Estimating the Effects of Milk Inspections on Infant and Child Mortality, 1880-1910

D. Mark Anderson*

Kerwin Kofi Charles†

Michael McKelligott‡

Daniel I. Rees§

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Abstract. In the mid-19th century, the urban milk supply in the United States was regularly skimmed or diluted with water, reducing its nutritional value. At the urging of public health experts, cities across the country hired milk inspectors, who were tasked with collecting and analyzing milk samples with the goal of preventing adulteration and skimming. Using city-level data for the period 1880-1910, we explore the effects of milk inspections on infant mortality and mortality among children under the age of 5. Event-study estimates are small and statistically insignificant, providing little evidence of post-treatment reductions in either infant or child mortality.

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* Department of Agricultural Economics and Economics, Montana State University, IZA and NBER. E-mail: dwight.anderson@montana.edu.
† Yale School of Management, Yale University and NBER. E-mail: kerwin.charles@yale.edu.
‡ Harris School of Public Policy, University of Chicago. E-mail: mckelligott@uchicago.edu.
§ Department of Economics, Universidad Carlos III de Madrid. E-mail: daniel.rees@uc3m.es.

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1. Introduction

Nineteenth century cities were filthy and rife with disease. Nonetheless, urban mortality rates in the United States began to fall in the 1870s and continued to fall through the first several decades of the 20th century (Higgs 1979; Haines 2001). By the 1940s, the urban mortality penalty had been eliminated (Haines 2001). This phenomenon, referred to as the mortality transition, was driven primarily by reductions in infant mortality and infectious diseases (Costa 2015).

What factors drove the mortality transition? This has been called "the most important question in medical history" (McKeown and Brown 1955, p. 139), but the causes of the mortality transition are still poorly understood. McKeown (1976) and Fogel (1997) point to the onset of modern economic growth and attendant improvements in nutrition, while recent reviews of the literature emphasize the role of public health, especially efforts to purify municipal water supplies (Cutler et al. 2006; Costa 2015).

The focus of the current study is on efforts to provide American city dwellers with clean milk, as opposed to clean water. In the mid-19th century, the urban milk supply was regularly skimmed or diluted with (potentially contaminated) water, reducing its nutritional value; caramel, salt, and sugar were added to restore its body, color, and taste; boric acid was often added as a preservative (Newton 1877; Martin 1884; Kastle 1908; Hart 1952).[1] Public health experts began sounding the alarm in the 1870s, claiming these practices were killing thousands of children every year (Meckel 1990, p. 68). In response, city governments hired milk inspectors, who were tasked

[1] Today, boric acid is used as an insecticide and fungicide (See et al. 2010). Derived from borax, it is toxic and, if ingested by humans, can cause abdominal pain, diarrhea, and vomiting (Litovitz et al. 1988). There had been consumer complaints about adding borax to milk for decades ("Pure and Impure Milk" 1876, p.9; "Dangerous Milk Adulteration" 1879, p. 2; "How Milk is Adulterated" 1887, p. 10; "A Chemical Examination Shows Borax Acid in Milk" 1889, p. 1.) but the practice was still widespread at the turn of the 20th century and vigorously defended by dairy interests (Committee on Interstate and Foreign Commerce 1902). Other preservatives frequently added to milk in the 19th century include formaldehyde, sodium carbonate, and sodium bicarbonate (Newton 1877; Drescher 1893; Hart 1952).

with collecting and analyzing milk samples from dairymen and dealers.[2] If the milk was found to have been adulterated or skimmed, then stiff fines were levied and the milk was confiscated or spilled onto the ground.

There is anecdotal evidence that milk inspections were effective. For instance, 40 percent of the milk sold in New York City was either diluted with water or skimmed in 1882, the year before inspections began; the next year, only 20 percent of the New York City supply was watered or skimmed (Morris 1885). According to one contemporary observer, a Dr. H.A. Pooler, the milk inspections "had a very happy effect by reducing the death rate of children…3,673 less in 1883 than in 1882, other conditions of the city being about the same" (Morris 1885, p. 250).

Using city-level data for the period 1880-1910, we estimate the effects of milk inspections on infant and child deaths per 100,000 population. Mortality counts come from a variety of historical sources, including public health reports available in the archives of the National Library of Medicine and the U.S. Census Bureau's *Mortality Statistics*. During the 1880s and 1890s, most major cities in the United States undertook regular inspections of their milk supply with the goal of preventing its adulteration and skimming. When analyzing infant mortality, we are able to exploit pre- and post-treatment data from 30 American cities; when analyzing mortality among children under the age of 5, we exploit pre- and post-treatment data from 28 cities.

Our event-study estimates provide little evidence that milk inspections were effective. In the post-treatment period, estimated effects of milk inspections on infant and child mortality are

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[2] On-the-spot analysis of milk samples could be performed with a "lactometer," an instrument used to check milk density. Geisler (1891 p. 93) provided instructions for its use:

> The milk to be tested should be warmed or cooled, as the case may be, to the temperature of 60° Fahr. The lactometer is placed in it, care being taken not to wet that part of the stem above the milk. Now take the lactometer out of the milk and observe whether the thin film adhering to it runs rapidly off, and whether the milk appears thin and blueish and the taste of the milk is flat and watery: if such is the case and the lactometer floats at some point less than 100—as, for instance, 90—then we are reasonably certain that water has been added.

generally small and, without exception, statistically insignificant at conventional levels. We conclude that milk inspections may have reduced infant and child mortality, but their effects were not sufficiently large so as to be reliably detectable.

2. Background

Exclusive breastfeeding was not the norm at the turn of the 20th century among American mothers. For example, Wolf (2001, 2003) reports that most mothers in Chicago did not exclusively breastfeed their newborns and, as a consequence, diarrhea was the leading cause of infant mortality.[3] Instead of breast milk, mothers typically fed their infants a gruel that contained water and cows' milk (Alsan and Goldin 2019).

Because infants were weaned at such an early age, the diluting of cows' milk with water represented a direct threat to their health. Although it was widely recognized that water could carry deadly pathogens such as diphtheria and typhoid, public health officials in the 1870s and 1880s were focused on ensuring that infants received adequate nutrition (Meckel 1990, pp. 68-70).[4] Several cities had already prohibited the selling of adulterated food and milk, but these ordinances appear to have been of little practical value either because "adulteration" was vaguely defined or inadequate provision was made for enforcement.[5] The hiring of milk inspectors was viewed as a crucial step

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[3] In 1912, the *Journal of the American Medical Association* lamented that the "nursing period has gradually been diminished to one year, then to six months, then to three months, and now it is largely a question as to whether the mother will nurse her baby at all" ("The Care of Infants" 1912, p. 542).

[4] For instance, Newton (1877, p. 222), the New Jersey milk inspector, wrote:

> If we try to nourish a child on skimmed or water milk, fat in insufficient quantities is supplied, wasting results, death may follow; or, in other words, the child is starved…Milk, being the principal article of diet in infancy, we naturally turn to that period of life to find the effects of impure milk; and it is just at that period of life that we note the highest mortality. Thousands of children perish annually from starvation due to feeding on skimmed and watered milk.

[5] In February of 1880, the Boston milk inspector complained that "under existing laws, it was almost impossible to convict the sellers of watered or doctored milk ("The Adulteration of Milk" 1880, p. 2). Shortly thereafter, a pure milk standard was adopted as were new penalties for selling adulterated or skimmed milk ("The New Milk Law" 1880, p. 1).

towards reducing the alarmingly high rates of infant mortality. Perhaps because of data limitations, no previous study has investigated whether it was effective.

By the late 1800s, public health officials had shifted their focus from preventing the skimming and watering of milk to preventing its contamination with harmful microscopic pathogens (Meckel 1990, p. 70). These efforts included requirements that milk sold within city limits meet strict bacteriological standards (e.g., a maximum of 500,000 bacteria per cubic centimeter of milk), requirements that milk come from tuberculin-tested cows, dairy farm inspections, and the licensing of milk sellers (Parker 1917; Preston and Haines 1991; Anderson et al. 2022).[6] Using data from 26 cities for the period 1900-1940 and a difference-in-differences (DD) regression, Anderson et al. (2022) found no evidence that infant mortality was related to either the adoption of bacteriological standards or the requirement that milk come from tuberculin-tested cows. Descriptive evidence from Lentzner (1987) suggests that the licensing of milk sellers was similarly ineffective.

Using data from 40 U.S. cities for the period 1900-1920 and a DD model, Komisarow (2017) investigated the effects of dairy farm inspections on mortality from diarrhea and enteritis among infants and young children. She found that dairy farm inspections were associated with a 14-20 percent reduction in mortality from diarrhea and enteritis among one-year-olds. Although there was no evidence of an effect on infant mortality, Komisarow's inspection dates came from Parker (1917, Table 114, p. 371) and are, with some frequency, contradicted by information available from other contemporary sources (e.g., newspaper accounts and public health reports). Moreover, it is

In June of 1890, the Philadelphia milk inspector complained that in order to obtain a conviction, "the act of adulteration must be witnessed by an officer of the law." ("Long Live the Pump" 1890, p. 8). Later that year, a new ordinance defining what constituted impure milk was passed by the Philadelphia City Council ("Sale of Impure Milk" 1890, p. 3).

[6] Ordinances requiring milk to meet bacteriological standards are often referred as "pasteurization ordinances" (Troesken 2015, pp. 33-34; Komisarow 2017, p. 131) because these standards were difficult to meet without resorting to pasteurization (Meckel 1990, pp. 88-89).

not clear whether the dates provided by Parker (1917) correspond to when dairy farms within city limits were first inspected or whether the inspections extended to farms located outside city limits.

3. Data and Methods

The mortality data used in the analysis are at the city level and were collected from a variety of sources. For the pre-1900 period, mortality counts come from municipal and state public health reports, obtained either through interlibrary loan, the Hathi Trust Digital Library, or the archives at the National Library of Medicine in Bethesda, Maryland.[7] For the years 1900-1910, mortality counts come from *Mortality Statistics*, published annually by the U.S. Census Bureau.

Figure 1 shows trends in infant and child deaths per 100,000 population for the cities in our sample. From 1880 to 1910, the infant mortality rate fell from 601.6 to 318.5, or 47 percent. The decline in child mortality was even more dramatic, falling from 1,007.2 to 418.2 (58 percent). The most notable mortality reductions occurred in the 1890s, although chlorine was not added to drinking water until 1908 and water filtration plants were largely a post-1900 phenomenon (Anderson et al. 2020; Anderson et al. 2022). Figure 1 is, to our knowledge, the first attempt to document pre-1900 trends in infant and child mortality for such a broad sample of American cities.[8]

To investigate whether the trends shown in Figure 1 can be explained by milk inspections, we estimate a two-way fixed effects regression model:

[7] For example, mortality data for St. Louis, MO come from city health department reports and were obtained from the St. Louis Public Library via interlibrary loan (1880-1896) and the Hathi Trust Digital Library (1897-1899). To take another example, mortality data for Cleveland, OH were obtained from the Hathi Trust Digital Library (1880-1883, 1892, 1895, 1898-1899), the Cleveland Public Library via interlibrary loan (1884-1885), and the archives at the National Library of Medicine (1886-1891, 1893-1894, 1896-1897). See Appendix Table A1 for a list of the cities and years used in our analysis. We collected mortality data for several major U.S. cities that were ultimately excluded from our analysis. These cities were excluded either because we could not determine when milk inspections began or because they would have entered our sample as "always-treated" units (Goodman-Bacon 2021).

[8] Anderson et al. (2021a) showed infant mortality trends over the period 1880–1940 for 14 U.S. cities.

$$(1) \qquad MR_{ct} = a_0 + v_c + \lambda_t + \sum_{y=-7}^{-2} \pi_y 1(t - T_c^* = y) + \sum_{y=0}^{7} \pi_y 1(t - T_c^* = y) + \boldsymbol{X}_{ct}\boldsymbol{\beta} + \varepsilon_{ct},$$

where MR_{ct} is the infant (or child) mortality rate in city c and year t = 1880…1910.[9] City fixed effects, v_c, account for time-invariant determinants of mortality; year fixed effects, λ_t, account for common shocks. The event-year dummies, y, are equal to 1 when the year of observation is y = -7,…,0,…7 years from T_c^*, the year in which city c's milk supply was first regularly sampled and inspected with the goal of preventing adulteration and skimming. Finally, the vector $\boldsymbol{X}_{ct}$ includes controls for whether city c filtered its water, treated it with chlorine, or had undertaken a major clean water project.[10] Appendix Table 2 provides descriptive statistics.

4. Results

We report ordinary least squares (OLS) estimates of equation (1) in Panel A of Figure 2. With or without controlling for other public health interventions, these estimates exhibit a similar pattern: there is little evidence of systematic pre-treatment trends, while the post-treatment estimates of π_y are generally small and statistically insignificant at conventional levels. Based on the lower bounds of their 90 percent confidence intervals, we can easily reject the hypothesis that milk inspections drove the dramatic reductions in infant and child mortality shown in Figure 1.[11]

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[9] We omit y = -1 from equation (1), which normalizes the estimates of π_y to 0 in that year. The y = -7 event-year dummy is equal to 1 if t is 7 or more years before T_c^*. Likewise, the y = 7 event-year dummy is equal to 1 if t is 7 or more years after T_c^*. The results presented below are qualitatively similar if we define the event-year dummies based on alternative time horizons.

[10] Appendix B provides sources for the water-related intervention dates. See Anderson et al. (2021b, 2022) for more information on the water-related interventions included in $\boldsymbol{X}_{ct}$. We also experimented with controlling for dairy farm inspections based on the dates provided in Parker (1917, Table 114, p. 371). Doing so did not materially change the estimates reported below.

[11] For instance, in event-year y = 2 (and controlling for other public health efforts), milk inspections are associated with 9.93 fewer infant deaths per 100,000 population (p-value = 0.389). The lower bound of the 90 percent confidence interval for this estimate is -29.2, which represents a 5.3 percent reduction relative to the pre-treatment mean, or 10.3 percent of the actual reduction in the infant mortality rate over the period 1880-1910.

If the effects of milk inspections on infant mortality were dynamic and heterogeneous, then our estimates of π_y are potentially biased (Sun and Abraham 2021). In Panel B of Figure 2, we report results from the interaction-weighted estimator proposed by Sun and Abraham (2021), which uses never-treated or last-treated units as counterfactuals and is more robust to treatment effect heterogeneity.[12] While less precise and often positive in the post-treatment period, the interaction-weighted estimates exhibit a similar overall pattern to those shown in Panel A of Figure 2.[13]

In Panel A of Figure 3, we report estimates of equation (1), replacing infant deaths per 100,000 population with the child mortality rate. There is little evidence that child mortality fell after regular milk inspections were undertaken. The post-treatment estimates of π_y are, without exception, statistically insignificant at conventional levels and exhibit no clear-cut pattern. Again, we can reject the hypothesis that milk inspections contributed meaningfully to the observed mortality reductions during the period under study (Figure 1).[14] The interaction-weighted estimates, reported in Panel B, are often positive in the post-treatment period and are never statistically significant.

5. Conclusion

Recent descriptions of the mortality transition and its causes have focused on efforts to purify municipal water supplies (Cutler et al. 2006; Costa 2015), while other scholars have

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12 The Sun and Abraham (2021) interaction-weighted estimator represents a special case of the estimator proposed by Callaway and Sant'Anna (2021). To implement the interaction-weighted estimator, we defined our counterfactual units as never-treated cities and cities that began inspecting their milk in 1900 or later, effectively limiting the analysis period to 1880-1899. Interaction-weighted estimates based on using either never-treated or late-treated cities as comparisons were qualitatively similar to those shown in Figure 2.

13 We also experimented with controlling for underlying trends in a variety of ways (e.g., including city-specific trends, timing-group-specific trends, and state-by-year fixed effects). These experiments produced no consistent evidence that milk inspections were negatively related to infant mortality.

14 For instance, in event-year $y = 2$ (and controlling for other public health efforts), milk inspections are associated with 25.3 fewer child deaths per 100,000 population (p-value = 0.223). The lower bound of the 90 percent confidence interval for this estimate is -66.8, which represents a 7.6 percent reduction relative to the pre-treatment mean, or 11.3 percent of the actual reduction in the child mortality rate over the period 1880-1910.

emphasized the importance of clean milk, especially for infant and early child mortality (North 1921; Preston and Haines 1991; Lee 2007). Using city-level data for the period 1880-1910, we investigate the effects of municipal milk inspections on infant and child mortality. These inspections were undertaken at the urging of public health experts with the goal of preventing the adulteration and skimming of urban milk supplies.

Our post-treatment estimates are generally small and, without exception, statistically insignificant at conventional levels. This pattern of results is consistent with Preston and Haines's (1991) observation that public health efforts undertaken before the turn of the 20th century did not materially improve the quality of urban milk supplies. It is possible that heating milk in the home, a practice introduced from Germany in the 1880s (Ewbank and Preston 1989), did more to protect infants and children from deadly pathogens commonly found in milk than did municipal inspections. Alternatively, new technologies, including the introduction of mechanical ice in the 1880s (Rees 2013), may have played an important role.

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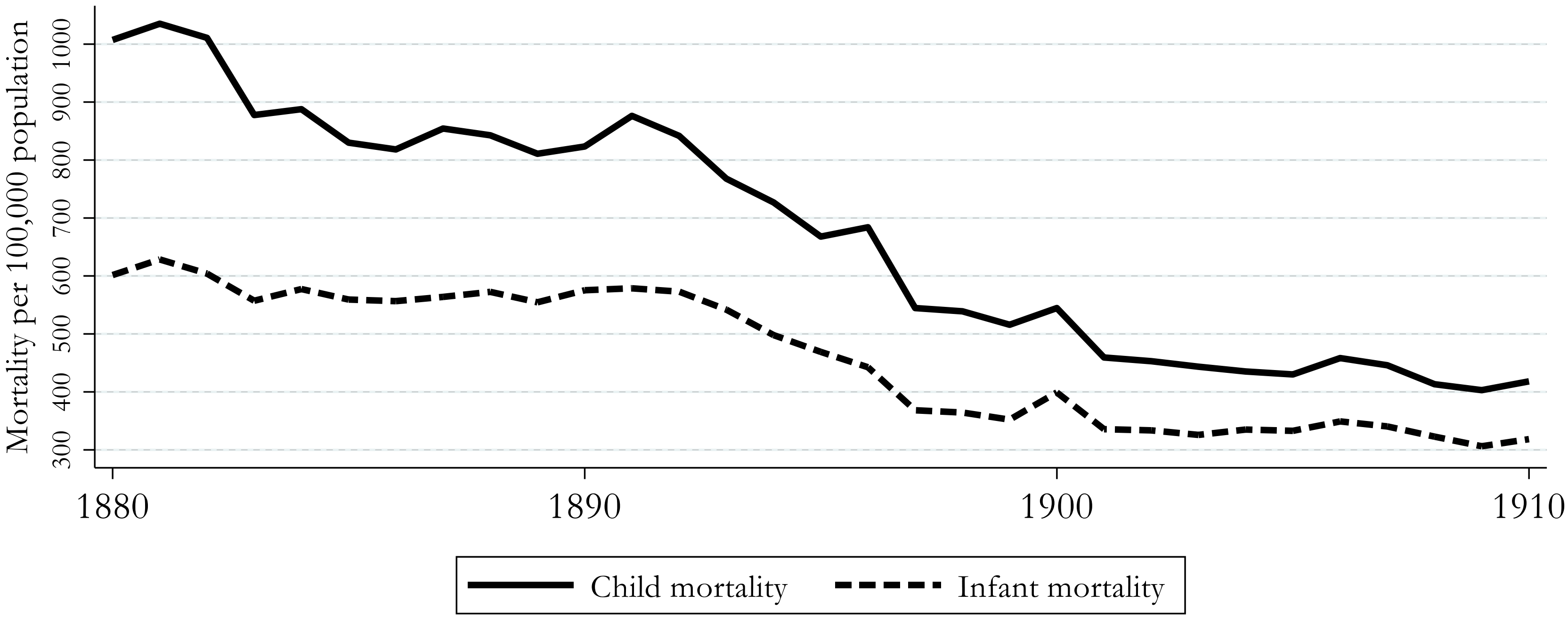
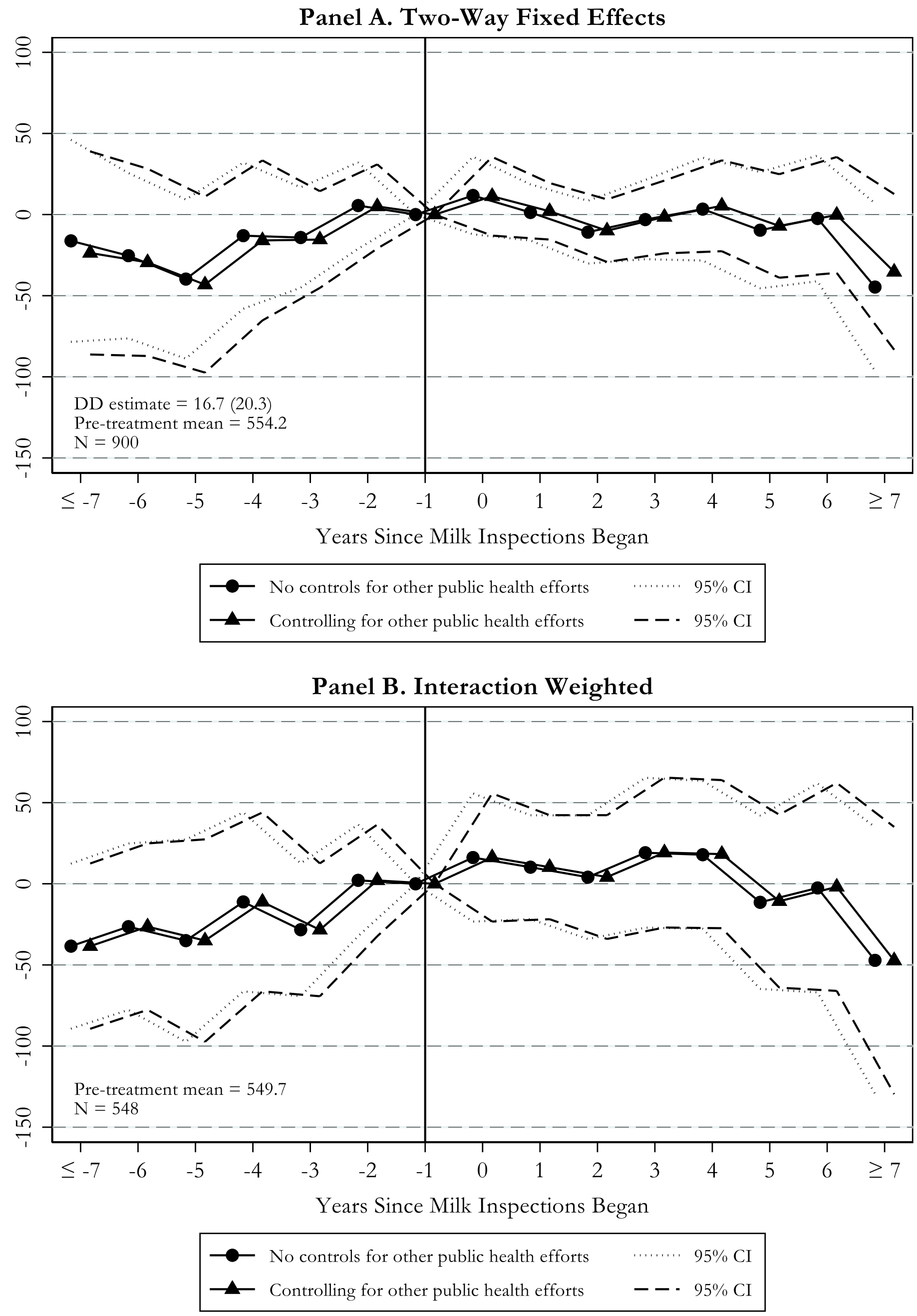
Figure 1. Infant and Child Mortality Rates, 1880-1910



Notes: Based on annual data from municipal and state public health reports (1880-1899) and *Mortality Statistics* (1900-1910).

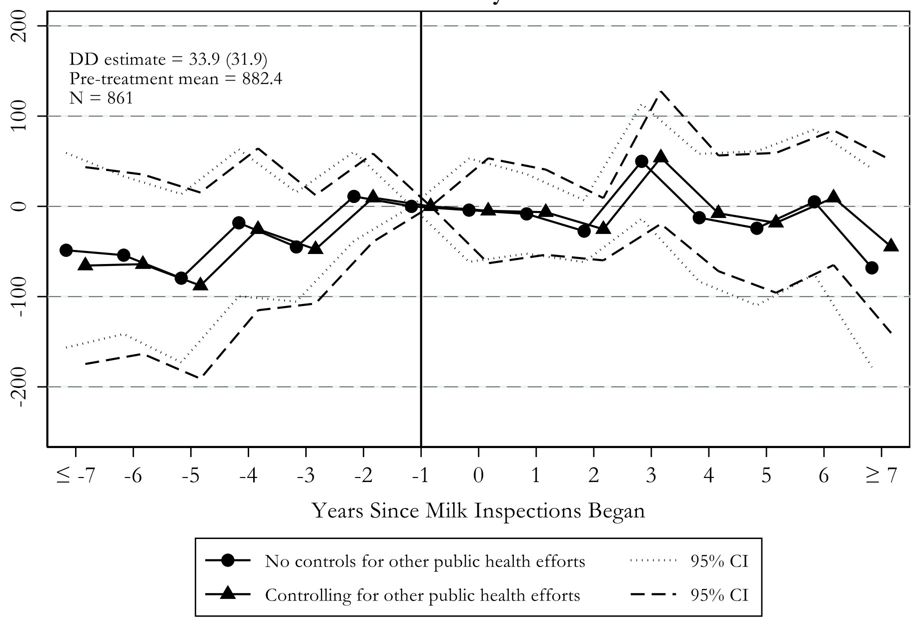
Figure 2. Milk Inspections and Infant Mortality, 1880-1910



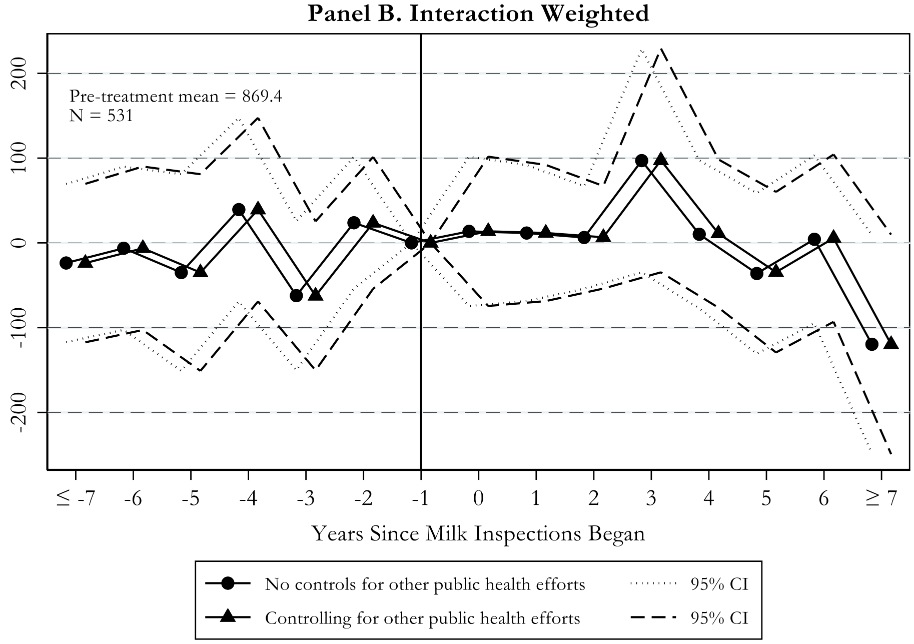
Notes: Based on annual data from municipal and state public health reports (1880-1899) and *Mortality Statistics* (1900-1910). Two-way fixed effects (panel A) and interaction-weighted (panel B) estimates (and their 90% confidence intervals) are reported, where the omitted category is one year before treatment. The dependent variable is equal to the number of infant deaths per 100,000 population in city *c* and year *t*. All models control for city and year fixed effects. Estimates are weighted by city population and standard errors are corrected for clustering at the city level. Reported DD estimate (panel A) comes from a regression that controls for other public health efforts in which the event-study indicators are replaced by the variable *Inspection* (equal to one if city *c* was inspecting its milk supply in year *t*, and equal to zero otherwise).

Figure 3. Milk Inspections and Child Mortality, 1880-1910

Panel A. Two-Way Fixed Effects



Panel B. Interaction Weighted



Notes: Based on annual data from municipal and state public health reports (1880-1899) and *Mortality Statistics* (1900-1910). Two-way fixed effects (panel A) and interaction-weighted (panel B) estimates (and their 90% confidence intervals) are reported, where the omitted category is one year before treatment. The dependent variable is equal to the number of deaths among children under the age of 5 per 100,000 population in city *c* and year *t*. All models control for city and year fixed effects. Estimates are weighted by city population and standard errors are corrected for clustering at the city level. Reported DD estimate (panel A) comes from a regression that controls for other public health efforts in which the event-study indicators are replaced by the variable *Inspection* (equal to one if city *c* was inspecting its milk supply in year *t*, and equal to zero otherwise).

Appendix

For Online Publication

Appendix A

Appendix Table 1. Municipal Milk Inspection Dates and Data Availability

City and state	Year milk inspections began	Years covered for infant mortality counts	Years covered for child mortality counts
Mobile, AL	1905	1889-1910	1889-1910
San Francisco, CA	1898	1881-1897, 1900-1910	1881-1897, 1900-1910
Bridgeport, CT	…	1880-1910	1880-1910
Hartford, CT	1883	1880-1881, 1883-1910	1880-1881, 1883-1910
New Haven, CT	…	1880-1910	1880-1910
Waterbury, CT	…	1880-1910	1880-1910
Washington, D.C.	1893	1880-1910	1880-1910
Atlanta, GA	1895	1893-1910	1880-1910
Chicago, IL	1893	1880-1910	1880-1910
Indianapolis, IN	1897	1884-1887, 1895-1896, 1899-1910	1884-1887, 1895-1896, 1899-1910
New Orleans, LA[a]	1892	1881-1910	…
Portland, ME	1902	1887-1910	1887-1910
Baltimore, MD	1894	1880-1910	1880-1910
Grand Rapids, MI	1897	1890, 1892-1910	1890, 1892-1910
St. Paul, MN	1899	1885-1910	1885-1910
St. Louis, MO	1887	1880-1896, 1900-1910	1880-1910
Manchester, NH	1884	1883-1910	1883-1910
Camden, NJ	1883	1880-1910	1880-1910
Elizabeth, NJ	1883	1880-1910	1880-1910
Hoboken, NJ	1883	1880-1910	1880-1910
Jersey City, NJ	1883	1880-1910	1880-1910
Newark, NJ	1883	1880-1910	1880-1910
Paterson, NJ	1883	1880-1910	1880-1910
Trenton, NJ	1883	1880-1910	1880-1910
New York City, NY	1883	1880-1897	1880-1897
Rochester, NY	1891	1881-1910	1881-1910
Cleveland, OH	1887	1880-1910	1880-1910
Dayton, OH	1887	1880, 1890-1891, 1893-1896, 1898-1910	1880, 1890-1891, 1893-1896, 1898-1910
Toledo, OH	1884	1881-1883, 1885, 1898-1910	1881-1883, 1885, 1898-1910
Philadelphia, PA	1889	1880-1910	1880-1910
Memphis, TN	1889	1880-1897, 1900-1910	1880-1897, 1900-1910
Richmond, VA	1893	1887-1910	1887-1910
Milwaukee, WI[a]	1891	1885-1890, 1892-1910	…

[a] These cities are not included in the sample on child mortality because mortality counts are unavailable for the pre-treatment period.

Appendix Table 2. Descriptive Statistics

	Mean (SD)	Description
Inspection	0.661 (0.473)	= 1 if city sampled and inspected its milk supply, = 0 otherwise
Filtration	0.082 (0.273)	= 1 if city had a water filtration plant, = 0 otherwise
Chlorination	0.005 (0.063)	= 1 if city treated water supply with chlorine, = 0 otherwise
Clean Water Project	0.043 (0.201)	= 1 if city had completed a clean water project, = 0 otherwise
N = 900		

Notes: Unweighted means with standard deviations in parentheses.

Appendix B

Sources for Milk- and Water-Related Pubic Health Interventions

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