

THE PHENOMENON OF SUMMER DIARRHEA AND ITS WANING, 1910-1930

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Abstract. During the first two decades of the 20th century, diarrheal deaths among American infants and children surged every summer. Although we still do not know what pathogen (or pathogens) caused this phenomenon, the consensus view is that it was eventually controlled through public health efforts at the municipal level. Using data from 26 major American cities for the period 1910-1930, we document the phenomenon of summer diarrhea and explore its dissipation. We find that water filtration is associated with a 15 percent reduction in diarrheal mortality among children under the age of two during the non-summer months, but does not seem to have had an effect on diarrheal mortality during the summer. In general, we find little evidence to suggest that public health interventions undertaken at the municipal level contributed to the dissipation of summer diarrhea.

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1. INTRODUCTION

Summer diarrhea (also known as “cholera infantum” or the “disease of the season”) was first described in the medical literature by Benjamin Rush (1794). According to Rush (1794, p. 160), it would sometimes begin “with a diarrhoea, which can last for several days without any other symptom...but it more frequently comes on with a violent vomiting and purging, and a high fever.” He argued that it was likely caused by the “discharge of bile which generally introduces the disease...and exacerbations of the fever which accompanies it...” (Rush 1794, p. 163).

By the turn of the 20th century, physicians had gained a better understanding of how gastronomical diseases are contracted but still had not discovered why thousands of American infants and children were dying of diarrhea every summer. In fact, to this day, we can only speculate as to precisely what pathogen (or pathogens) caused the phenomenon (Meckel 1990; Thompson and Keeling 2012).

Economists and historians have argued that summer diarrhea was controlled through the combined effects of public health interventions (Meckel 1990; Fishback et al. 2011). Specifically, they point to municipal-level efforts during the early 1900s to purify water and milk supplies. Because breastfeeding was typically discontinued at an early age (Wolf 2003), and because there is anecdotal evidence that children were at the greatest risk of dying from diarrhea in their “second summer” (Condie 1858, p. 224; Moss 1903; Southworth 1904), focusing on these efforts is not without justification.¹

¹ See also Reedy (2007, p. 42), who asserted that summer diarrhea was controlled through “handwashing and safer food-handling procedures at home and in the marketplace” along with “better built and maintained sewage treatment plants” that “helped keep infants and children from playing in and drinking contaminated water.” Graham-Smith (1929) attributed the dissipation of summer diarrhea among infants in England to the introduction of the automobile, which had the effect of reducing horse manure in the streets.

We begin our study by documenting the phenomenon of summer diarrhea using newly transcribed mortality data from 26 major American cities for the period 1910-1930.² These data, which were originally published by the U.S. Bureau of the Census, include monthly counts of diarrheal deaths among children under the age of two. We show that 21,000 children under the age of two died of diarrhea in 1910, and 14,000 of these deaths occurred in the months of June-September. By the end of the period under study, the phenomenon of summer diarrhea had largely dissipated. Fewer than 4,000 children under the age of two died of diarrhea in 1930, and fewer than 1,500 of these deaths occurred in the summer.³

Next, we build upon the work of Anderson et al. (forthcoming), who, using data on 25 major American cities for the period 1900-1940, found that filtering the water supply was associated with an 11-12 percent reduction in infant mortality. Our interest is in whether filtration and other public health efforts at the municipal level contributed to the dissipation of summer diarrhea among children under the age of two. We find that the construction of a water filtration plant is associated with a 15 percent reduction in diarrheal mortality during non-summer months, consistent with the hypothesis that transmission occurred through contaminated water. Surprisingly, there is little evidence that filtration reduced diarrheal mortality during the hottest 4 months of the year (June-September), which suggests that transmission was through contaminated food or person-to-person contact, although efforts to purify the milk supply do not appear to have affected diarrheal mortality during the summer either. In fact, we find little evidence that public health interventions can explain the waning of summer diarrhea. We

² We focus on the period 1910-1930 because monthly-level mortality data are not available from the U.S. Bureau of the Census prior to 1910 or after 1930. To our knowledge, we are the first to document the phenomenon of summer diarrhea using data from such a large number of cities.

³ In 1910, the ratio of diarrheal deaths to the population of children under the age of two was .031 (21,101/678,292 = .031). By 1920, this ratio had dropped to .015; by 1930, it had dropped to .005.

conclude that the phenomenon of summer diarrhea was serious and widespread, but, contrary to the consensus view, its dissipation was not due to municipal-level efforts to purify the milk or water supplies or treat sewage. It is possible that improvements in the refrigeration chain, better nutrition, or some combination of these and other factors may have contributed to the dramatic reduction in diarrheal deaths among American infants and children during the summer months.

2. BACKGROUND

Today, diarrheal disease is the second-leading cause of death among children under the age of 5 (Liu et al. 2015). Between 500,000 and 800,000 children under the age of 5 die of diarrhea every year and most of these deaths occur in developing countries (Liu et al. 2015; Kovacs et al. 2015). A wide variety of bacteria, parasites and viruses cause diarrhea and other symptoms of gastroenteritis (Hodges and Gill. 2010). Infection is usually through contaminated food or water, or person-to-person contact (Pawlowski et al. 2009). In temperate climates, bacterial infections are more common during the summer (Ramos-Alvarez and Sabin 1958; Fletcher et al. 2013), while viral gastroenteritis is more common during the winter (Pawlowski et al. 2009). In tropical climates, the incidence of diarrhea peaks during the rainy season (Zhang et al. 2010; Phung et al. 2015; Xu et al. 2015; Kulinkina et al. 2016; Muluken et al. 2017).⁴

Over 70 percent of total deaths from diarrhea occur among children under of the age of two (Walker et al. 2013). Susceptibility is highest at 6-11 months, presumably because exclusive breastfeeding protects against infection and crawling brings children into contact with human

⁴ According to a recent review, noroviruses “are the most common cause of sporadic cases and outbreaks of gastroenteritis across all age groups worldwide” (Ahmed et al. 2013, p. 1). Rotavirus infections are another important cause of gastroenteritis among children under the age of 5 (Patel et al. 2013). Hospitalizations and outpatient visits for rotavirus and norovirus infections typically peak in the winter months (D’Souza et al. 2008; Gastañaduy et al. 2013; Patel et al. 2013). Parasitic infections, which can also cause diarrhea, are more common in the summer months (Amin 2002).

and/or animal feces (Walker et al. 2013; Mduduzi et al. 2015). Death is typically caused by dehydration and loss of electrolytes (King et al. 2003), although malnutrition is often a contributing factor (Baqui and Ahmed 2006).

2.1. Previous Research on Summer Diarrhea

In the decades leading up to its dissipation, summer diarrhea received a great deal of attention from physicians, who described its symptoms, noted that its victims were often born in crowded tenement housing districts, and proposed various causes.⁵ One school of thought held that exposure to summer heat was directly responsible for the annual wave of diarrheal deaths among infants and children (Miller 1879; Schereschewsky 1913), while another held that overfeeding was the cause (Burg 1902; Tilden 1909). Even among physicians who believed that summer diarrhea was caused by bacteria, there were several competing theories as to the mode of transmission (Zahorsky 1913, 1918). For instance, Hewitt (1910) and Youmans and Youmans (1922) argued that houseflies were the principal vector of transmission, a possibility that cannot be dismissed out of hand (Levine and Levine 1991; Förster et al. 2007).⁶

Since its dissipation, only a handful of studies have examined the phenomenon of summer diarrhea. Cheney (1984) focused on the experience of Philadelphia during the period 1869-1921, while Condran (1988) focused on New York City during the period 1870-1919. These authors noted that infant mortality spiked every summer through the early 1900s, due principally to diarrheal diseases. By the second decade of the 20th century, the phenomenon of

⁵ See, for instance, Miller (1879), Burg (1902), Kiefer (1902), McKee (1902), Moss (1903), Southworth (1904), Ostheimer (1905), Snyder (1906), Brennemann (1908), Murphy (1908), Tilden (1909), Stoner (1912), and Youmans and Youmans (1922).

⁶ Alsan and Goldin (2019) also mention the potential link between houseflies and infant mortality in Massachusetts at the turn of the 20th century.

summer diarrhea had begun to wane in both Philadelphia and New York City, which Cheney (1984) and Condran (1988) attributed to the purification of municipal milk supplies.

Certainly, many contemporary physicians and public health experts were convinced that purifying the milk supply was key to reducing diarrheal mortality during the summer.⁷ The refrigeration chain was still missing important links during this period (Rees 2013), and bacteria such as *E. coli* and *Shigella* grow rapidly in warm, moist summer conditions (Winfield and Groisman 2003; Noor 2013; Girma 2015). It is, however, difficult to rule out the possibility that other factors, including efforts to purify the water supply, contributed to the observed reduction.

Condran and Lentzner (2004) used data from Chicago, New Orleans, and New York for the period 1870-1917 to document the phenomenon of summer diarrhea and its waning. These authors found that excess mortality during the summer months fell gradually after the turn of the 20th century, but noted that identifying the cause of this phenomenon is made exceedingly difficult by the large number of public health interventions that were undertaken at the municipal level. They concluded that better sanitation and efforts to purify the milk and water supplies likely contributed to the decline in summer diarrhea but wrote that no single factor is “sufficient to understand either the poor life chances of infants in nineteenth-century cities or the improvements in those chances...” (Condran and Lentzner 2004, p. 352).

3. SUMMER DIARRHEA, 1910-1930

Our focus throughout is on diarrheal deaths among children under the age of two in major American cities, defined as the 26 most populous cities as of 1910. City-level counts of diarrheal

⁷ See, for instance, Kiefer (1902), McKee (1902), Park and Holt (1904), Snyder (1906), M’Mechan (1907), Stoner (1912), and the United States Children’s Bureau (1914).

deaths are available by month for the period 1910-1930 from *Mortality Statistics*, which was published annually by the U.S. Census Bureau.⁸ These counts, which are listed under the title “diarrhea and enteritis”, include deaths due to cholera infantum, colitis, diarrhea, enteritis, enterocolitis, gastroenteritis, summer complaint⁹, and other similar causes (United States Bureau of the Census 1910).

In 1910, there were 21,101 diarrheal deaths among children under the age of two in the 26 most populous American cities (Figure 1), accounting for 30 percent of total mortality in this age group.¹⁰ Two-thirds of these deaths occurred in the months of June-September. Between 1910 and 1930, diarrheal mortality fell by 83 percent, to 3,513. The reduction in diarrheal deaths during the months of June-September was even more pronounced: only 1,482 children under the age of two died from diarrhea in the summer of 1930, a reduction of almost 90 percent as compared to the summer of 1910.¹¹

⁸ This data source has been used by other authors interested in the effects of public health interventions on mortality at the turn of the 20th century (Cutler and Miller 2005, 2018; Beach et al. 2016; Anderson et al. 2019a, 2019b, forthcoming; Alsan and Goldin 2019). Cause of death was obtained from the death certificate and classified according to the International List of Causes of Death (ILCD) (Moriyama et al. 2011). When two or more causes of death were reported on the death certificate, a set of rules proposed by Jacques Bertillon, a French statistician and demographer, were used to determine the primary underlying cause of death. For instance, according to Bertillon, if one of the diseases was an “immediate and frequent complication of the other, the death should be classified under the heading of the primary disease.” (Moriyama et al. 2011, p. 30). While Bertillon generally gave the highest priority to acts of violence, he also emphasized the importance of infectious diseases. During the period under study, the ILCD underwent its 3rd and 4th revisions (in 1920 and 1929, respectively). In 1920, the cause of death category “diarrhea and enteritis” was changed so that it no longer included deaths due to “ulcer of the duodenum” and “flagellate diarrhea.” Deaths due to ulcers of the duodenum were reclassified as a separate subcategory and flagellate diarrheal deaths were lumped together with “other diseases due to intestinal parasites” (United States Bureau of the Census 1924). In 1929, there were no changes to the “diarrhea and enteritis” classification (United States Bureau of the Census 1934).

⁹ The term “summer complaint” was used to refer to a “form of bowel disorder of infants characterized usually by diarrhea, sometimes by constipation, and accompanied by more or less well-marked symptoms traceable to the central nervous system” (Christopher 1893, p. 250).

¹⁰ Appendix Figure 1 shows annual diarrheal deaths as a percentage of total deaths among children under the age of two. Appendix Figure 2 shows summer diarrheal deaths as a percentage of total diarrheal deaths.

¹¹ In 1930, 42.2 percent of diarrheal deaths among children under the age of two occurred in the months of June-September, accounting for only 5 percent of total mortality among children in this age group.

Figure 2 shows diarrheal deaths by month among children under the age of two per 100,000 population.^{12, 13} It is clear from this figure that seasonality waned considerably during the period under study. For instance, the diarrhea mortality rate was 3.8 in January of 1910 but reached as high as 29.1 in July of that same year, a peak-to-trough ratio of 7.7. The peak-to-trough ratio had fallen to 3.5 by 1920, and it had fallen to 2.6 by 1930.¹⁴

4. PUBLIC HEALTH EFFORTS AND THE WANING OF SUMMER DIARRHEA

Economists and historians have long asserted that public health efforts undertaken at the municipal level caused the waning of summer diarrhea (Cheney 1984; Condran 1988; Meckel 1990; Fishback et al. 2011). For instance, Cheney (1984) and Condran (1988) asserted that efforts to purify milk supplies caused its waning, while Meckel (1990) and Fishback et al. (2011) pointed to the combined effects of purifying milk and water supplies.¹⁵

¹² City populations for 1910, 1920, and 1930 are from the Census. Population was linearly interpolated for intercensal months. The results presented below were similar if we instead used log-linear interpolation. An alternative strategy would be to divide mortality counts by live births. However, live birth data are not available at the city level during the period under study. Previous studies exploring the determinants of city-level infant mortality deflate by population precisely because there is no information on live births (e.g., Clay et al. 2014; Komisarow 2017; Anderson et al. forthcoming). *Mortality Statistics* began reporting live births in 1915, but only at the state level (Linder and Grove 1947, Table 44).

¹³ Appendix Figure 3 shows annual diarrheal deaths among children under the age of two per 100,000 population. In 1910, there were 124 diarrheal deaths among children under the age of two per 100,000 population; by 1930, the diarrhea mortality rate had fallen to 14, a reduction of 89 percent. The summer diarrheal mortality rate fell from 82 to 6 over the same period, a reduction of 93 percent.

¹⁴ In September of 1930, diarrheal deaths among children under the age of two peaked at 2.0 per 100,000 population in the 26 cities that compose our sample; in December of 1930, there were only 0.8 diarrheal deaths per 100,000 population.

¹⁵ Fishback et al. (2011, p. 140) noted that as “pasteurized milk became more common and cities filtered public water supplies, the rates of typhoid and diarrhea no longer varied much by season or in response to temperature.” Meckel (1990, p. 89) was considerably more cautious. He wrote, “It is extremely difficult to assess with any certainty the effect that milk regulation and especially commercial pasteurization had on the urban infant death rate.”

The best evidence on public health interventions and diarrhea mortality in American cities at the turn of the 20th century comes from Anderson et al. (forthcoming) and Alsan and Goldin (2019). Using data on 25 major American cities for the period 1900-1940, Anderson et al. (forthcoming) found that water filtration was associated with an 11-12 percent reduction in infant mortality and a (statistically insignificant) 15 percent reduction in diarrheal deaths among children under the age of two. Alsan and Goldin (2019) analyzed data on 60 Massachusetts municipalities from the period 1880-1920. Instead of filtering or chlorinating their water supply, these municipalities built a series of “impounding reservoirs in which spring floodwaters were stored” (Alsan and Goldin 2019, p. 595). Alsan and Goldin (2019) found that the provision of clean water combined with access to a regional sewerage system was associated with a 23 percent reduction in mortality among children under the age of 5. Over half of this reduction was due to fewer deaths from gastrointestinal diseases, a category that included diarrhea.¹⁶

The remainder of our study builds upon the research described above by exploring the relationship between municipal public health interventions and the phenomenon of summer diarrhea during the period 1910-1930. We begin our exploration of this relationship by estimating the following regression:

$$(1) \quad \ln(Diarrhea_{ct}) = \beta_0 + \beta_1 Filtration_{ct} \times Non-Summer_t + \beta_2 Filtration_{ct} \times Summer_t + \beta_3 Chlorination_{ct} \times Non-Summer_t + \beta_4 Chlorination_{ct} \times Summer_t + \mathbf{X}'_{ct} \boldsymbol{\beta}_5 + \theta_c + \delta_t + \varepsilon_{ct},$$

¹⁶ Gastrointestinal-related mortality included deaths from diarrhea, enteritis, colitis, cholera, typhoid, malnutrition/marasmus, and polio (Alsan and Goldin 2019, p. 620). By the early 1900s, every major U.S. 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 (2019).

where *Diarrhea* is equal to diarrheal deaths per 100,000 population among children under the age of two in city c and month t , where $t = 1 \dots 252$.¹⁷ *Filtration* is an indicator for whether a water filtration plant was in operation and *Chlorination* is an indicator for whether the water supply was chemically treated.¹⁸ These indicators are interacted with two mutually exclusive season dummies: *Summer*, which is equal to 1 for the months of June-September and equal to zero for the non-summer months; and *Non-Summer*, which is equal to 1 for the months of October-May and equal to zero for the summer months.

Demographic controls, based on information from the 1910, 1920, and 1930 Censuses (and linearly interpolated for intercensal months), are represented by the vector \mathbf{X}_{ct} and are listed in Appendix Table 1, along with descriptive statistics and definitions. City-level characteristics include the natural log of population and percentages of the population by gender, race, foreign-born status, and age group. City and month-by-year fixed effects are represented by the terms θ_c and δ_t , respectively. The city fixed effects control for determinants of diarrheal mortality that were constant over time, and the month-by-year fixed effects control for common shocks. All regressions are weighted by city populations and standard errors are corrected for clustering at the city level (Bertrand et al. 2004).¹⁹

¹⁷ Our data are at the city-month level and cover the period 1910-1930 ($12 \times 21 = 252$).

¹⁸ Water filtration technology was originally developed to reduce discoloration and turbidity, but gained support as the study of bacteriology advanced and city governments came under increasing pressure to protect their citizens from infectious diseases (McCarthy 1987; Melosi 2008). Unlike water filtration, the chlorination process was simple and inexpensive: water was added to calcium hypochlorite, which was then mixed with the water supply before delivery (Hooker 1913). The filtration indicator is equal to 1 in every year, t , for cities that began filtering their water before 1910. Likewise, the chlorination indicator is equal to 1 in every year, t , for cities that began chlorinating their water before 1910. The results reported below are similar if we drop these always-treated cities from the sample.

¹⁹ See Anderson et al. (2020) for the data replication files.

Our primary interest is in the parameters β_1 through β_4 . β_1 represents the effect of filtration on diarrheal mortality in the non-summer months, while β_2 represents the effect of filtration in the months of June-September; similarly, β_3 represents the effect of chlorination on diarrheal mortality in the non-summer months, while β_4 represents the effect of chlorination in the months of June-September. Based on the results of previous studies (Knutsson 2017; Bhalotra et al. 2018; Anderson et al. forthcoming) and contemporary accounts (Elms 1914; Jennings 1918; Morse and Hall 1919), we expect the estimates of β_1 through β_4 to be negative. Because filtration and chlorination are more effective at eliminating bacteria than viruses (Centers for Disease Control 2012; Hijnen et al. 2004; Jenkins et al. 2011) and because bacterial infections are most common during the summer (Ramos-Alvarez and Sabin 1958; Fletcher et al. 2013), we expect $\hat{\beta}_2 - \hat{\beta}_1 < 0$ and $\hat{\beta}_4 - \hat{\beta}_3 < 0$.²⁰

4.1. Main Results

Estimates of $\beta_1 - \beta_4$ are reported in the first column of Table 1. The estimated effects of filtration and chlorination in the non-summer months are negative, but not statically significant at conventional levels. Their estimated effects for the summer months are positive but, again, are statistically indistinguishable from zero.

In the second column of Table 1, we introduce two additional municipal-level public health interventions, both of which are interacted with the season indicators. The first, *Clean Water Project*, is equal to 1 if a new aqueduct or underground tunnel was built to deliver clean

²⁰ The cities used in our analysis are listed in Appendix Table 2, along with the dates each began filtering and/or chlorinating their water supplies. These cities are similar to those used by Anderson et al. (forthcoming). We include data from Los Angeles and Seattle, which Anderson et al. (forthcoming) did not. We do not, however, include Memphis, which was not among the 26 most populous cities in the United States as of 1910. During the period 1910-1930, 8 cities in our sample adopted filtration technology and 24 began treating their water with chlorine.

water to the municipality and is equal to zero otherwise.²¹ The second, *Sewage Treated*, is an indicator for whether the city treated its sewage before discharging it into local waterways.²² With their inclusion, water filtration is associated with an 11 percent reduction in diarrheal mortality during the non-summer months ($e^{-.111} - 1 = -.105$) and an 11 percent increase during the summer months ($e^{.103} - 1 = .108$). It should be noted, however, that neither of these estimates is statistically significant. Likewise, the estimated coefficients of the *Clean Water Project* and *Sewage Treated* interactions are statistically indistinguishable from zero.

In the third column of Table 1, we introduce an indicator for whether city c required milk sold within its limits to meet a strict bacteriological standard. During the period 1910-1930, 15 cities passed ordinances requiring that milk sold within their limits meet a bacteriological standard (Appendix Table 5). Because such ordinances were difficult to meet without resorting to pasteurization (Meckel 1990, pp. 88-89), they are often referred to as “pasteurization ordinances” (Harding 1917, p. 57; Swinford 2016, p. 254; Komisarow 2017, p. 131). For instance, New York passed an ordinance, effective on January 1, 1912, requiring that “certified” raw milk have less than 30,000 bacteria per cubic centimeter, and that “inspected” raw milk have less than 60,000 bacteria per cubic centimeter.²³

²¹ Identification comes from water projects undertaken by 4 cities during the period under study (Buffalo, Los Angeles, Providence, and Newark). See Appendix Table 3 for more information.

²² Identification comes from sewage treatment plants built by 8 cities during the period under study (Baltimore, Chicago, Cleveland, Indianapolis, Jersey City, Milwaukee, Newark, and Rochester). Following Anderson et al. (forthcoming), we code our sewage treatment indicator as equal to zero for cities that were treating less than 25 percent of their effluent (Mohlman 1940). See Appendix Table 4 for more information. With the exception of Anderson et al. (forthcoming), previous studies have focused on estimating the effects of providing sewerage (i.e., the building and extending of sewer systems) as distinct from treating sewage (i.e., using chemical or biological processes to remove contaminants from waste water) before its discharge. See, for instance, Kesztenbaum and Rosenthal (2017) and Alsan and Goldin (2019).

²³ Pasteurized “selected milk” was required to have less than 50,000 bacteria per cubic centimeter (New York 1912; New York Department of Health 1913). Other cities 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

Anderson et al. (forthcoming) found little evidence that setting a bacteriological standard for milk reduced infant mortality. Our results are consistent with theirs. Specifically, the estimated coefficient of the bacteriological standard indicator interacted with *Non-Summer* is actually positive and statistically significant at the .05 level. The estimated coefficient of the interaction between *Bacteriological Standard* and the summer indicator is also positive but smaller in magnitude and not sufficiently precise to reject the null.

In the final column of Table 1, we report estimates from a regression model that controls for city-specific linear time trends. These trends are designed to capture smoothly evolving social and demographic factors that could have affected diarrhea mortality among infants and children at the city level.²⁴ With their inclusion, filtration is associated with a statistically significant 15 percent reduction in diarrhea mortality during the non-summer months ($e^{-.161} - 1 = .149$). By contrast, the estimated effect of filtration on diarrhea mortality among children under the age of 2 during the summer months is small, positive and statistically insignificant at conventional levels. Based on the lower bound of the 90 percent confidence interval of this estimate, we can rule out mortality reductions greater than 14 percent during the summer.²⁵

sold. During the period 1910-1930, only two cities in our sample (Detroit and Chicago) required that all milk sold within their limits be pasteurized.

²⁴ Cutler and Miller (2005), Alsan and Goldin (2019), and Anderson et al. (forthcoming) included city-specific linear trends on the right-hand side of their regression models.

²⁵ In Appendix Table 6, we replace the *Summer* and *Non-Summer* dummies with a series of temperature indicators (e.g., an indicator for average temperature in city c and month t equal to or greater than 70° F, an indicator for average temperature in city c and month t equal to or greater than 60° F. and less than 70° F, etc.). Interacting these indicators with *Filtration* and *Chlorination* produced results that are qualitatively similar to those reported in Table 1. Specially, there is a clear negative association between filtration and diarrhea mortality at lower temperatures, which is not apparent at higher temperatures. We also experimented with controlling for temperature, controlling for the manufacturing wage, including region-by-year fixed effects, not weighting by population, dropping the most populous city (i.e., New York City) from the sample, and specifying the dependent variable in levels. The results from these various robustness checks suggest that the negative relationship between water filtration and diarrheal mortality in the non-summer months is not an artifact of specification or sample choice.

To gauge the contribution of water filtration to the overall decline in non-summer diarrhea mortality from 1910 to 1930, we calculated a predicted diarrhea mortality rate for every non-summer month (and its 90 percent confidence interval) under the assumption that no filtration plants were built. The results from this exercise are shown in Appendix Figure 4.²⁶ The solid line represents the actual non-summer diarrhea mortality rate per 100,000 population among children under the age of two and the dashed line represents the predicted rate. Had no filtration plants been built, we predict that the January non-summer diarrhea mortality rate would have fallen from 2.99 to 1.53, or almost 50 percent. In reality, the January non-summer diarrhea mortality rate fell by more than 70 percent, to 0.84.²⁷

4.2. Event-Study Analysis

The negative association between filtration and diarrhea mortality in the non-summer months reported in column (4) of Table 1 is consistent with the hypothesis that transmission occurred through contaminated water. To explore the robustness of this association, we replace the filtration indicator with a series of its leads and lags, each of which is interacted with *Non-Summer*. The results from this exercise are reported in Panel A of Figure 3. During the first two post-adoption years, water filtration is associated with a 12 percent reduction in non-summer diarrheal mortality, and this effect appears to be fairly stable over time, although the coefficients

²⁶ See Anderson et al. (2019a) and Anderson et al. (forthcoming) for more details on this approach. Predicted non-summer diarrhea mortality rates are from a regression model that controls for the city characteristics listed in Appendix Table 1, interactions between the public health interventions and the indicators *Summer* and *Non-Summer*, city fixed effects, month-by-year fixed effects, and city-specific linear trends.

²⁷ In January of 1910, 2.99 children under the age of two per 100,000 population died from diarrhea/enteritis in our sample of 26 cities. In January of 1930, 0.84 children under the age of two per 100,000 population died from diarrhea/enteritis. The annual non-summer diarrhea mortality rate fell from 34.1 per 100,000 population in 1910 to 8.15 per 100,000 population in 1930, or 76 percent. We calculate that, had none of the cities in our sample adopted filtration technology, the annual non-summer diarrhea mortality rate would have fallen to 13.7 per 100,000 population, or 60 percent.

of the subsequent lags are measured with less precision. Panel B of Figure 3 provides additional evidence that filtration was not effective at reducing diarrheal deaths in the summer.

Importantly, neither of these event studies provide evidence that diarrheal mortality was trending differently in treated versus non-treated cities prior to the adoption of filtration technology.

5. CONCLUSION

In the United States at the turn of the 20th century, tens of thousands of American children would die from diarrhea-related disease every summer. One of the principal contributions of this study is to document the scale of this phenomenon. Using newly transcribed diarrheal mortality data for 26 major American cities, we find that summer diarrhea was an important cause of child mortality. In 1910, the year in which mortality counts at the month level first became available, there were over 21,000 diarrheal deaths among children under the age of two in these cities, accounting for 30 percent of total mortality in this age group; two-thirds of diarrheal deaths among children under the age of two occurred in the months of June-September.

The phenomenon of summer diarrhea had largely dissipated by 1930, when only 3,513 children under the age of two died from diarrhea in the cities under study, and only 1,482 of these deaths occurred in the summer months. The precise cause of summer diarrhea was never isolated and the memory of its toll eventually receded.

Economists and historians generally believe that the dissipation of summer diarrhea was due to public health efforts undertaken at the municipal level (Cheney 1984; Condran 1987; Meckel 1990; Fishback et al. 2011). Evidence for this belief, however, is anecdotal or based on only a handful of case studies (Cheney 1984; Condran 1987; Condran and Lentzner. 2004). In

addition to documenting the phenomenon of summer diarrhea, we explore whether its waning over the period 1910-1930 was, in fact, related to public health interventions undertaken at the municipal level.

We find no evidence that treating sewage or setting bacteriological standards for milk resulted in the dissipation of summer diarrhea, which is consistent with the results of Anderson et al. (2019a) and Anderson et al. (forthcoming), who concluded that public health efforts at the municipal level were not important drivers of the urban mortality transition. Likewise, we find no evidence that water filtration reduced diarrhea mortality among children under the age of two during the months of June-September, which is perhaps surprising given that water filtration plants built at the turn of the 20th century are associated with sizeable reductions in infant mortality (Anderson et al. forthcoming) and that diarrhea-causing bacterial infections are most common during the summer (Ramos-Alvarez and Sabin 1958; Fletcher et al. 2013).

By contrast, we find that filtering water is associated with a 15 percent reduction in diarrhea mortality among children under the age of two during the non-summer months. Between 1910 and 1930, 8 of the 26 cities in our sample adopted water filtration technology and non-summer diarrhea mortality fell by more than 70 percent. Had none of these cities adopted filtration technology, we estimate that the non-summer diarrhea mortality rate would have fallen by 50 to 60 percent.

We conclude by inviting further investigation in this area and acknowledging that we still do not know what caused the waning of summer diarrhea. Although improvements in medical care, the adoption of more hygienic practices, or better living conditions may have been responsible for its dissipation, it is also possible that the introduction of refrigeration technology played a role. During the period under study, important links in the refrigeration chain were

forged (Rees 2013). As mechanical ice replaced ice cut from lakes and ponds and refrigerated transportation of perishables became the norm, city dwellers gained year-round access to fresh, unspoiled milk, meat, and produce.

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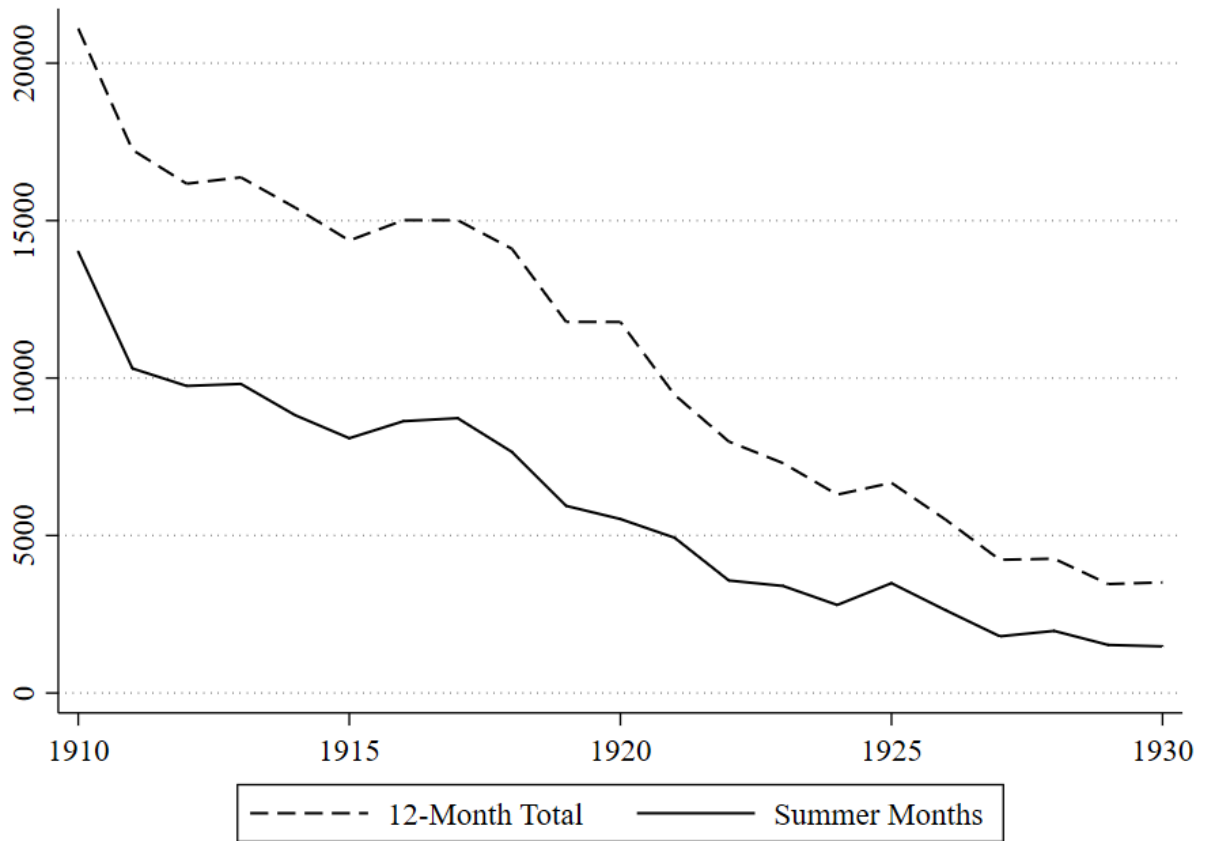
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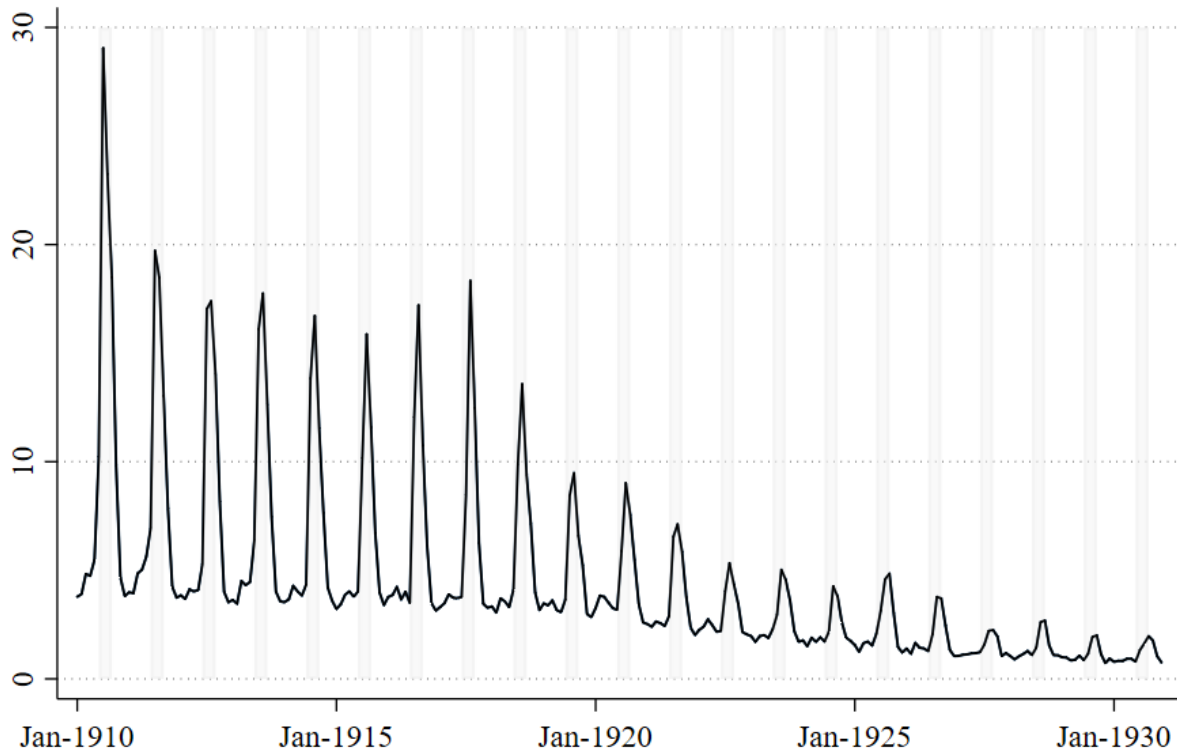
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Figure 1. Diarrheal Mortality among Children Under the Age of Two



Notes: Based on data from *Mortality Statistics* for the 26 cities under study, published by the U.S. Census Bureau. The summer months are defined as June-September.

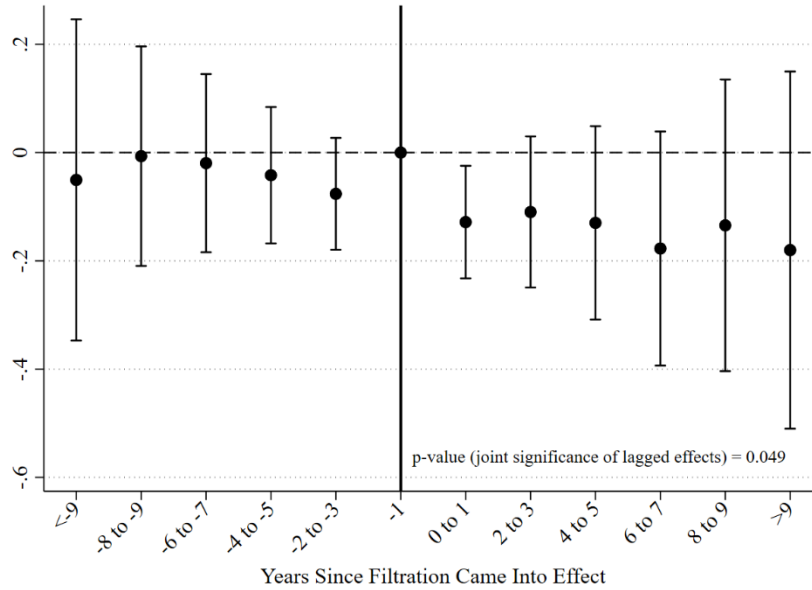
Figure 2. Monthly Diarrheal Mortality Among Children Under the Age of Two per 100,000 Population



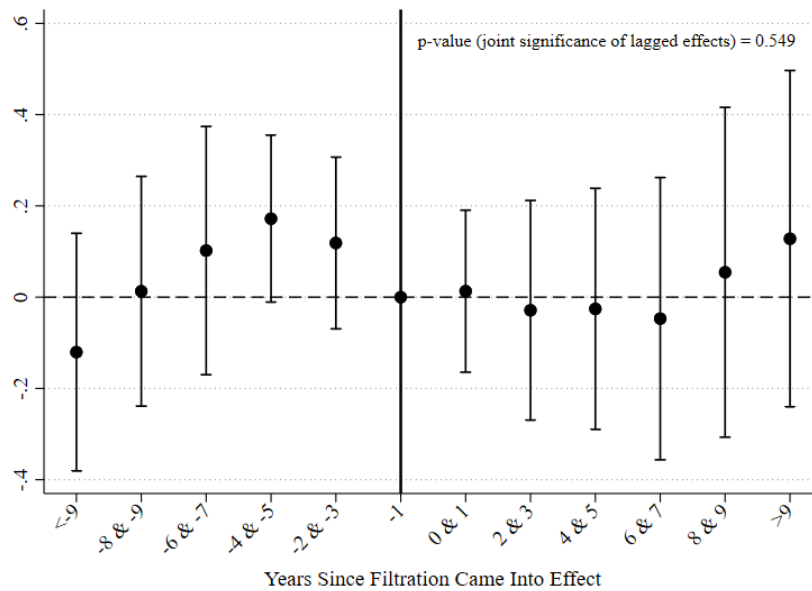
Notes: Based on data from *Mortality Statistics* for the 26 cities under study, published by the U.S. Census Bureau. The shaded vertical bars indicate the summer months (June-September).

Figure 3. Pre- and Post-Filtration Trends in Diarrheal Mortality among Children Under the Age of Two

Panel A. Non-Summer Months



Panel B. Summer Months



Notes: OLS coefficient estimates (and their 90% confidence intervals) are reported, where the omitted category is one year before treatment. The dependent variable is equal to the natural log of the number of diarrheal deaths among children under the age of two per 100,000 population in city c and month t . Controls include the city characteristics listed in Appendix Table 1, interactions between the remaining public health interventions and the *Summer* and *Non-Summer* indicators, city fixed effects, month-by-year fixed effects, and city-specific linear trends. Regressions are weighted by city population. Standard errors are corrected for clustering at the city level.

Table 1. Public Health Interventions and Summer Diarrhea, 1910-1930

	(1)	(2)	(3)	(4)
	ln(<i>Diarrhea</i>)			
<i>Filtration</i> × <i>Non-Summer</i>	-.092 (.075)	-.111 (.068)	-.100 (.060)	-.161*** (.047)
<i>Filtration</i> × <i>Summer</i>	.069 (.128)	.103 (.142)	.088 (.134)	.029 (.108)
<i>Chlorination</i> × <i>Non-Summer</i>	-.014 (.079)	-.013 (.071)	-.043 (.074)	-.029 (.062)
<i>Chlorination</i> × <i>Summer</i>	.055 (.060)	.047 (.056)	.031 (.052)	.052 (.056)
<i>Clean Water Project</i> × <i>Non-Summer</i>	...	.021 (.084)	.016 (.103)	.120 (.131)
<i>Clean Water Project</i> × <i>Summer</i>	...	.128 (.113)	.133 (.125)	.236 (.156)
<i>Sewage Treated</i> × <i>Non-Summer</i>	...	.022 (.089)	.031 (.082)	.034 (.074)
<i>Sewage Treated</i> × <i>Summer</i>	...	.026 (.128)	.049 (.117)	.051 (.077)
<i>Bacteriological Standard</i> × <i>Non-Summer</i>	...	...	.219*** (.062)	.111* (.060)
<i>Bacteriological Standard</i> × <i>Summer</i>	...	...	.077 (.082)	-.024 (.074)
City-specific linear trends	no	no	no	yes
N	6,552	6,552	6,552	6,552
R ²	.840	.841	.844	.858

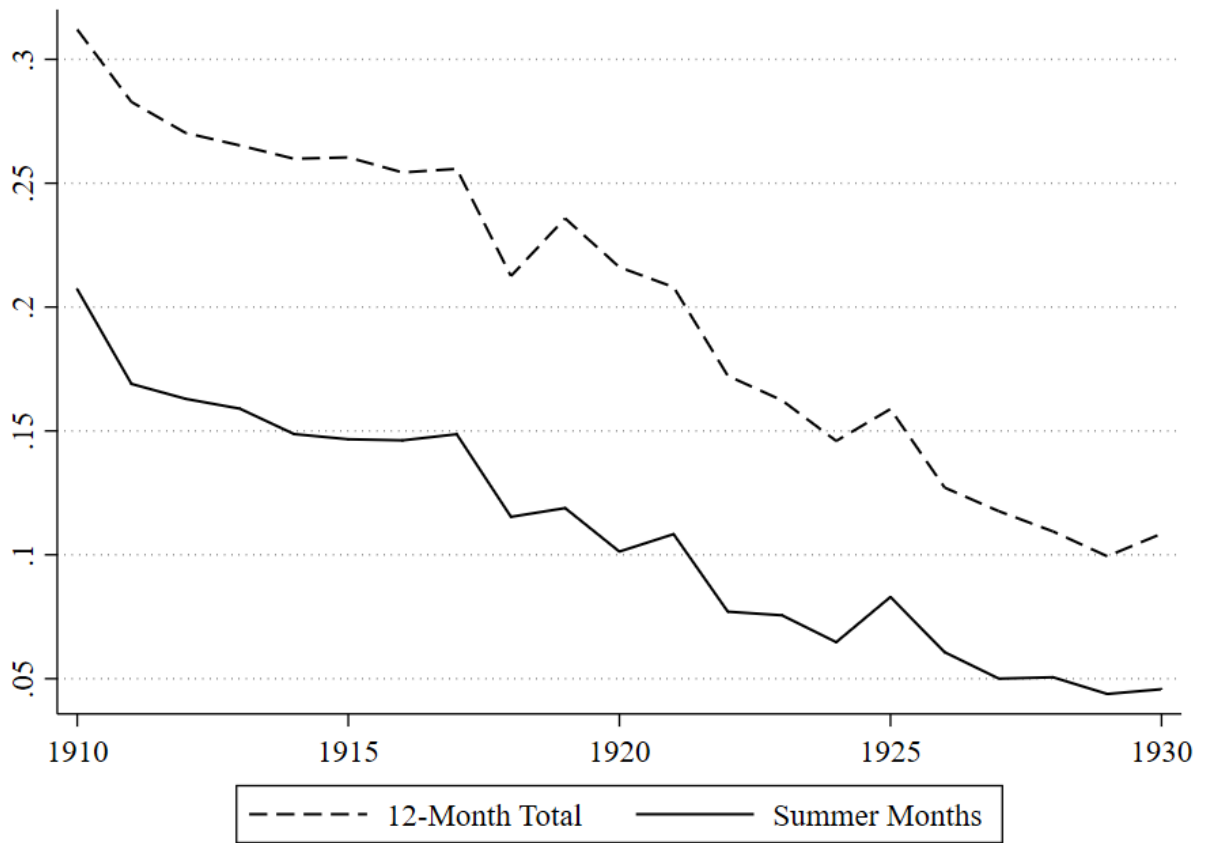
*Statistically significant at 10% level; ** at 5% level; *** at 1% level.

Notes: Based on annual data from *Mortality Statistics* for the period 1910-1930, 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 diarrheal deaths among children under the age of two per 100,000 population in city c and month t . Controls include the city characteristics listed in Appendix Table 1, city fixed effects, and month-by-year fixed effects. Regressions are weighted by city population. Standard errors, corrected for clustering at the city level, are in parentheses.

Appendix

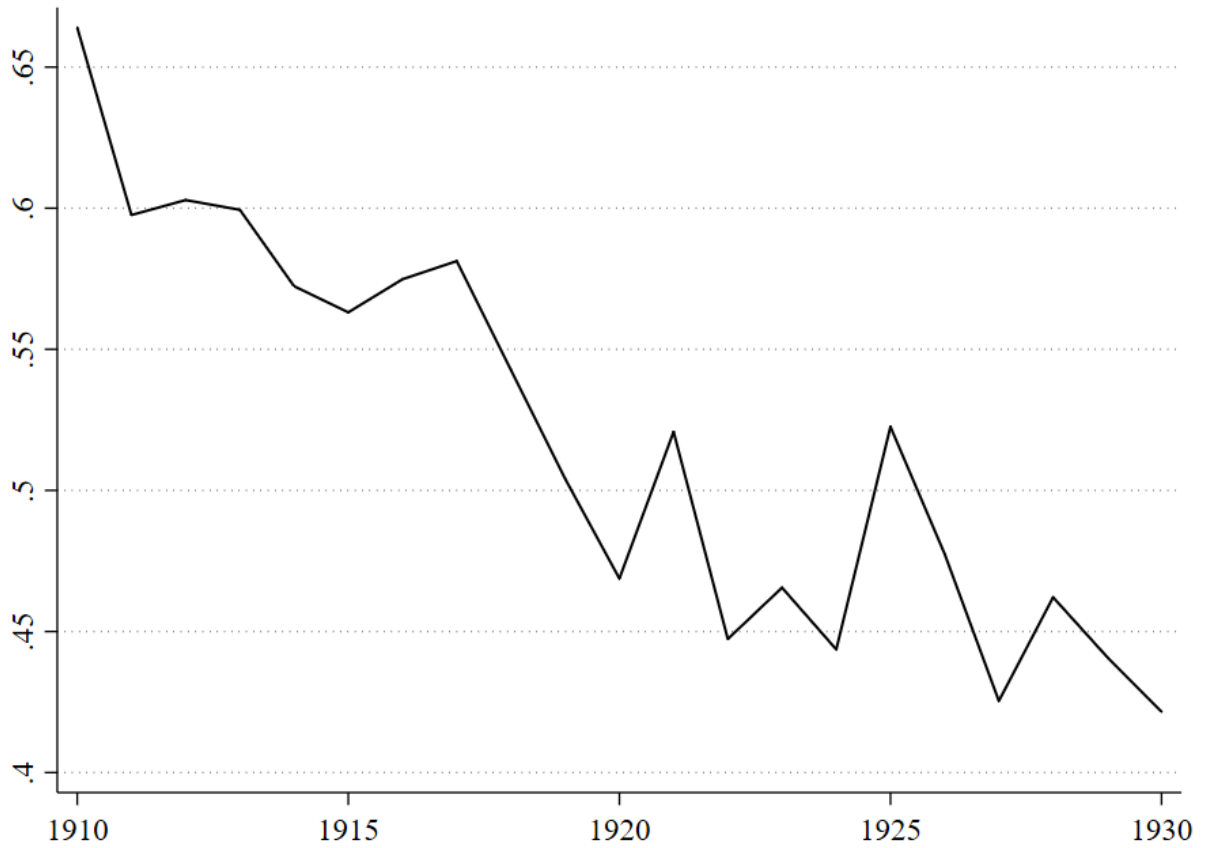
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Appendix Figure 1. Ratio of Diarrheal Mortality to Total Mortality among Children Under the Age of Two



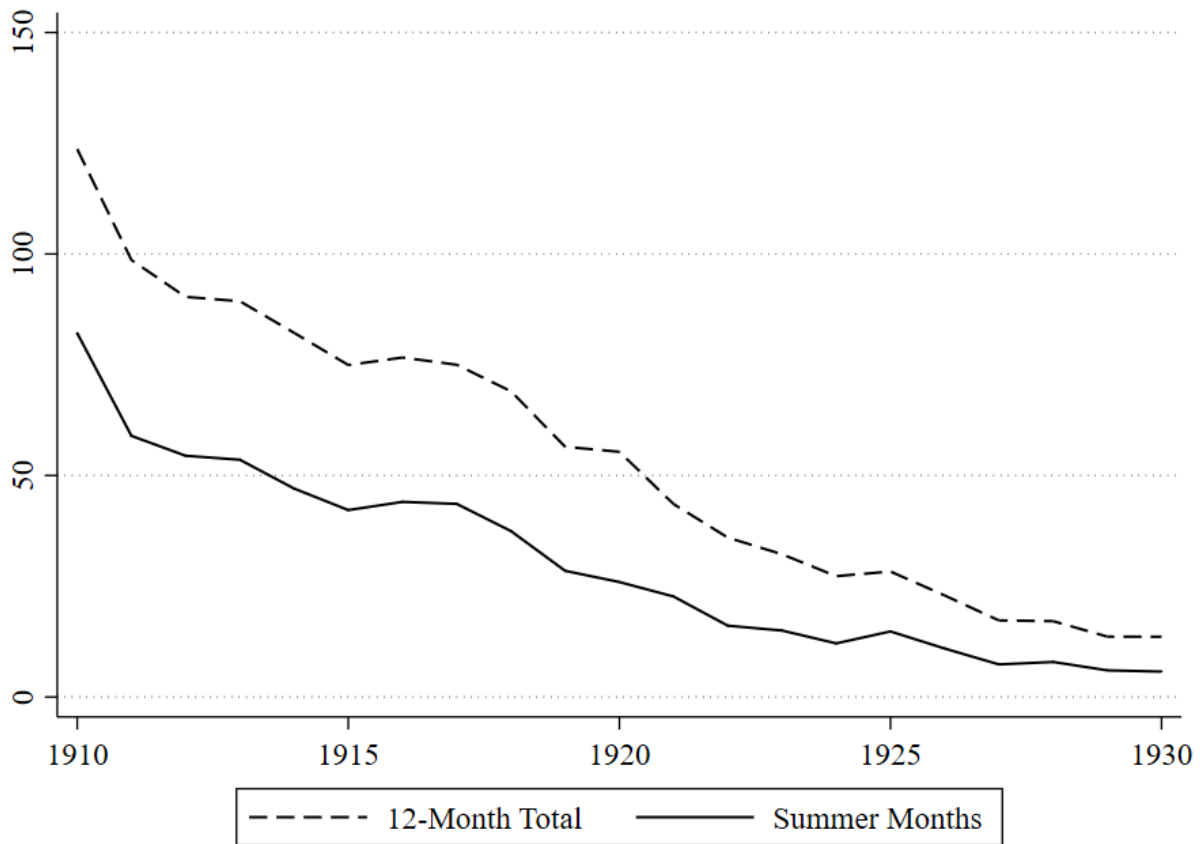
Notes: Based on data from *Mortality Statistics* for the 26 cities under study, published by the U.S. Census Bureau. The summer months are defined as June-September.

Appendix Figure 2. Ratio of Summer Diarrheal Mortality to Total Diarrheal Mortality among Children Under the Age of Two



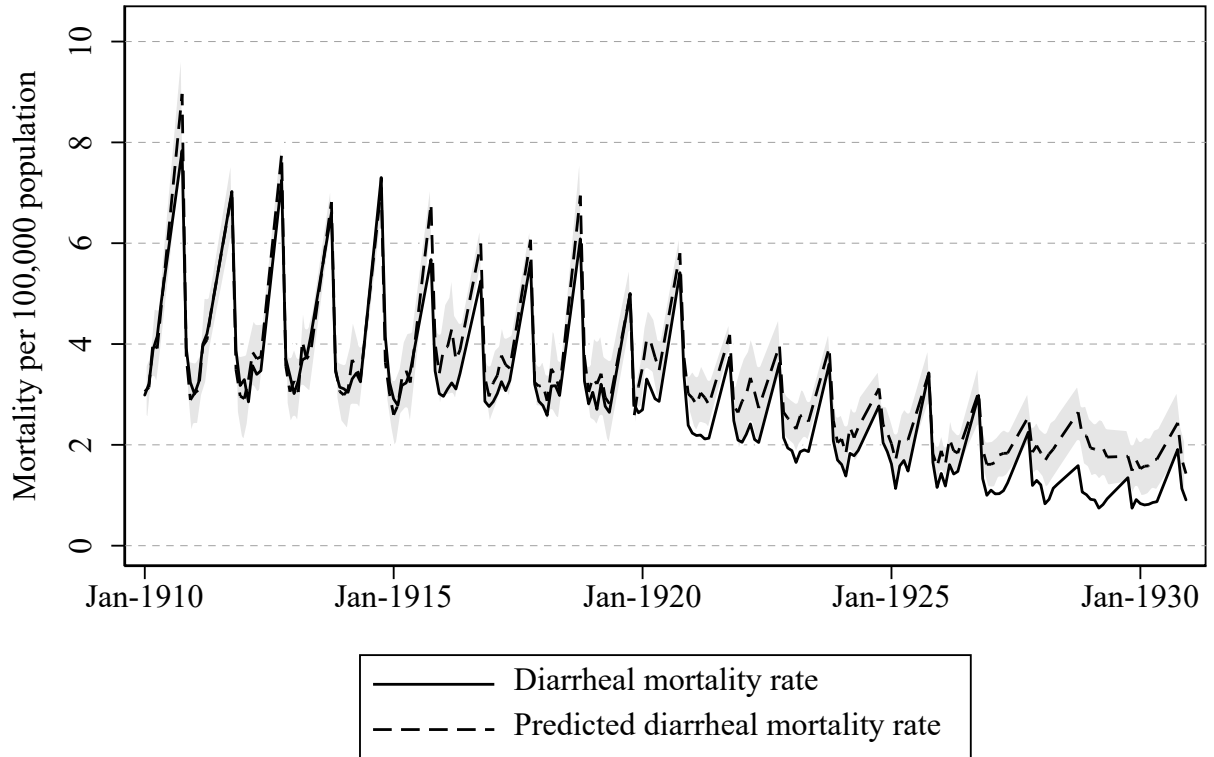
Notes: Based on data from *Mortality Statistics* for the 26 cities under study, published by the U.S. Census Bureau. The summer months are defined as June-September.

Appendix Figure 3. Diarrheal Mortality among Children Under the Age of Two per 100,000 Population



Notes: Based on data from *Mortality Statistics* for the 26 cities under study, published by the U.S. Census Bureau. The summer months are defined as June through September.

Appendix Figure 4. Actual vs. Predicted Non-Summer Diarrheal Mortality Rates among Children Under the Age of Two
The Effect of Municipal Water Filtration



Notes: Based on annual data from *Mortality Statistics* for the period 1910-1930, published by the U.S. Census Bureau. Predicted diarrheal mortality rates are calculated under the assumption that municipalities did not filter their water supply. Shaded area represents 90% confidence region around diarrheal mortality rates.

Appendix Table 1. Descriptive Statistics

	Mean (SD)	Description
<i>Diarrhea</i>	4.08 (5.16)	Monthly diarrheal mortality per 100,000 population among children under the age of two
<i>ln(Population)</i>	13.2 (.762)	Natural log of the city population
<i>Percent Female</i>	.500 (.018)	Percent of the city population that was female
<i>Percent Nonwhite</i>	.072 (.072)	Percent of the city population that was nonwhite
<i>Percent Foreign</i>	.212 (.096)	Percent of the city population that was foreign born
<i>Percent Age < 15</i>	.253 (.031)	Percent of the city population that was less than 15 years of age
<i>Percent Age 15-44</i>	.529 (.025)	Percent of the city population that was 15-44 years of age
<i>Percent Age 45+</i>	.218 (.030)	Percent of the city population that was 45 years of age or older

N = 6,552

Notes: Unweighted means with standard deviations in parentheses.

Appendix Table 2. Municipal Water Purification, 1900-1930

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
Los Angeles, California	...	1925
Louisville, Kentucky	1909	1913
Milwaukee, Wisconsin	...	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
Seattle, Washington	...	1911
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.

Notes: Identification of the filtration estimates comes from cities that began filtering their water supply during the period 1910-1930. Identification of the chlorination estimates comes from cities that began chlorinating their water supply during the period 1910-1930.

Appendix Table 3. Clean Water Projects, 1900-1930

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.
Los Angeles, California	1913	Los Angeles began receiving water from Owens Valley on November 5, 1913.
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.

Notes: Identification of the clean water estimates comes from the cities that undertook clean water projects during the period 1910-1930.

Appendix Table 4. Sewage Treatment/Diversion, 1900-1930

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).
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.
Newark, New Jersey	1924	The sewage treatment plant began operations in 1924.
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

Notes: Identification of the sewage treatment estimates comes from the cities that began treating their sewage during the period 1910-1930.

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Appendix Table 5. Bacteriological Standards for Milk, 1900-1930

City and State	Bacteriological Standard ^a
Baltimore, Maryland	1913
Boston, Massachusetts	1905
Buffalo, New York	1918
Chicago, Illinois	1909
Cincinnati, Ohio	1914
Cleveland, Ohio	1906
Detroit, Michigan	1915
Indianapolis, Indiana	1916
Jersey City, New Jersey	1915
Kansas City, Missouri	1910
Los Angeles, California	1905
Milwaukee, Wisconsin	1908
Minneapolis, Minnesota	1907
Newark, New Jersey	1913
New Orleans, Louisiana	1923
New York, New York	1912
Philadelphia, Pennsylvania	1915
Pittsburgh, Pennsylvania	1910
Providence, Rhode Island	1915
Rochester, New York	1907
San Francisco, California	1909
Seattle, Washington	1910
St. Louis, Missouri	1923
St. Paul, Minnesota	1907

^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.

Notes: Identification of the *Bacteriological Standard* indicator comes from the cities that began requiring that milk sold within their limits meet a bacteriological standard during the period 1910-1930.

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Appendix Table 6. Public Health Interventions and Summer Diarrhea by Average City Temperature

	$\ln(\text{Diarrhea})$
<i>Filtration</i> × <i>Below 30°F</i>	-.146** (.059)
<i>Filtration</i> × <i>30°- 40°F</i>	-.175*** (.059)
<i>Filtration</i> × <i>40°- 50°F</i>	-.183*** (.047)
<i>Filtration</i> × <i>50°- 60°F</i>	-.090 (.055)
<i>Filtration</i> × <i>60°- 70°F</i>	-.047 (.085)
<i>Filtration</i> × <i>70°F and Above</i>	.128 (.146)
<i>Chlorination</i> × <i>Below 30°F</i>	.056 (.057)
<i>Chlorination</i> × <i>30°- 40°F</i>	.024 (.063)
<i>Chlorination</i> × <i>40°- 50°F</i>	-.042 (.057)
<i>Chlorination</i> × <i>50°- 60°F</i>	-.098* (.056)
<i>Chlorination</i> × <i>60°- 70°F</i>	-.001 (.056)
<i>Chlorination</i> × <i>70°F and Above</i>	.048 (.073)
N	6,552
R ²	.862

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

Notes: Based on annual data from *Mortality Statistics* for the period 1910-1930, 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 diarrheal deaths among children under the age of two per 100,000 population in city c and month t . Controls include the city characteristics listed in Appendix Table 1, temperature indicators, interactions between the temperature indicators and the remaining public health interventions (*Clean Water Project*, *Sewage Treated*, and *Bacteriological Standard*), city fixed effects, month-by-year fixed effects, and city-specific linear trends. Regressions are weighted by city population. Standard errors, corrected for clustering at the city level, are in parentheses. Data on temperature come from the nClimDiv data set at the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA), which is available at: <ftp://ftp.ncdc.noaa.gov/pub/data/cirs/climdiv/>. Temperature is measured at the climate division-by-month level.