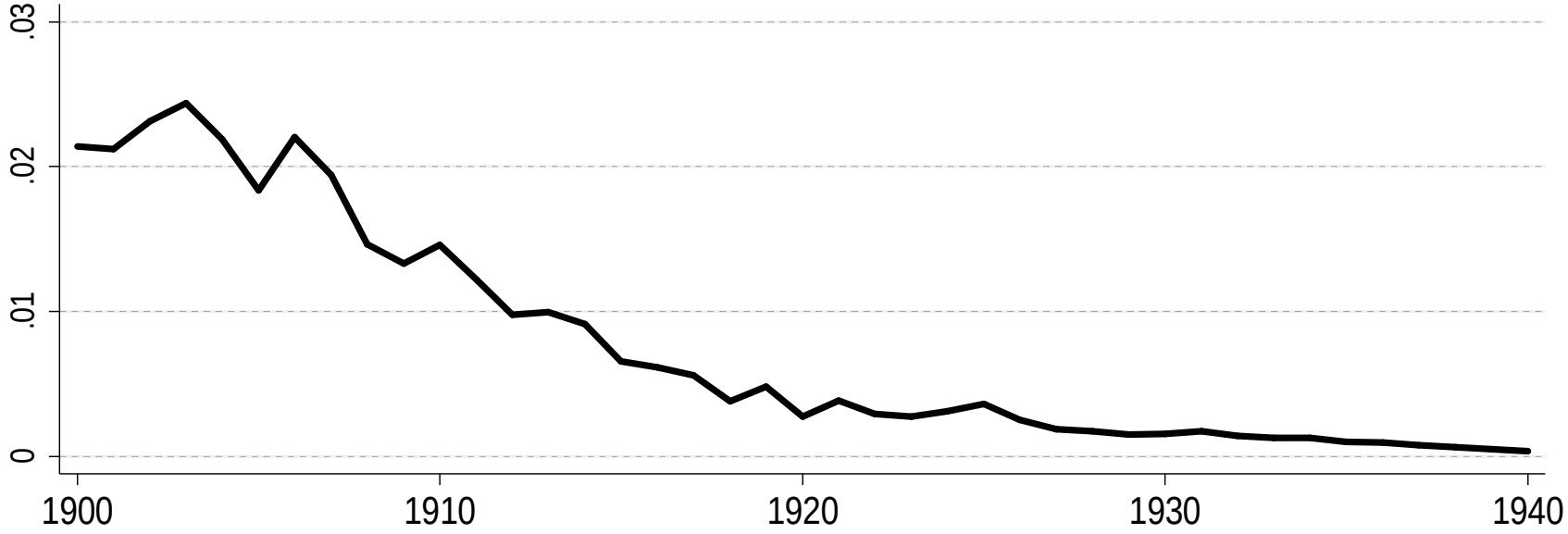
Appendix Figure 1. Municipal Water-Related Interventions Over Time



Appendix Figure 2. Municipal Milk-Related Interventions Over Time

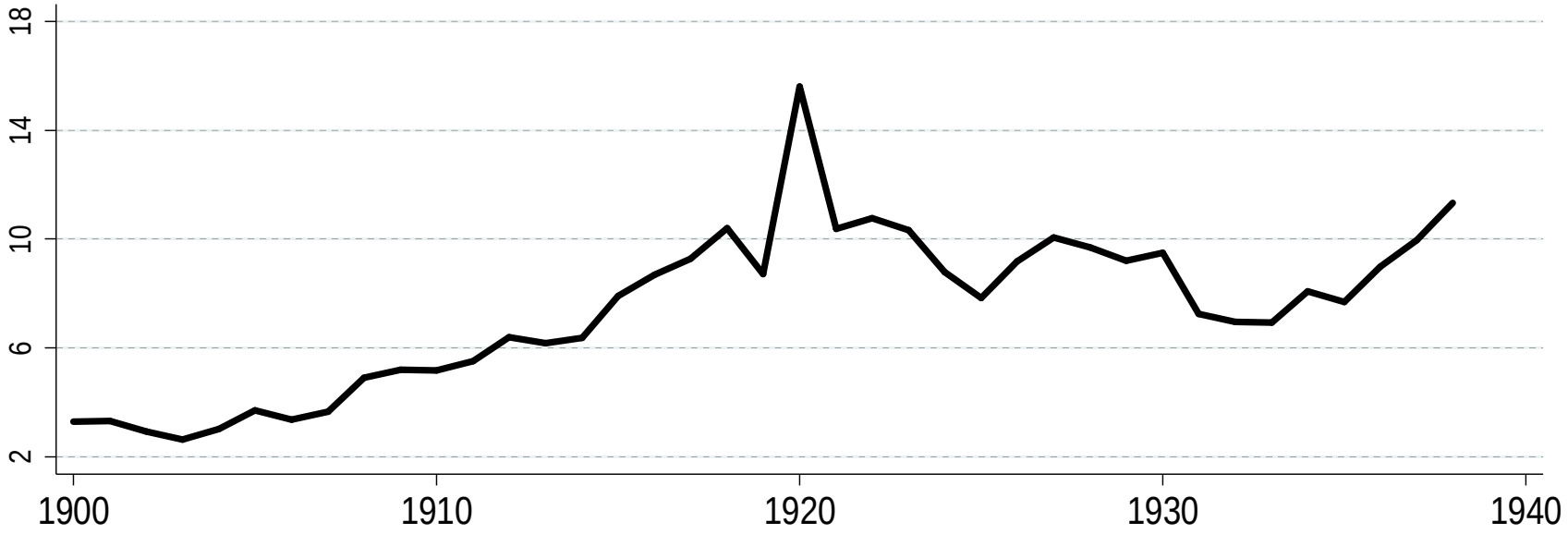


Appendix Figure 3. Percent of Overall Mortality Due to Typhoid, 1900-1940



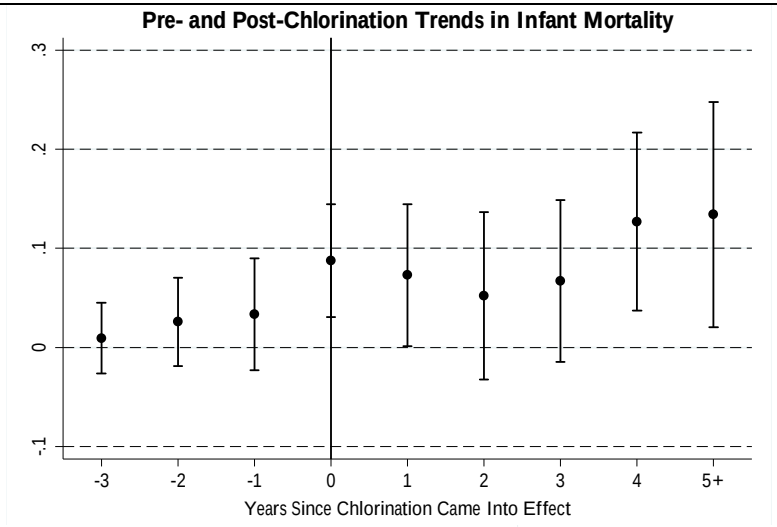
Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1940, published by the U.S. Census Bureau.

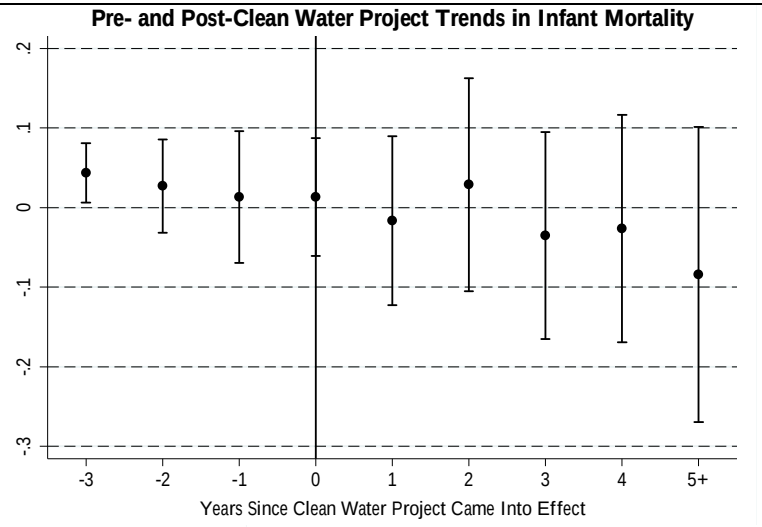
Appendix Figure 4. Ratio of Diarrhea / Enteritis to Typhoid Mortality, 1900-1938

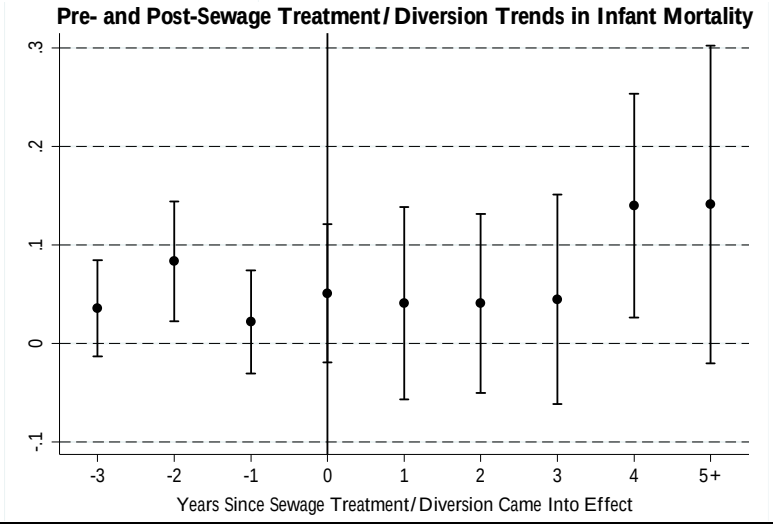


Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1938, published by the U.S. Census Bureau.

Appendix Figure 5

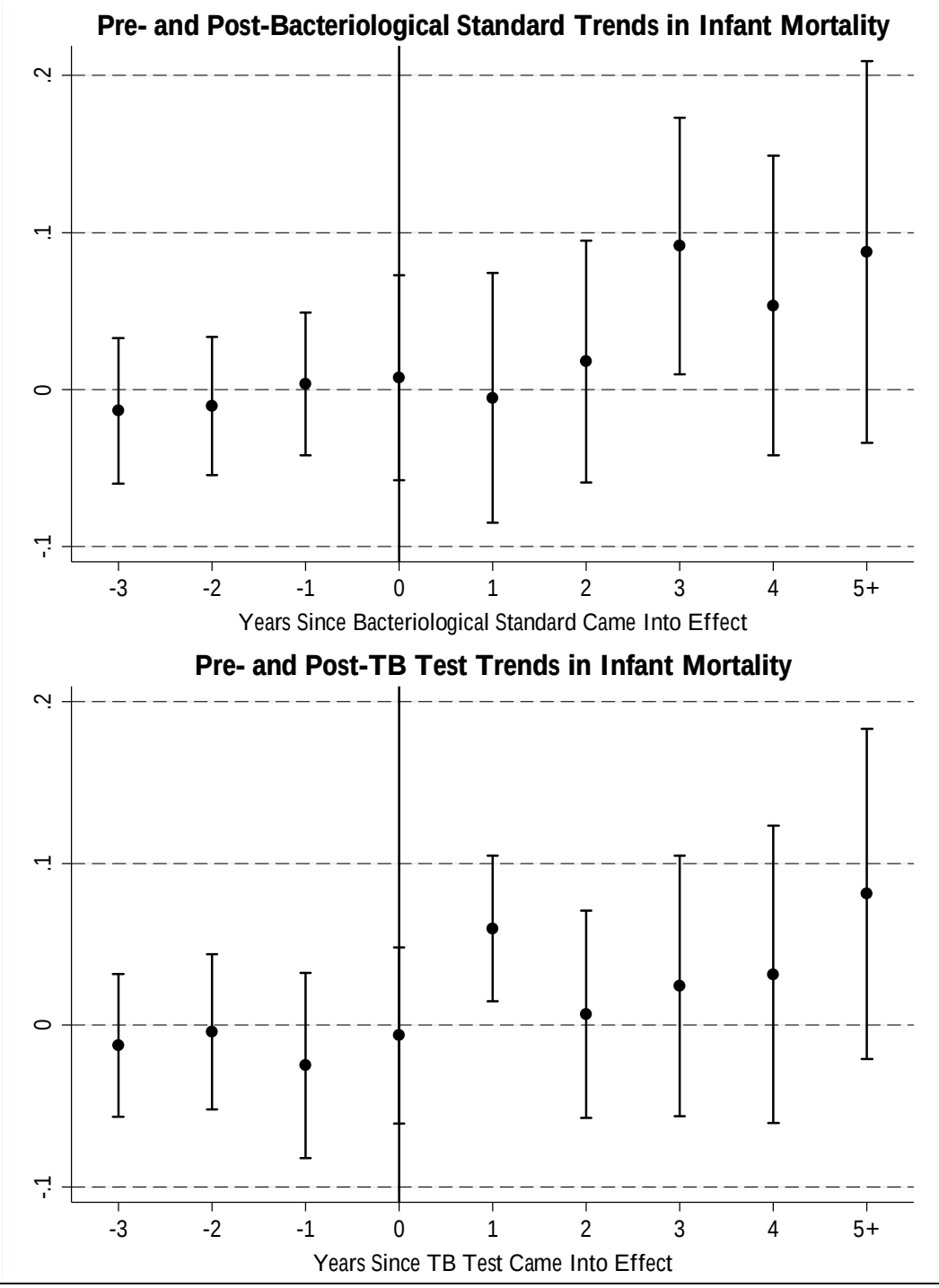






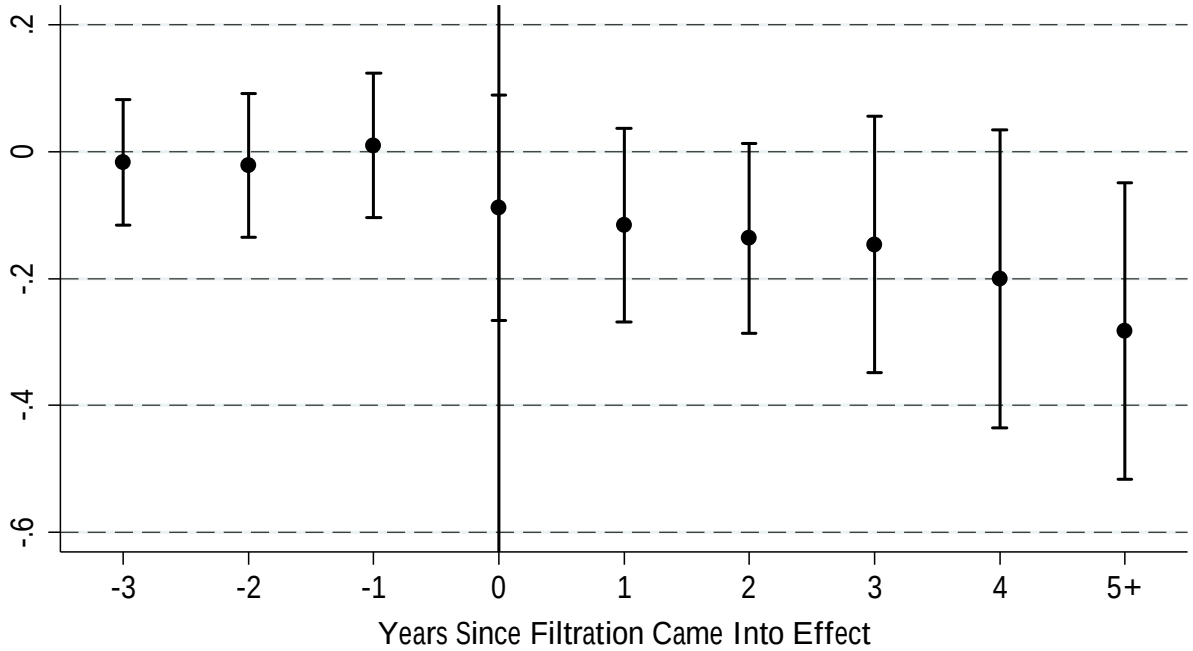
Notes: OLS coefficient estimates (and their 90% confidence intervals) are reported. The dependent variable is equal to the natural log of the number of infant deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects, and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors are corrected for clustering at the municipal level.

Appendix Figure 6



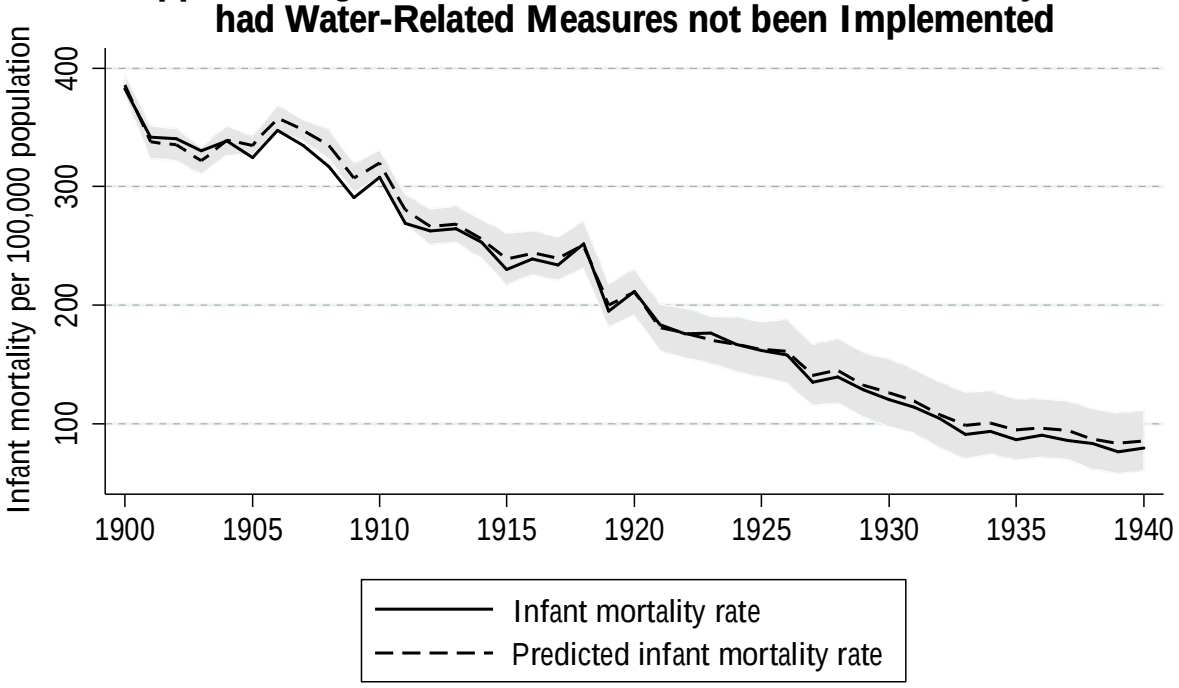
Notes: OLS coefficient estimates (and their 90% confidence intervals) are reported. The dependent variable is equal to the natural log of the number of infant deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects, and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors are corrected for clustering at the municipal level.

Appendix Figure 7. Pre- and Post-Filtration Trends in Diarrhea/Enteritis Mortality



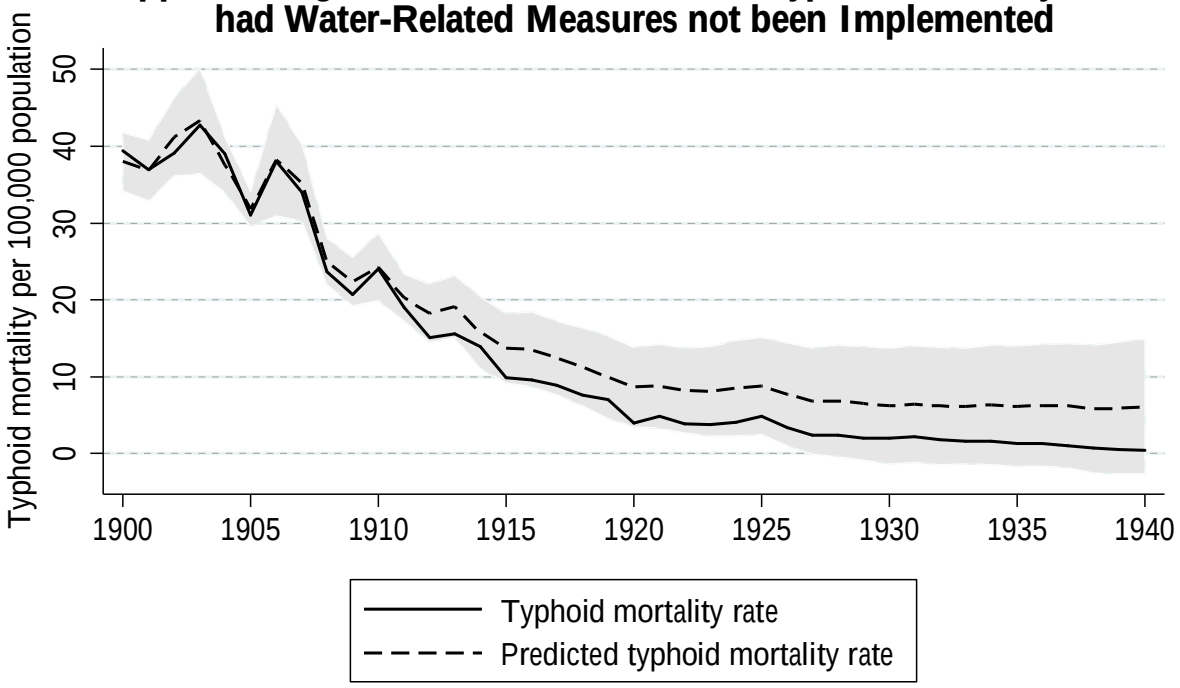
Notes: OLS coefficient estimates (and their 90% confidence intervals) are reported. The dependent variable is equal to the natural log of the number of diarrhea/enteritis deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects, and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors are corrected for clustering at the municipal level.

Appendix Figure 8. Actual vs. Predicted Infant Mortality Rates had Water-Related Measures not been Implemented



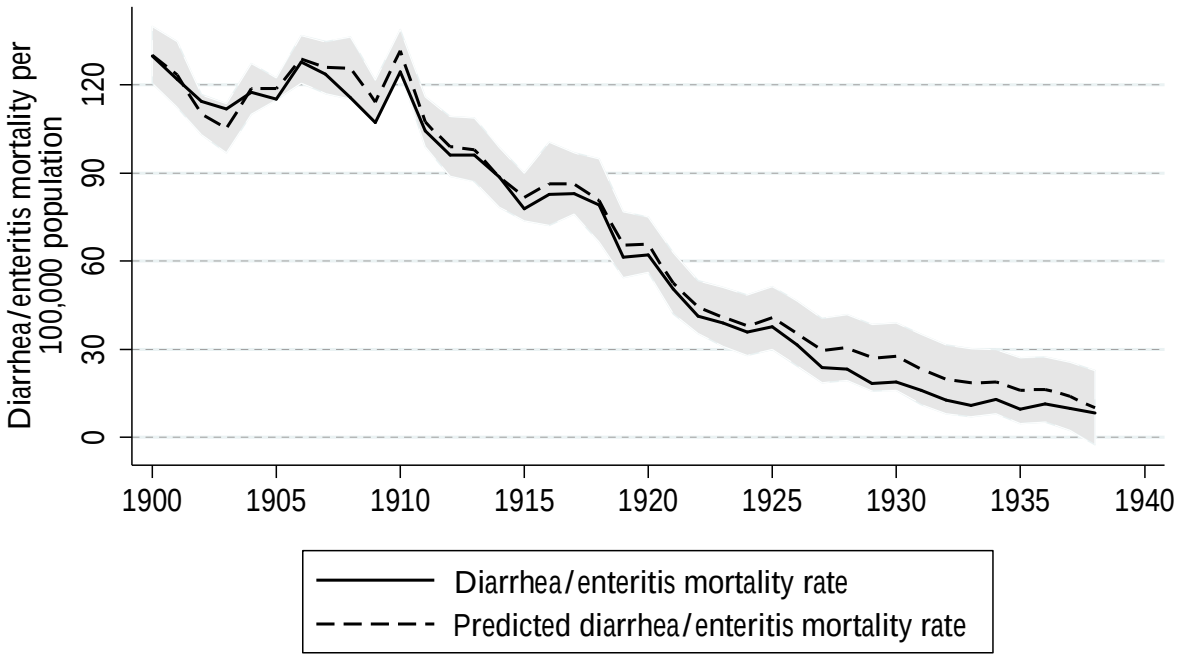
Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1940, published by the U.S. Census Bureau. Predicted infant mortality rates are calculated under the assumption that none of the water-related measures listed in Table 5 were implemented. Shaded area represents 90% confidence region around infant mortality rates.

Appendix Figure 9. Actual vs. Predicted Typhoid Mortality Rates had Water-Related Measures not been Implemented



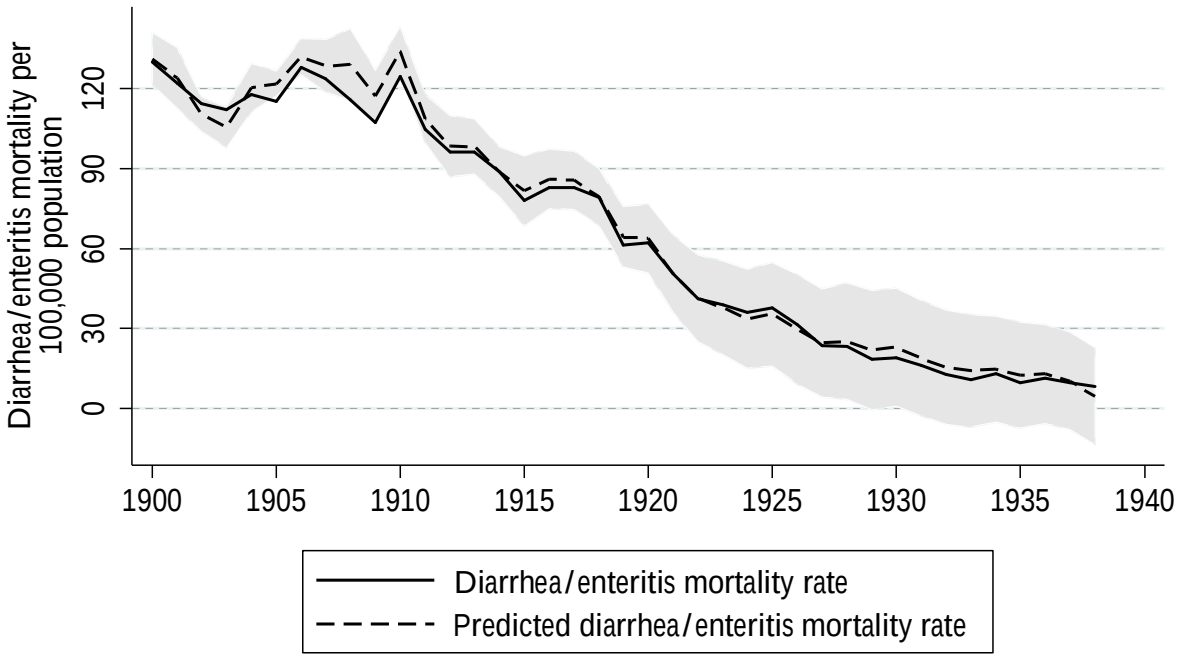
Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1940, published by the U.S. Census Bureau. Predicted typhoid mortality rates are calculated under the assumption that none of the water-related measures listed in Table 5 were implemented. Shaded area represents 90% confidence region around typhoid mortality rates.

Appendix Figure 10. Actual vs. Predicted Diarrhea/Enteritis Mortality Rates
The Effect of Municipal Water Filtration



Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1938, published by the U.S. Census Bureau. Predicted diarrhea/enteritis mortality rates are calculated under the assumption that municipalities did not filter their water supply. Shaded area represents 90% confidence region around diarrhea/enteritis mortality rates.

Appendix Figure 11. Actual vs. Predicted Diarrhea/Enteritis Mortality Rates had Water-Related Measures not been Implemented



Notes: Based on annual data from *Mortality Statistics* and *Vital Statistics of the United States* for the period 1900-1938, published by the U.S. Census Bureau. Predicted diarrhea/enteritis mortality rates are calculated under the assumption that none of the water-related measures listed in Table 5 were implemented. Shaded area represents 90% confidence region around diarrhea/enteritis mortality rates.

Appendix Table 1. Robustness Checks: The Effects of Water Quality, Sewage Treatment/Diversion, and Clean Milk on Diarrhea/Enteritis Mortality

	(1)	(2)	(3)	(4)	(5)	(6)
	Control for wages	Control for region-by-year fixed effects	Unweighted	Drop New York City	Drop years 1917-1920	Dependent variable in levels
Water						
Filtration	-.146*	-.164*	-.213***	-.176**	-.161	-8.32
	(.080)	(.093)	(.059)	(.071)	(.094)	(9.96)
Chlorination	.074	-.006	.044	.161**	.099	6.46
	(.066)	(.069)	(.074)	(.071)	(.087)	(6.08)
Clean Water Project	-.131	-.236**	.110	.129	-.121	-22.3*
	(.111)	(.106)	(.126)	(.174)	(.128)	(10.9)
Sewage						
Sewage Treatment/Diversion	.208*	.201**	.146	.267**	.181	14.7
	(.121)	(.097)	(.096)	(.097)	(.113)	(11.0)
Milk						
Bacteriological Standard	.039	.096	.105	.047	.005	-1.53
	(.051)	(.070)	(.067)	(.069)	(.059)	(4.99)
TB Test	.156**	.112**	.093	.217**	.187**	10.7*
	(.073)	(.044)	(.079)	(.079)	(.074)	(5.99)
Joint effect of water-related interventions	.004	-.205*	.087***	.382**	-.001	-9.43*
{*F* statistic}	{1.62}	{2.72}	{4.41}	{3.20}	{1.61}	{2.25}
Joint effect of milk-related interventions	.195**	.208***	.198***	.264***	.191**	9.17
{*F* statistic}	{4.51}	{6.44}	{6.58}	{13.4}	{3.86}	{1.79}
Mean of diarrhea/enteritis mortality rate	67.0	65.5	65.5	65.2	64.8	65.5
N	949	974	974	935	874	974
R^2	.973	.979	.958	.969	.974	.938

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1900-1938, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. In columns (1)-(5), the dependent variable is equal to the natural log of the number of diarrhea/enteritis deaths per 100,000 population in municipality *m* and year *t*. In column (6), the dependent variable is equal to the number of diarrhea/enteritis deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. In columns (1)-(2) and (4)-(6), regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses.

Appendix Table 2. Diarrhea/Enteritis Mortality and Lags of *Filtration*

	(1)	(2)	(3)
	Diarrhea/Enteritis Mortality		
Year 0	-.074	-.084	-.089
	(.081)	(.080)	(.082)
1 Year After Filtration	-.100	-.111	-.117*
	(.067)	(.067)	(.068)
2 Years After Filtration	-.118	-.132*	-.138*
	(.072)	(.071)	(.070)
3+ Years After Filtration	-.230**	…	…
	(.106)		
3 Years After Filtration	…	-.142	-.149
		(.099)	(.097)
4 Years After Filtration	…	-.196*	-.204*
		(.113)	(.113)
5+ Years After Filtration	…	-.277**	…
		(.113)	
5 Years After Filtration	…	…	-.227*
			(.110)
6 Years After Filtration	…	…	-.277**
			(.109)
7+ Years After Filtration	…	…	-.302**
			(.128)
Mean of dependent variable	65.5	65.5	65.5
N	974	974	974
R^2	.971	.972	.972

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1900-1938, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the natural log of the number of diarrhea/enteritis deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses.

Appendix Table 3. p-Values from Wild Bootstrap

	(1)	(2)	(3)	(4)
	Estimate from Table 7, Column (5)	Estimate from Table 11, Column (1)	Estimate from Table 11, Column (2)	Estimate from Table 11, Column (3)
	Infant Mortality	*Typhoid Mortality*	*Diarrhea/ Enteritis Mortality*	*Diarrhea/ Enteritis* (*Under Age 2*) *Mortality*
Filtration	-.114**	-.171**	-.162*	-.163
	(.045)	(.073)	(.091)	(.105)
		[-4.63]		
p-value from wild cluster bootstrap procedure	.051	.038	.116	.161
Mean of dependent variable	207.8	12.8	65.5	52.0
N	1,024	1,024	974	1,024
R^2	.981	.938	.971	.964

*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics*, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the natural log (or, in the case of typhoid, the quartic root) of the number of specified deaths per 100,000 population in municipality *m* and year *t*. Controls include the demographic characteristics and remaining public health interventions listed in Table 5, municipality fixed effects, year fixed effects and municipality-specific linear trends. Regressions are weighted by municipality population. Standard errors, corrected for clustering at the municipal level, are in parentheses.

Appendix Table 4. Comparing our Preferred Specification to that of Cutler and Miller (2005)

	C&M Specification	Our Specification
Set of controls	See Appendix Table 5	See Table 5
Model choice	OLS	OLS
Weighting	Unweighted	Weighted by municipality population
Standard errors	Huber-White	Clustered at the municipal level
N	415	1,024
Years	1905-1936	1900-1940
Number of cities	13	25
	City in C&M sample	City in our sample
Baltimore, MD	yes	yes
Boston, MA	…	yes
Buffalo, NY	…	yes
Chicago, IL	yes	yes
Cincinnati, OH	yes	yes
Cleveland, OH	yes	yes
Detroit, MI	yes	yes
Indianapolis, IN	…	yes
Jersey City, NJ	yes	yes
Kansas City, MO	…	yes
Louisville, KY	yes	yes
Memphis, TN	yes	yes
Milwaukee, WI	yes	yes
Minneapolis, MN	…	yes
Newark, NJ	…	yes
New Orleans, LA	yes	yes
New York, NY	…	yes
Philadelphia, PA	yes	yes
Pittsburgh, PA	yes	yes
Providence, RI	…	yes
Rochester, NY	…	yes
San Francisco, CA	…	yes
St. Louis, MO	yes	yes
St. Paul, MN	…	yes
Washington, D.C.	…	yes

Appendix Table 5. List of Controls in Cutler and Miller (2005)

	Description
Filtration	= 1 if municipality had a water filtration plant, = 0 otherwise
Chlorination	= 1 if municipality chemically treated water supply, = 0 otherwise
Filtration w/in 5 Years	= 1 if municipality began filtering water supply within 5 years, = 0 otherwise
Chlorination w/in 5 Years	= 1 if municipality began chemically treating water supply within 5 years, = 0 otherwise
Sewage Treatment [a]	= 1 if municipality had a sewage treatment plant, = 0 otherwise
Sewage Chlorination[b]	= 1 if municipality chemically treated its sewage, = 0 otherwise
Lake Michigan Outfalls	= 1 for Chicago after Lake Michigan sewer outfalls were shut off, = 0 otherwise
Cleveland Intake Tunnel	= 1 for Cleveland after intake tunnel was built to draw water from Lake Erie, = 0 otherwise
$\ln(Mortality)_{t-1}$	One-year lag of natural log of municipal mortality rate
$\ln(Mortality)_{t-2}$	Two-year lag of natural log of municipal mortality rate
$\ln(Mortality)_{t-3}$	Three-year lag of natural log of municipal mortality rate
$\ln(Mortality)_{t-4}$	Four-year lag of natural log of municipal mortality rate
$\ln(Mortality)_{t-5}$	Five-year lag of natural log of municipal mortality rate
ln(*Population*)	Natural log of municipal population
% Female	Percent of municipal population that was female
% Black	Percent of municipal population that was black
% Other Nonwhite	Percent of municipal population that was a nonwhite race other than black
% Foreign	Percent of municipal population that was foreign born
% Under 1	Percent of municipal population that was under 1 years of age
% 1 to 4	Percent of municipal population that was 1 to 4 years of age
% 5 to 9	Percent of municipal population that was 5 to 9 years of age
% 10 to 14	Percent of municipal population that was 10 to 14 years of age
% 15 to 19	Percent of municipal population that was 15 to 19 years of age
% 20 to 24	Percent of municipal population that was 20 to 24 years of age
% 25 to 34	Percent of municipal population that was 25 to 34 years of age
% 35 to 44	Percent of municipal population that was 35 to 44 years of age
% 45 to 64	Percent of municipal population that was 45 to 64 years of age
% 65 and Older	Percent of municipal population that was 65 years of age or older

[a] Three cities in C&M's sample period constructed sewage treatment plants (Baltimore in 1911, Cleveland in 1922 and Milwaukee in 1925).

[b] One city in C&M's sample period chlorinated its sewage (Cleveland in 1922).

Appendix Table 6a. Differences in Recorded Total Mortality Counts between Cutler and Miller (2005) and the U.S. Census Bureau's *Mortality Statistics*

City	Year	C&M's recorded total mortality count[a]	Correct total mortality count from *Mortality Statistics*[b]	Reason for difference (when known)
Baltimore, MD	1910	10729.06	10753	
	1911	10608.85	10407	
	1912	10813.78	10389	
	1913	11280.34	10624	
	1914	11351	10486	
	1915	11053.58	10008	
	1916	11997.81	10668	
	1917	12996.24	11355	
	1929	11647	11629	To calculate, one needs to add white infant mortality (=8,746) and nonwhite infant mortality (=2,883). It appears as if C&M incorrectly transposed the "4" and the "6" for white infant mortality before adding with nonwhite infant mortality.
Chicago, IL	1910	33065.65	33241	
	1911	32378.07	32531	
	1912	34043.64	34034	
	1913	35379.42	35298	
	1914	34070.28	33959	
	1915	35054.38	34894	
	1916	36537.19	36305	
	1917	38620.73	38011	
Cincinnati, OH	1910	6307.244	6319	
	1911	6059.659	6225	
	1912	6198.802	6449	
	1913	6373.602	6735	
	1914	6102.63	6431	
	1915	6043.042	6360	
	1916	6424.347	6741	
	1917	6567.196	6827	
Cleveland, OH	1910	8001.782	8047	
	1911	8071.839	7999	
	1912	8305.11	8156	
	1913	8941.641	8817	
	1914	8383.752	8183	
	1915	9095.276	8808	

	1916	10404.91	9986	
	1917	11360.98	10833	
Detroit, MI	1910	7382.857	7452	
	1911	7478.113	7110	
	1912	8831.332	7782	
	1913	10784.51	8995	
	1914	10575.69	8400	
	1915	11471.23	8720	
	1916	14899.83	10985	
	1917	15820.67	11736	
Jersey City, NJ	1910	4376.58	4401	
	1911	4291.277	4381	
	1912	3834.909	3942	
	1913	4036.024	4194	
	1914	3849.303	4042	
	1915	4096.986	4347	
	1916	4182.075	4480	
	1917	4186.827	4528	
Louisville, KY	1910	3749.809	3756	
	1911	3618.942	3661	
	1912	3702.519	3761	
	1913	3678.877	3784	
	1914	3747.795	3869	
	1915	3434.447	3550	
	1916	3457.839	3586	
	1917	3766.568	3919	
Memphis, TN	1910	2812.165	2818	
	1911	2856.282	2847	
	1912	2964.224	2977	
	1913	2910.776	2923	
	1914	2954.449	2970	
	1915	2950.558	2895	
	1916	0	...	Data for Memphis, TN are not reported in 1916.
	1917	3096.153	3019	
Milwaukee, WI	1910	5172.686	5205	
	1911	4567.123	4727	
	1912	5082.943	5210	
	1913	5058.14	5183	
	1914	4812.378	4959	

	1915	4757.083	4901	
	1916	5387.316	5549	
	1917	5303.467	5461	
New Orleans, LA	1910	7221.468	7250	
	1911	7016.516	7055	
	1912	7004.326	7054	
	1913	7027.57	7088	
	1914	7344.996	7417	
	1915	7685.571	7752	
	1916	6782.515	6847	
	1917	7433.125	7510	
	1930	8003	8030	C&M incorrectly transposed the "0" and "3"
Philadelphia, PA	1910	26937.75	27045	
	1911	26228.93	26276	
	1912	24504.65	24513	
	1913	25689.32	25612	
	1914	26874.71	26739	
	1915	26434.42	26291	
	1916	27895.48	27703	
	1917	30010.18	29649	
Pittsburgh, PA	1910	9574.963	9603	
	1911	8053.422	8099	
	1912	8673.595	8762	
	1913	9433.767	9550	
	1914	8734.226	8857	
	1915	8580.255	8728	
	1916	9901.419	10077	
	1917	10478.07	10645	
St. Louis, MO	1910	10844.5	10888	
	1911	10702.95	10765	
	1912	10560.21	10634	
	1913	10673.76	10761	
	1914	10945.34	11052	
	1915	10173.31	10293	
	1916	11115.76	11263	
	1917	11490.49	11584	

[a] Because the data set provided by Cutler and Miller did not include a variable for the total mortality count, we calculated it based on the provided total mortality rate ("allmort") and population ("pop") variables. Specifically, we used the following command in STATA:

gen mortality = (allmort*pop)/100000.

[b] The total mortality counts for each year listed above can be found in the following *Mortality Statistics* tables:

Year	Location
1910	*Mortality Statistics 1910*, Table 1, pp. 161-180
1911	*Mortality Statistics 1911*, Table 1, pp. 150-173
1912	*Mortality Statistics 1912*, Table 1, pp. 28-49
1913	*Mortality Statistics 1913*, Table 1, pp. 222-243
1914	*Mortality Statistics 1914*, Table 3, pp. 192-219
1915	*Mortality Statistics 1915*, Table 3, pp. 184-211
1916	*Mortality Statistics 1916*, Table 3, pp. 150-175
1917	*Mortality Statistics 1917*, Table 3, pp. 172-197
1929	*Mortality Statistics 1929*, Table 9, pp. 392-424
1930	*Mortality Statistics 1930*, Table 9, pp. 498-542

Appendix Table 6b. Differences in Recorded Infant Mortality Counts between Cutler and Miller (2005) and the U.S. Census Bureau's *Mortality Statistics*

City	Year	C&M's recorded infant mortality count[a]	Correct infant mortality count from *Mortality Statistics*[b]	Reason for difference (when known)
Baltimore, MD	1910	1417.07	2146	
	1911	1295.99	1960	
	1912	1384.03	2022	
	1913	1343	2011	
	1914	1312.43	1949	
	1915	1093.48	1626	
	1916	1158.78	1770	
	1917	1183.75	1780	
Chicago, IL	1910	6595.52	6844	
	1911	6017.86	6252	
	1912	6394.31	6678	
	1913	6649.87	6939	
	1914	6571.52	6878	
	1915	5942.99	6219	
	1916	6566.35	6910	
	1917	6246.72	6664	
	1931	766	2992	To calculate, one needs to add white infant mortality (=2,617) and nonwhite infant mortality (=375). It appears as if C&M incorrectly added mortality for one-year-olds, rather than infants, for whites (=391) and nonwhite infant mortality, which gives their recorded total of 766.
Cincinnati, OH	1910	793.435	917	
	1911	630.712	721	
	1912	693.419	805	
	1913	706.664	801	
	1914	637.264	750	
	1915	524.823	619	
	1916	623.426	736	
	1917	563.757	688	
Cleveland, OH	1924	2366	1386	To calculate, one needs to add white infant mortality (=1,219) and nonwhite infant mortality (=167). It appears as if C&M incorrectly added overall nonwhite mortality (=1,147) and white infant mortality (=1,219), which gives their recorded total of 2,366.
Detroit, MI	1920	2734	2885	C&M incorrectly recorded infant mortality for whites only, which was 2,734. Nonwhite infant mortality was 151.

Jersey City, NJ				No mistakes for Jersey City
Louisville, KY	1910	328.389	503	
	1911	298.928	441	
	1912	46.4965	448	
	1913	322.27	486	
	1914	338.518	496	
	1915	250.146	379	
	1916	283.827	418	
	1917	271.929	397	
Memphis, TN	1910	173.2	345	
	1911	175.645	348	
	1912	185.973	373	
	1913	157.88	319	
	1914	158.831	317	
	1915	118.738	228	
	1916	0	...	Data for Memphis, TN are not reported in 1916.
	1917	158.43	311	
Milwaukee, WI	1926	865	856	C&M incorrectly transposed the “5” and “6”
New Orleans, LA	1910	571.931	1061	
	1911	595.471	1071	
	1912	416.903	774	
	1913	500.74	934	
	1914	477.419	883	
	1915	492.79	927	
	1916	404.008	757	
	1917	446.364	866	
Philadelphia, PA	1910	4557.6	5334	
	1911	4093.3	4769	
	1912	3659.92	4201	
	1913	3925.69	4618	
	1914	4170.24	4870	
	1915	3634.78	4233	
	1916	3669.4	4252	
	1917	3921.49	4637	
Pittsburgh, PA	1901	6578	1580	C&M incorrectly recorded the overall mortality count instead of the infant mortality count.
	1904	771	1771	C&M incorrectly entered “1771” as “771”
	1910	2024.02	2259	
	1911	1648.01	1812	
	1912	1648.71	1811	

	1913	1754.65	1957
	1914	1672.1	1868
	1915	1670.73	1765
	1916	1688.55	1893
	1917	1744.14	1983
	1924	1530	1440
St. Louis, MO	1910	1452.74	1689
	1911	1345.61	1573
	1912	1263.1	1467
	1913	1246.83	1478
	1914	1278.93	1508
	1915	1014.65	1181
	1916	1061.51	1264
	1917	1012.88	1252

[a] In the Cutler and Miller data set, the variable "mort0_1" represents the infant mortality count. Their dependent variable of interest, the natural log of the infant mortality rate, can be recreated with the following STATA command:

gen lninfmrt = ln((mort0_1*100000)/age0_1), where "age0_1" is the municipal infant population.

[b] The infant mortality counts for each year listed above can be found in the following *Mortality Statistics* tables:

Year	Location
1901	*Mortality Statistics 1900 to 1904*, Table 2, pp. 180-197; or Table 8, pp. 270-311
1904	*Mortality Statistics 1900 to 1904*, Table 2, pp. 654-671; or Table 8, pp. 744-785
1910	*Mortality Statistics 1910*, Table 3, pp. 204-251; or Table 9, pp. 455-501; or Table 11, pp. 533-574
1911	*Mortality Statistics 1911*, Table 1, pp. 150-173; or Table 2, pp. 174-257; or Table 7, pp. 466-512; or Table 9, pp. 537-567
1912	*Mortality Statistics 1912*, Table 1, pp. 28-49; or Table 6, pp. 255-301; or Table 8, pp. 335-377
1913	*Mortality Statistics 1913*, Table 1, pp. 222-243; or Table 6, pp. 486-539; or Table 8, pp. 577-625
1914	*Mortality Statistics 1914*, Table 3, pp. 192-219; or Table 4, pp. 220-303; or Table 9, pp. 567-621; or Table 11, pp. 660-709
1915	*Mortality Statistics 1915*, Table 3, pp. 184-211; or Table 4, pp. 212-297; or Table 9, pp. 553-607; or Table 11, pp. 645-694
1916	*Mortality Statistics 1916*, Table 3, pp. 150-175; or Table 9, pp. 406-449; or Table 11, pp. 483-525
1917	*Mortality Statistics 1917*, Table 3, pp. 172-197; or Table 9, pp. 441-487; or Table 11, pp. 523-568
1920	*Mortality Statistics 1920*, Table 3, pp. 140-174; or Table 9, pp. 479-539; or Table 11, pp. 586-646
1924	*Mortality Statistics 1924*, Table 9, pp. 358-390
1926	*Mortality Statistics 1926*, Table 9, pp. 285-317
1931	*Mortality Statistics 1931*, Table 9, pp. 396-440

Appendix B

Sources for Tables 1-3

Baltimore, Maryland

Hendrickson, Martha A. 2012. "The Montebello Water Filtration Plant I: Clean Water for City & Suburb Alike." *History Trails*, 43(3-4): 1-20.

Jennings, C.A. 1918. "Some Results Secured by Chlorine Compounds in Water Purification and Sewage Treatment." *Municipal Engineering*, LV(1): 249-251.

Wagenhals, H.H., E.J. Theriault, and H.B. Hommon. 1925. Report on the Study of Fifteen Representative Sewage Treatment Plants. Washington, D.C.: Government Printing Office.

Boston, Massachusetts

Castellon, Cynthia M. 2008. "Disinfection Byproduct (DBP) Precursors in Central MA." Environmental & Water Resources Engineering Masters Projects, University of Massachusetts-Amherst.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

Ropes, Horace. 1904. "Westin Aqueduct Department". In the *Third Annual Report of the Metropolitan Water and Sewage Board* (Public Document 57). Boston, MA: Wright and Potter Printing Company, pp. 113-136.

Buffalo, New York

Andrews, George C. 1927. "The Buffalo Water Works." *Journal of the American Water Works Association*, 17(3): 279-290.

Fronczak, Francis E. 1915. "Reduction in Typhoid." *Buffalo Sanitary Bulletin*, 8(8): 85-86.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

Rossi, Mary C. 1995. "The History of Sewage Treatment in the City of Buffalo, New York." *Middle States Geographer*, 28: 9-19.

Chicago, Illinois

Baylis, John R. 1949. "Chicago South District Filtration Plant." *Journal of the American Water Works Association*, 41(7) :599-615.

Cain, Louis P. 1978. *Sanitation Strategy for a Lakefront Metropolis: The Case of Chicago.* DeKalb, IL: Northern Illinois University Press.

Gustaitis, Joseph. 2013. *Chicago's Greatest Year, 1893: The White City and the Birth of a Modern Metropolis*. Carbondale, IL: Southern Illinois University Press.

Hering, Rudolph and George W. Fuller. 1907. "Sewage Disposal at Chicago and Vicinity." *Engineering Record*, 55(5): 130-134.

Jennings, C. A. 1923. "The Disinfection of Public Water Supplies and its Relation to Public Health." *Journal of the American Water Works Association,* 10(1): 127-138.

Melosi, Martin. 2008. *The Sanitary City: Environmental Services in Urban America from Colonial Times to the Present*. Pittsburgh, PA: University of Pittsburgh Press.

Cincinnati, Ohio

Cutler, David M. and Grant Miller. 2005. "The Role of Public Health Improvements in Health Advances: The Twentieth-Century United States." *Demography*, 42(1): 1-22.

Eddy, Harrison P. 1913. "Report upon Necessity and Feasibility of Treating the Sewage of Cincinnati before its Discharge into the Ohio River." *Progress Report on a Plan of Sewerage for the City of Cincinnati.* Department of Public Works, Cincinnati, OH, pp. 295-610.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

Cleveland, Ohio

Ellms, J. W. and John J. Wirts. 1943. "Sewage Treatment Problems in Cleveland, Ohio." *Sewage Works Journal*, 15(1): 40-47.

Hyde, Charles Gilman, George H. Wilhelm, and Frank C. Miller. 1916. *A Report Upon Possible Sources of Water Supply for the City of Sacramento.* Sacramento, CA: Rincon Publishing Company, Printers.

Ohio (state). 1913. *Twenty Seventh Annual Report of the State Board of Health.* Columbus, Ohio: F.J. Heer Printing Company, pp. 623-633.

Orth, Samuel Peter. 1910*. A History of Cleveland, Ohio, Volume 1*. Chicago-Cleveland: S.J. Clarke Publishing Company.

Perkins, Roger G. 1921. "Typhoid Fever in Cleveland Ohio for the Years 1918, 1919, and 1920" *Public Health Reports*, 36(20): 1095-1132.

Stradling, David and Richard Stradling. 2015. *Where the River Burned: Carl Stokes and the Struggle to Save Cleveland*. Ithaca, NY: Cornell University Press.

Detroit, Michigan

Detroit Water and Sewerage Department. 2002. *Detroit Water and Sewerage Department: The First 300 Years* (Daisy, Michael, editor). Detroit, MI: Detroit Water and Sewerage Department.

Jennings, C.A. 1918. "Some Results Secured by Chlorine Compounds in Water Purification and Sewage Treatment." *Municipal Engineering*, LV(1): 249-251.

Indianapolis, Indiana
Calvert, C.K. 1934. "The Sanitary Works of Indianapolis." *American Journal of Public Health*, 24(7): 739-742.

Jordan, H.E. 1909. "Preliminary Chemical Treatment as an Aid to Slow Sand Filtration; Indianapolis Water Company." *Engineering News*, 66(6): 144-148.

Mabee, W.C. 1909. "Concrete in Waterworks Construction." *Fire and Water Engineering*, 46:242-244.

Unknown Author. 1919. "Disinfection of Water Supplies." *Municipal Journal and Public Works*, 46(24): 437-439 and 444.

Jersey City, New Jersey
Jennings, C.A. 1918. "Some Results Secured by Chlorine Compounds in Water Purification and Sewage Treatment." *Municipal Engineering*, LV(1): 249-251.

Leith, Rodney B. 1972. "Jersey City Gives Up its Sewage Treatment Plant." *New York Times*, April 30. Available at: https://www.nytimes.com/1972/04/30/archives/jersey-city-gives-up-its-sewagetreatment-plant.html.

McGuire, Michael J. 2013. *The Chlorine Revolution: Water Disinfection and the Fight to Save Lives*. Denver, CO: American Water Works Association.

Stoddard, Andrew, Jon B. Harcum, Jonathan T. Simpson, James R. Pagenkopf, and Robert K. Bastian. 2002. *Municipal Wastewater Treatment: Evaluating Improvements in National Water Quality*. New York, NY: John Wiley and Sons.

Kansas City, Missouri
Bullard, Loring. 2010. *Source to Tap: A History of Missouri's Public Water Supplies.* Available at: http://www.watershedcommittee.org/wp-content/uploads/2010/08/copy-of-copy-of-source-to-tapfinal.pdf.

Hyde, Charles Gilman, George H. Wilhelm, and Frank C. Miller. 1916. *A Report Upon Possible Sources of Water Supply for the City of Sacramento.* Sacramento, CA: Rincon Publishing Company, Printers.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

Samuel, T.D. 1930. "The Water Supply System of Kansas City Missouri." *Journal of the American Water Works Association*, 22(9): 1236-1246.

Louisville, Kentucky
Bruggers, James. 2016. "Yuk! Louisville Still has a $943m Sewer Problem." *The Courier Journal,* October 22. Available at: https://www.courier-journal.com/story/tech/science/environment/2016/10/22/yuck-louisville-still-has-943m-sewer-problem/87721810/.

Gazlay, Webster. 1912. "The Louisville Water Purification Plant." *Engineering Record*, 65(26): 728.

Recktenwold, Roger. 2017. “Water and Wastewater Service for the Commonwealth of Kentucky.” In *Water in Kentucky: Natural History, Communities, and Conservation* (editors Brian D. Lee, Daniel I. Carey, Alice L. Jones), Lexington, KY: University Press of Kentucky.

Unknown Author. 1911. “Louisville Waterworks Report.” *Fire and Water Engineering*, 49(22): 209.

Memphis, Tennessee

Hardin, Eugene. 1932. “Design and Operation Data on Large Rapid Sand Filtration Plants in the United States and Canada.” *Journal of the American Water Works Association*, 24(8): 1190-1207.

JAMA (editorial board). 1921. “Typhoid in the Large Cities of the United States in 1920.” *Journal of the American Medical Association*, 76(13): 860-863.

JAMA (editorial board). 1922. “Typhoid in the Large Cities of the United States in 1921.” *Journal of the American Medical Association*, 78(12): 890-893.

Preble, Paul. 1921. “Review of Public Health Administration in Memphis, Tennessee.” *Public Health Bulletin No. 113*. Treasury Department, United States Public Health Service.

Milwaukee, Wisconsin

Foss-Mollan, Kate. 2001. *Hard Water: Politics and Water Supply in Milwaukee, 1870-1995.* West Lafayaette, IN: Purdue University Press.

Jennings, C. A. 1918. “Some Results Secured by Chlorine Compounds in Water Purification and Sewage Treatment.” *Municipal Engineering*, LV(1): 249-251.

Minneapolis, Minnesota

Cappelen, F.W. 1918. *Annual Report of the City Engineer of the City of Minneapolis for the Year Ending December 31, 1914*. Minneapolis, MN: Syndicate Printing Company.

Mohlman, F. W. 1940. “Sewage Treatment in Large American Cities.” *Sewage Works Journal*, 12(1): 168-171.

National Research Council of the National Academies. 2008. *Mississippi River Water Quality and the Clean Water Act*. Washington, D.C.: National Academies Press.

Saint Paul (MN). 1938. *Annual Report of the Commissioner of Public Works*. Saint Paul, MN: Department of Public Works.

Stokes, William Royal. 1911. “A Report Concerning the Treatment of Baltimore Drinking Water with Hypochlorite of Calcium.” *Maryland Medical Journal*, LIV(7): 204-214.

Unknown Author. 1917. “Chlorine Disinfection in Water-Works Plants.” *Water and Gas Review*, 27(10): 17-22.

Newark, New Jersey

Hendricks David. 2011. *Fundamentals of Water Treatment Unit Processes: Physical, Chemical, and Biological.* New York, NY: CRC Press.

Modica, Glenn R.2001. *The History of the Newark Sewer System*. Cranbury, NJ: Richard Grubb & Associates.

Newark (NJ), Dept. of Streets and Public Improvements. 1922. *Annual Report*, Newark, NJ.

North Jersey District Water Supply Commission. 1950. *Wanaque and Ramapo Projects*. Wanaque, NJ.

Unknown Author. 1917. "Chlorine Disinfection in Water-Works Plants." *Water and Gas Review*, 27(10):17-22.

Unknown Author. 1919. "Disinfection of Water Supplies." *Municipal Journal and Public Works*, 46 (24): 437-439 and 444.

New Orleans, Louisiana

Cutler, David M. and Grant Miller. 2005. "The Role of Public Health Improvements in Health Advances: The Twentieth-Century United States." *Demography*, 42(1): 1-22.

Porter, John L. 1909. "Operation and Maintenance Purification Stations." In the *Semi-annual Report of the Sewerage and Water Board of the City of New Orleans, La*, pp. 57-63.

Reeves, William D. 2003. *Historic Louisiana: An Illustrated History.* San Antonio, TX: Historical Publishing Network.

New York, New York

Coffin, T.D.L. 1913. "Chlorinating Plants, Croton Water Supply." *Engineering News*, 69(9): 419-422.

Donaldson, Wellington. 1939. "First Year's Operation of Wards Island Sewage Treatment Works." *Sewage Works Journal,* 11(1): 100-116.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

New York City Department of Environmental Protection. "New York City's Wastewater Treatment System." Available at: http://www.nyc.gov/html/dep/pdf/wwsystem.pdf.

Unknown Author. 1908. "The Filling of the New Croton Reservoir." *The Engineering Review*, 18(1): 53.

Pittsburgh, Pennsylvania

Cutler, David M. and Grant Miller. 2005. "The Role of Public Health Improvements in Health Advances: The Twentieth-Century United States." *Demography*, 42(1): 1-22.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

Pittsburgh (PA), Dept. of Public Works. 1916. *The City of Pittsburgh and Its Public Works.* Pittsburgh, PA: Pittsburgh Printing Company.

Philadelphia, Pennsylvania
Hendricks, David W. 2006. *Water Treatment Unit Processes: Physical and Chemical*. Boca Raton, FL: CRC Press.

McCarthy, Michael P. 1987. *Typhoid and the Politics of Public Health in Nineteenth-century Philadelphia*. Philadelphia, PA: American Philosophical Society.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

Philadelphia (PA), 1909. *Description of the Filtration Works and Pumping Stations: Also Brief History of the Water Supply.* Philadelphia, PA: Bureau of Water.

West, Francis D. 1909. "Sanitary Control of Filter Plants." *Proceedings of the Engineers' Club of Philadelphia*, 26(2): 135-144.

West, Francis D. 1914. "Disinfecting 200,000,000 Million Gallons of Water a Day—Experience with Chloride of Lime and Liquid Chlorine at the Torresdale Filtration Plant." *Journal of the American Water Works Association*, 1(3): 403-446.

Providence, Rhode Island
Bronsdon, M.H. 1919. "Operating Results of Slow-Sand Filtration Plant at Providence R.I." Chemical Abstracts, Volume 13(7): 760.

Cady, John Hutchins. 1957. *The Civic and Architectural Development of Providence, 1636-1950.* Providence, RI: The Book Shop

Nixon, Scott W. 1995. *Metal Inputs to Narragansett Bay: A History and Assessment of Recent Conditions*. Narragansett, RI: Rhode Island Sea Grant Communications Office.

Unknown Author. 1909. "Water Filters of Providence, R.I." *Municipal Journal and Engineer*, 27(3): 85-89.

Rochester, New York
Baker, Frank Collins. 1920. "Animal Life and Sewage in the Genesee River, New York." *The American Naturalist*, 54(631): 152-161.

McKelvey, Blake. 1972. "Water for Rochester." *Rochester History*, 34(3): 1-24.

Rochester (City of), Department of Environmental Services, Bureau of Water. 2013. *A Pocket History of the Rochester Water Works,* Rochester New York.

San Francisco, California
Environmental Protection Agency, Office of Enforcement. 1975. *Evaluation of Sewage Treatment Facilities San Francisco, California September 1975*. EPA-330/2-75-008, San Francisco, CA.

Hanson, Warren D. 2005. *A History of the Municipal Water Department and Hetch Hetchy System.* San Francisco, CA: San Francisco Public Utilities Commission.

Hassler, William C. 1930. "Typhoid Fever Epidemic Occurring During the Summer of 1928." *American Journal of Public Health*, 20(2): 137–146.

Schussler, Hermann. 1906. *The Water Supply of San Francisco, California, Before, During and After the Earthquake of April 18th, 1906, and the Subsequent Conflagration*. New York, NY: Martin B. Brown Press.

Unknown Author. 1919. "Disinfection of Water Supplies." *Municipal Journal and Public Works*, 46 (24): 437-439, 444.

St. Louis, Missouri

Cutler, David M. and Grant Miller. 2005. "The Role of Public Health Improvements in Health Advances: The Twentieth-Century United States." *Demography*, 42(1): 1-22.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

National Research Council of the National Academies. 2008. *Mississippi River Water Quality and the Clean Water Act*. Washington, D.C.: National Academies Press.

Wall, Edward E. 1920. "Water Treatment at St. Louis Mo." *American Journal of Public Health*, 10(5): 437-443.

St. Paul, Minnesota

Jensen, Bob. 2016. "A Drink of Water." *LillieNews.com*, August 3. Available at: http://www.lillienews.com/articles/2016/08/03/drink-water.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

Saint Paul (MN). 1938. *Annual Report of the Commissioner of Public Works*. Saint Paul, MN: Department of Public Works

Unknown Author. 1914. "St. Paul, Minn., Water Report for 1913." *Fire and Water Engineering*, 56(2): 20.

Washington, D.C.

Cosby, Spencer. 1909. "The Water Supply of Washington" In (editor, John H. Walker) the *Purification of the Washington Water Supply* (3rd edition), Washington, D.C.: Government Printing Office, Chapter 8, pp. 260-265.

Mohlman, F. W. 1940. "Sewage Treatment in Large American Cities." *Sewage Works Journal*, 12(1): 168-171.

Parker, Horatio N. 1907. "Stream Pollution, Occurrence of Typhoid Fever, and the Character of Surface Waters in the Potomac Basin." *Water-Supply and Irrigation Papers of the United States,* Paper No. 192: 191-290.

Penn, James R. 2001. *Rivers of the World: A Social, Geographical, and Environmental Sourcebook.* Santa Barbar, CA: ABC-CLIO, Inc.

United States Engineer Office, War Department. 1939. The Washington Aqueduct Water Supply, District of Columbia. Available at: http://www.waterworkshistory.us/DC/Washington/1939Aqueduct.pdf.

Unknown Author. 1978. "Blue Plains Treatment Plant, Washington D.C." *Journal Water Pollution Control Federation*, 50(5): 997-998, 315a, 317a.

Sources for Table 4

Baltimore, Maryland

Blanck, Fred. 1913. "Report of the Chemical Laboratory." *Annual Report Department of Public Safety*, Sub-Department of Health to the Mayor and City Council of Baltimore for the Fiscal Year Ended December 31, 1912. Baltimore, MD: Meyer and Thalheimer, p. 511-558.

City of Baltimore. 1943. *One Hundred and Twenty-Ninth Annual Report of the Department of Health*. Baltimore, MD: Department of Health.

Early, Floyd R. 1925. "Restrictions of Milk Production in Different Large Cities in the East." *Milk Products Review*, 6(3): 8.

Steffens, D.H. 1913. "Some Weaknesses of the City Inspection Theory." *The Creamery and Milk Plant Monthly*, 1(10): 1-6.

Wessel, Joyce E. 1984. "Baltimore's Dairy Industry and the Fight for Pure Milk, 1900-1920." Business and Economic History, 13 (Papers presented at the thirtieth annual meeting of the Business History Conference), pp. 150-157.

Boston, Massachusetts

Jordan, James O. 1907. "Boston's Campaign for Clean Milk." *Journal of American Medical Association*, 49: 1082-1087.

Massachusetts (State Board of Health). 1912. *The State Board of Health of Massachusetts: A Brief History of its Organization and its Work, 1869-1912.* Boston, MA: Wright and Potter Printing Company, State Printers.

Prescott, Samuel C. 1906. "The Production of Clean Milk as a Practical Proposition" *Maryland Medical Journal*, 49(6): 208-281.

Rosenau, Milton J. 1908. "The Number of Bacteria in Milk and the Value of Bacterial Counts." In *Milk and its Relation to the Public Health*, Washington, D.C.: Government Printing Office, pp. 429-453.

United States Public Health Service. 1946. *List of American Municipalities with Compulsory Pasteurization*. Washington D.C.: U.S. Public Health Service, Sanitary Engineering Division, Milk and Food Section.

Unknown Author. 1943. "Curtains for Raw Milk." *New England Journal of Medicine*, 229(20): 765.

Buffalo, New York

Baker, Moses M. 1910. "The Economic and Sanitary Supervision of City Milk Supplies." *Statistics of Cities Having a Population of Over 25,000: 1907*. Washington, D.C.: Government Printing Office, pp. 36-45, 450.

Mangold, George B. 1908. "Infant Mortality in the American Cities." *Annals of the American Academy of Political and Social Science*, 31(2): 484-494.

Wende, Ernest. 1908. "The Bulletin's Mission." *The Buffalo Sanitary Bulletin*, 1(1): 1-4.

Chicago, Illinois

Czaplicki, Alan. 2007. "Pure Milk Is Better Than Purified Milk": Pasteurization and Milk Purity in Chicago, 1908-1916." *Social Science History*, 31(3): 411-433

Eastman, Francis. 1912. *Chicago City Manual 1912*. Chicago, IL: Bureau of Statistics and Municipal Library.

Fuchs, A. W., and Frank, L. C. 1938. "Milk Supplies and Their Control in American Urban Communities of Over 1,000 Population in 1936." *Public Health Bulletin, No. 245*. Washington D.C.: U.S. Public Health Service.

Olmstead, Alan, and Rhode, Paul. 2004. "An Impossible Undertaking: The Eradication of Bovine Tuberculosis in the United States." *Journal of Economic History*, 64(3): 734–772.

Rose, James A. 1914. "Dairy Animals – Tuberculin Test." *Bulletin of the Chicago Tuberculosis Institute*, Series 2, No. 8.

Ward, Archibald Robinson and Myer Edward Jaffa. 1909. *Pure Milk and the Public Health: A Manual of Milk and Dairy Inspection*. Ithaca, NY: Taylor and Carpenter, pp. 200-205.

Cincinnati, Ohio

Blume, R.B. 1922. "Report of the Medical Milk Commission of the Cincinnati Academy of Medicine." Proceedings of the American Association of Medical Milk Commissions and Certified Milk Producers Association of America. Chicago, IL: American Association of Medical Milk Commissions, pp. 282-286.

Cincinnati (OH). 1913. "Milk. Production, Care, and Sale." *Public Health Reports* (1896-1970), 28(14): 672-677.

Mangold, George B. 1908. "Infant Mortality in the American Cities." *Annals of the American Academy of Political and Social Science*, 31(2): 484-494.

United States Public Health Service. 1915. *Municipal Ordinances, Rules, and Regulations Pertaining to Public Health*. Washington, D.C.: Washington Government Printing Office, pp. 240-241.

United States Public Health Service. 1946. *List of American Municipalities with Compulsory Pasteurization*. Washington D.C.: U.S. Public Health Service, Sanitary Engineering Division, Milk and Food Section.

Unknown Author. 1949. "City's Main Source Closed for Certified Grade Milk at End of Month, is Word." *Cincinnati Enquirer*, September 16, p. 12.

Cleveland, Ohio

Cleveland (OH). 1915. "Milk and Milk Products. Production, Care, and Sale. Bureau of Dairy and Food Inspection Created." *Public Health Reports*, 30(46): 3380-3387.

Commission of Publicity and Efficiency. 1919. "Does Regulation Increase the Price of Milk?" *Toledo City Journal*, 4(7): 104.

Lane, C.B. and Ivan C. Weld. 1908. "A City Milk and Cream Contest as a Practical Method of Improving the Milk Supply." *Bureau of Animal Industry Circular 117*. Washington D.C.: Government Printing Office.

Milk Commission of the City of Cleveland. 1906. "Report of the Milk Commission of the City of Cleveland, December 1906." *Cleveland Medical Journal*, 6(1): 31-38.

Mowry, Don E. 1908. "Milk Regulation in the Larger Cities." *Municipal Journal and Engineer*, 25(2): 55.

Detroit, Michigan

Clement, Clarence Elbert and Gustav Paul Warber. 1918. "The Market Milk Business of Detroit, Mich., in 1915" United States Department of Agriculture Bulletin No. 639 (February 15).

Kiefer, Guy L. 1911. "Report of the Milk Inspector." *Thirtieth Annual Report of the Board of Health of the City of Detroit for the Fiscal Year Ending June 30, 1911*. Detroit, MI: Board of Health, pp. 94-106.

Indianapolis, Indiana

City of Indianapolis (IN) 1940. "Regular Meeting, Monday August 19." *Journal of the Common Council of the City of Indianapolis, Indiana*, pp. 469-580.

United States Public Health Service. 1917. *Public Health Reports*, 31 (Part 2), Washington, D.C.: Washington Government Printing Office, pp. 2130-2134.

United States Public Health Service. 1946. *List of American Municipalities with Compulsory Pasteurization*. Washington D.C.: U.S. Public Health Service, Sanitary Engineering Division, Milk and Food Section.

Jersey City, New Jersey

Gray, Thomas N. 1913. "Infant Mortality." *Journal of the Medical Society of New Jersey*, 10(1): 3-9.

United States Public Health Service. 1917. Municipal Ordinances, Rules, and Regulations Pertaining to Public Health, 1915. Washington DC: Washington Government Printing Office, pp. 291-296.

Kansas City, Missouri

Baker, Moses M. 1910. "The Economic and Sanitary Supervision of City Milk Supplies." *Statistics of Cities Having a Population of Over 25,000: 1907*. Washington, D.C.: Government Printing Office, pp. 36-45.

Treasury Department, United States. 1912*. Municipal Ordinances, Rules, and Regulations Pertaining to Public Hygiene*. Washington, D.C.: Washington Government Printing Office, pp. 102-105

United States Public Health Service. 1916. *Public Health Reports*, 31 (Part 1), Washington, D.C.: Washington Government Printing Office, pp. 34-46.

Louisville, Kentucky

Baker, Moses M. 1910. "The Economic and Sanitary Supervision of City Milk Supplies." *Statistics of Cities Having a Population of Over 25,000: 1907*. Washington, D.C.: Government Printing Office, pp. 36-45.

United States Department of Agriculture. 1953. The Marketing of Milk in the Louisville Area Under Federal Regulation. Marketing Research Report No. 43, Washington, D.C.: Government Printing Office.

Memphis, Tennessee

Preble, Paul. 1921. A Review of Public Health Administration in Memphis, Tennessee. Public Health Bulletin No. 113, Washington D.C.: Government Printing Office, pp. 101-106.

United States, Public Health Service. 1912. Municipal Ordinances, Rules, and Regulations Pertaining to Public Hygiene. Washington D.C.: Government Printing Office, pp. 112-115.

Milwaukee, Wisconsin

Baker, Moses M. 1910. "The Economic and Sanitary Supervision of City Milk Supplies." *Statistics of Cities Having a Population of Over 25,000: 1907*. Washington, D.C.: Government Printing Office, pp. 36-45.

Mangold, George B. 1908. "Infant Mortality in the American Cities." *Annals of the American Academy of Political and Social Science*, 31(2): 484-494.

Minneapolis, Minneapolis

Baker, Moses M. 1910. "The Economic and Sanitary Supervision of City Milk Supplies." *Statistics of Cities Having a Population of Over 25,000: 1907*. Washington, D.C.: Government Printing Office, pp. 36-45.

Minneapolis (MN). 1917. Annual Report of the Health Department. Minneapolis, MN: Syndicate Printing Company, p. 83.

Minneapolis (MN), City Council. 1919. Proceedings of the City Council of the City of Minneapolis from January 1, 1919 to January 1, 1920, Volume 45, pp. 364-365.

Minneapolis (MN), City Council. 1907. Proceedings of the City Council of the City of Minneapolis from January 1, 1907 to January 1, 1908, Volume 33, pp. 553-556.

Newark, New Jersey

Gray, Thomas N. 1913. "Infant Mortality." *Journal of the Medical Society of New Jersey*, 10(1): 3-9.

Newark (NJ), Mayor. 1915. "The Mayor's Message Together with the Reports of the City Officers of the City of Newark, NJ." Newark, NJ: Daily Advertiser Office.

United States Congress, House Committee on the District of Columbia. 1921. Sale of Milk, Cream, and Certain Milk Products in the D.C.: Hearings Before the Subcommittee on the District of Columbia, Part 1, House of Representatives. Washington, D.C.: Government Printing Office, p. 39.

New Orleans, Louisiana
Maes, Urban. 1910. "Report of the Milk Commission of the New Orleans Pure Milk Society." *Proceedings of the Fourth Annual Conference of the American Association of Medical Milk Commissions*, 4: 41-43.

New Orleans (LA), Board of Health 1922. "The Following Resolution was Passed at a Regular Meeting of the Board of Health for the Parish of Orleans and the City of New Orleans, October 11." *Monthly Bulletin*, *Municipal Health Department*, 10(11).

Tuley, Henry Enos. 1915. "President's Address." Proceedings of the Sixth, Seventh, and Eighth Annual Conferences of the American Association of Medical Milk Commissions, Volumes 6-8, pp. 89-93.

United States Public Health Service. 1946. *List of American Municipalities with Compulsory Pasteurization*. Washington D.C.: U.S. Public Health Service, Sanitary Engineering Division, Milk and Food Section.

Unknown Author. 1925. "Hefferman Says Monroe Needing Milk Inspector." *The Monroe News-Star*, January 21, p. 3.

New York, New York
Baker, Moses M. 1910. "The Economic and Sanitary Supervision of City Milk Supplies." *Statistics of Cities Having a Population of Over 25,000: 1907*. Washington, D.C.: Government Printing Office, pp. 36-45 (and page 450).

New York (NY). 1912. "Milk. Production, Care, and Sale. With Special Reference to Pasteurization." *Public Health Reports* (1896-1970), 27(12): 434-438.

New York (NY), Department of Health. 1913. *Weekly Bulletin of the Department of Health of the City of New York*, 2(44): 1-3.

United States Public Health Service. 1946. *List of American Municipalities with Compulsory Pasteurization*. Washington D.C.: U.S. Public Health Service, Sanitary Engineering Division, Milk and Food Section.

Unknown Author. 1943. "New York City Certified Milk to be Pasteurized." *American Journal of Public Health*, 33 (October): 1305.

Philadelphia, Pennsylvania
Beard, Charles Austin. 1913. "Notes and Events." *National Civic Review*, 2(4): 675-719.

Early, Floyd R. 1925. "Restrictions of Milk Production in Different Large Cities in the East." *Milk Products Review*, 6(3): 8.

Gittings, J.C. 1922. "Report of the Milk Commission of the Philadelphia Pediatric Society" Proceedings of the American Association of Medical Milk Commissions and Certified Milk Producers Association of America. Chicago, IL: American Association of Medical Milk Commissions, pp. 463-465.

Henry Phipps Institute. 1915. "Food Inspection Service in Philadelphia." *Report of the Henry Phipps Institute*, 12: 57-94.

Mowry, Don E. 1908. "Milk Regulation in the Larger Cities." *Municipal Journal and Engineer*, 25(2): 55.

Philadelphia, PA, Department of Public Health. 1931. *Quarterly Bulletin of the Department of Public Health of the City of Philadelphia*. Philadelphia, PA.

Pittsburgh, Pennsylvania

Pittsburgh City Council. 1911. Municipal Record. Minutes of the Proceedings of the Select Council of the City of Pittsburgh for the Years 1910-1911, Volume 43. Pittsburgh, PA: Devine and Co., pp. 212-215.

Edwards, Ogden M. 1910. "Report of the Milk Commission of the Allegheny County Medical Society of Pittsburgh, PA." *Proceedings of the Fourth Annual Conference of the American Association of Medical Milk Commissions*, 4: 44-50.

United States Public Health Service. 1946. *List of American Municipalities with Compulsory Pasteurization*. Washington D.C.: U.S. Public Health Service, Sanitary Engineering Division, Milk and Food Section.

Unknown Author. 1942. "Ban on Raw Milk Voted by Council." *The Pittsburgh Press*, June 23, p. 21.

Providence, Rhode Island

Providence, RI. 1916. *Resolutions and Ordinances of the City Council of the City of Providence*. Providence, RI: Providence Printing Company, pp. 166-173.

Rochester, New York

Goler, G.W. 1919. "Control of the Milk Supply by the Rochester Milk Department." *Report of the Rochester Milk Survey*, pp. 160-175.

Groenewold, Ellen. 1908. "Milk Supply and Public Health." *NDQ: North Dakota Quarterly*, 8: 239-254.

Mowry, Don E. 1908. "Milk Regulation in the Larger Cities." *Municipal Journal and Engineer*, 25(2): 55.

Rochester (NY), Common Council. 1922. *Record of the Proceedings of the Common Council of the City of Rochester*. Rochester, NY: Rochester Herald Company, p. 350.

San Francisco, California

Hutshing, E.E. 1913. "The Milk Supply of San Francisco and it Bacterial Content." *California State Journal of Medicine*, 11(1): 14-17.

San Francisco (CA). 1910. *San Francisco Municipal Reports for the Fiscal Year 1908-9*. San Francisco, CA: Neal Publishing Company.

San Francisco (CA). 1915. *Ordinances Relating to the Preservation of Public Health, Regulation of Hospitals, Prevention of Disease, Preparation of Food, and Regulation of Places where Food is Offered for Sale*, pp. 25-33.

Skelly, Al. 1944. "Concerning San Francisco Ordinance Requiring Pasteurization of Milk." California and Western Medicine, 60(6): 355.

United States Public Health Service. 1917. *Municipal Ordinances, Rules, and Regulations Pertaining to Public Health.* Washington, D.C.: Washington Government Printing Office, pp. 160-173.

United States Public Health Service. 1946. *List of American Municipalities with Compulsory Pasteurization*. Washington D.C.: U.S. Public Health Service, Sanitary Engineering Division, Milk and Food Section.

St. Louis, Missouri

Baker, Moses M. 1910. "The Economic and Sanitary Supervision of City Milk Supplies." *Statistics of Cities Having a Population of Over 25,000: 1907*. Washington, D.C.: Government Printing Office, pp. 36-45.

Board of Aldermen of the City of St. Louis. 1921. "An Ordinance to Regulate the Production and Sale of Milk, Cream, and Ice Cream, and for Other Purposes." *The City Journal*, 4(17): 16-17.

Brown, C.A. 1928. *Costs and Margins and Other Related Factors in the Distribution of Fluid Milk in Four Illinois Markets*. University of Illinois, Bulletin Number 318: Urbana, IL.

Unknown Author. 1922. "News from Far and Near." *The Milk Dealer: The National Journal for the City Milk Trade*, 11(12): 101-104.

St. Paul, Minnesota

Baker, Moses M. 1910. "The Economic and Sanitary Supervision of City Milk Supplies." *Statistics of Cities Having a Population of Over 25,000: 1907*. Washington, D.C.: Government Printing Office, pp. 36-45.

Mowry, Don E. 1908. "Milk Regulation in the Larger Cities." *Municipal Journal and Engineer*, 25(2): 55.

Washington, D.C.

Dahlberg, Arthur Chester, H.S. Adams, and M.E. Held. 1953. Sanitary Milk Control and Its Relation to the Sanitary, Nutritive, and Other Qualities of Milk. Washington D.C.: National Academy of Sciences.

United States Congress House Committee on the District of Columbia. 1921. Sale of Milk, Cream, and Certain Milk Products in the District of Columbia: Hearings before the Subcommittee on the District of Columbia, House of Representatives, 67th Congress. Washington, D.C.: Washington Government Printing Office, pp. 3-5.