THE ROLE OF PUBLIC HEALTH IMPROVEMENTS IN HEALTH ADVANCES: THE TWENTIETH-CENTURY UNITED STATES*

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Mortality rates in the United States fell more rapidly during the late nineteenth and early twentieth centuries than in any other period in American history. This decline coincided with an epidemiological transition and the disappearance of a mortality "penalty" associated with living in urban areas. There is little empirical evidence and much unresolved debate about what caused these improvements, however. In this article, we report the causal influence of clean water technologies—filtration and chlorination—on mortality in major cities during the early twentieth century. Plausibly exogenous variation in the timing and location of technology adoption was used to identify these effects, and the validity of this identifying assumption is examined in detail. We found that clean water was responsible for nearly half the total mortality reduction in major cities, three quarters of the infant mortality reduction, and nearly two thirds of the child mortality reduction. Rough calculations suggest that the social rate of return to these technologies was greater than 23 to 1, with a cost per person-year saved by clean water of about $500 in 2003 dollars. Implications for developing countries are briefly considered.

> The present water closet system, with all its boasted advantages, is the worst that can generally be adopted, briefly because it is a most extravagant method of converting a mole-hill into a mountain. It merely removes the bulk of our excreta from our houses to choke our rivers with foul deposits and rot at our neighbors' door. It introduces into our houses a most deadly enemy.
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> —chemist quoted in the *Scientific American* (July 24, 1869:57)

In the early twentieth century, mortality in the United States declined dramatically. Mortality rates fell by 40% from 1900 to 1940, an average decline of about 1% per year. Life expectancy at birth rose from 47 to 63. Together with the late nineteenth century, no other documented period in American history witnessed such rapidly falling mortality rates. This decline in mortality was part of the "epidemiological transition." Nearly all the mortality decline is accounted for by reductions in infectious disease, which today is only a small share of total mortality. It also coincided with the disappearance of the "urban penalty"—the higher mortality rates observed in urban areas throughout the

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nineteenth century.[1] Clearly, potent forces outside medical care were at work. But what were these forces?

Several explanations have been put forward. One posits that economic innovation and nutritional gains drove this change (Fogel 1994; McKeown 1976). Fogel showed that mortality declines track reductions in chronic malnutrition as reflected by the body mass index.[2] McKeown argued for the importance of nutrition and improvements in living standards in reducing mortality by ruling out other explanations.[3] A second explanation is that private actions by individuals and households to improve hygiene were a dominant factor in lowering mortality. Health-behavior campaigns, conducted in the late nineteenth and early twentieth centuries, often targeted hand and food washing, the boiling of milk, and breast-feeding (Ewbank and Preston 1990). There is considerable variation in infant and child health related to mothers' education (Deaton and Paxson 2001; Elo and Preston 1996)—a relationship that is commonly thought to operate through health behaviors—and there is evidence of an effect of education on own mortality later in life (Lleras-Muney 2002). A third view stresses large-scale public health innovations—including clean water technologies, sanitation, refuse management, milk pasteurization, and meat inspection—as the source of health improvement (Condran and Crimmins-Gardner 1978; Meeker 1972; Preston and Haines 1991). These explanations are not mutually exclusive, but it is important to discriminate among them. In formulating strategies to improve health in developing countries, it is essential to know the relative importance of nutritional gains, educational campaigns, and major public health initiatives. Empirical research on these topics can aid development institutions in selecting interventions to improve health that have the greatest social returns.

Unlike the other two explanations, relatively little empirical work has examined major public health interventions. Existing evidence has drawn on the link between spending on municipal sanitation and mortality (Cain and Rotella 2001), the decline in mortality in three nineteenth-century French *départments* as the water and sanitation infrastructures were built (Preston and van de Walle 1978), concomitant changes in deaths from waterborne diseases and urban infrastructure (Condran and Crimmins-Gardner 1978), racial differences in mortality from typhoid fever following water filtration (Troesken 2002), and the expansion of the water and sewer infrastructures across wards of Chicago (Ferrie and Troesken 2004). All this research shares common problems: it is difficult to rule out the influence of confounding factors,[4] and the interventions themselves are often difficult to pinpoint (municipal water and sewer projects often spanned many decades, for example).

In this article, we respond to these problems by examining the introduction of a major class of discrete public health interventions—clean water technologies—in large American cities in the early twentieth century. Clean water technologies are likely the most important public health intervention of the twentieth century. In 1900, waterborne diseases accounted for nearly one quarter of the reported deaths from infectious diseases in major cities. In the next few decades, waterborne disease mortality fell dramatically. The only disease that killed more people at the turn of the century—tuberculosis—had already declined enormously by the time drugs to combat it were developed and widely distributed (Smith 1988). In this article, we examine the importance of clean water using

1. As late as 1900, life expectancy at birth for white males was 10 years greater in rural areas than in urban areas.

2. Chronic malnutrition can be due either to a shortage of nutrients or to excessive demands on them (often by work or disease) and is commonly linked to the resilience of the immune system.

3. McKeown's evidence has been contested by numerous critics, such as Szreter (1988). There is also some evidence that the British mortality decline analyzed by McKeown was not unique compared to preindustrial fluctuations in mortality in Britain (Wrigley and Schofield 1989), refuting his central thesis.

4. Major urban infrastructure projects were often bundled with other municipal reforms, and they were often introduced in particular times of need.

a difference-in-difference approach that exploits plausibly exogenous variation in the timing of water filtration and chlorination across cities. This approach allows us to account for other major changes that did not vary across areas and over time in exactly the same way that clean water technologies did. We also provide historical evidence and report several specification tests to support our identifying assumption of jointly exogenous variation in intervention timing and location.

We first estimate the impact of clean water on cause-specific and total mortality. We show that the introduction of water filtration and chlorination systems led to major reductions in mortality, explaining nearly half the overall reduction in mortality between 1900 and 1936. Our results also suggest that clean water was responsible for three quarters of the decline in infant mortality and nearly two thirds of the decline in child mortality. The magnitude of these effects is striking. Clean water also appears to have led to the near-eradication of typhoid fever, a waterborne scourge of the nineteenth and early twentieth centuries.

We next discuss behavioral responses to clean water. Our analyses generally suggest that public health interventions and private health practices may be complements rather than substitutes. We then approximate the social rate of return to clean water investments. Water systems were expensive, but their benefits appear to have been substantially greater. Under conservative assumptions, we estimate that the rate of return to clean water technologies was about 23 to 1 and that the cost per person-year saved was about $500 in 2003 dollars. Finally, we conclude by considering broad implications for developing countries today.

BACKGROUND ON PUBLIC HEALTH ADVANCES

Disease Environment and Early Water Systems

At the turn of the twentieth century, infectious diseases accounted for a large share of deaths in American cities. As Table 1 shows for the major cities studied here (defined later), in 1900, 44% of deaths were due to infectious diseases, compared with only about 18% of deaths in 1936. Although our analysis begins in 1900 with the start of reliable annual mortality statistics in the death registration area, decennial census statistics clearly show that the striking mortality declines began before the turn of the century. The crude death rate during the 1850s was estimated to have been about 22 per 1,000 (Meeker 1972). This rate had fallen to about 18 by 1900 and declined to about 11 by 1940 (U.S. Census Bureau 1941; U.S. Census Office 1902).

Before the bacteriology revolution of the 1870s, the dominant view of contagious illnesses was the miasma theory of disease. This view essentially maintained that a variety of illnesses were the result of poisonous, malevolent vapors or "miasmas" that were offensive to the sense of smell (Duffy 1990). The widespread acceptance of the miasma theory appears to have been based on a kind of Pavlovian learning. People who were exposed to foul odors were more likely to get sick, foul-smelling areas tended to have more sick people, and more people seemed to get sick during the summer when offensive odors were more common. Consequently, concerns about the health effects of contaminated water and sewage emerged before the underlying basis of disease was fully understood. As the early provision of water to urban populations illustrates, however, knowledge of this association did not result in clean water supplies.

The first large-scale municipal water system in the United States was built by Benjamin Latrobe and his colleagues in Philadelphia at the dawn of the nineteenth century. Many large cities subsequently followed in Philadelphia's footsteps, often after years or decades of squabbling over water sources and the best means for tapping them (Blake 1956). Early municipal water systems did not prevent significant outbreaks of waterborne and related infectious diseases, however. Large amounts of street waste continued to be

Table 1. Percentage of Deaths, by Cause, in Major Cities

Cause of Death	1900	1936
Major Infectious Diseases	39.3	17.9
Tuberculosis	11.1	5.3
Pneumonia	9.6	9.3
Diarrhea and enteritis	7.0	N/A
Typhoid fever	2.4	0.1
Meningitis	2.4	0.3
Malaria	1.2	0.1
Smallpox	0.7	0.0
Influenza	0.7	1.3
Childhood Infectious Diseases	4.2	0.5
Measles	0.7	0.0
Scarlet fever	0.5	0.1
Whooping cough	0.6	0.2
Diphtheria and croup	2.3	0.1

Note: All percentages are shares of total mortality.

Source: U.S. Census Bureau's Mortality Statistics, 1900 and 1936.

swept or washed down drains and into sewers that ultimately emptied back into municipal water supplies. Because most sewer systems were designed only to carry storm water, they often became clogged—particularly after the advent of water closets in the United States during the 1870s (Duffy 1990). The end result was often backflow from sewers into streets and gutters; some observers began referring to sewers as "elongated cess-pools" (Duffy 1990).

Perhaps the worst type of backflow was the emptying of sewer systems directly into the supplies of drinking water. In the late nineteenth century, the primary sewer outfalls of many American cities emptied upstream of river water intakes or directly into large bodies of water (like the Great Lakes) in close proximity to water intakes. Ironically, cities with the most extensive sewer systems had the greatest potential to pollute their water sources. The few cities that addressed this problem early also suffered from the dumping of untreated sewage by upstream communities. This phenomenon essentially reproduced "circular water systems" (a term referring to the common mixing of the contents of household privy vaults and drinking wells through the groundwater) on the municipal level (Duffy 1990).

A substantial mortality "penalty" to living in urban places therefore developed as American cities grew during the nineteenth century (Haines 2001),[5] as can be seen in historical mortality statistics. In seven states with good data before 1900, urban mortality was 30% higher in cities than in rural areas in 1890. The gradient was much steeper for infants and children. In 1880, infant mortality was 140% higher in cities, and in 1890, mortality among children aged 1–4 was 94% higher (Haines 2001; U.S. Census Office 1888).

5. Historical data limitations make it difficult to pinpoint precisely when this mortality penalty first emerged. Szreter and Mooney (1998) provided evidence that an urban mortality penalty was evident in Great Britain as early as 1830.

Clean Water Technologies: Filtration and Chlorination

As the water quality in cities deteriorated, new technologies to purify dirty water were developed. Originally designed to combat turbidity, discoloration, and bad taste, rather than disease, effective water filtration was not common before the 1890s.[6] There were two major methods of filtration: slow sand filtration and rapid (or mechanical) filtration. Slow sand filtration is simply the large-scale pouring of untreated water into vats full of sand, gravel, and other porous matter. Particulate matter is strained out of the water, and bacteria are removed both by a sticky film of mud that forms on the sand's surface and by oxidization as water comes into contact with air that is trapped between sand particles (Baker 1948). Rapid filtration employs the same basic processes but uses pressure to force water through the sand and coagulants to help the protective film form. Although effective, filtration technologies did not remove all the bacteria from untreated water. A large number of complementary disinfection processes were investigated[7] (Baker 1948), but chlorination was the cheapest. The first large-scale adoption of water chlorination occurred at the Boonton Reservoir of the Jersey City, New Jersey, waterworks in 1908, and many other cities quickly followed in subsequent years.

In addition to the principal clean water technologies examined here, some cities sought clean water through other means. Jersey City abandoned the Passaic River to seek cleaner upland sources (Blake 1956). Chicago built its drainage canal to send wastewater down the Illinois and Mississippi Rivers, rather than back into Lake Michigan (Blake 1956). Cleveland extended its water intake tunnel four miles out into Lake Erie to distance the intake from its sewer outfalls (Melosi 2000). Memphis chose to draw deep groundwater, rather than to take water from the Mississippi River. Sewage treatment technologies are also important for the provision of clean water, of course. However, modern sewage treatment technologies were not generally in widespread use in the United States until the 1930s and 1940s.

Adoption of Clean Water Technologies

There was considerable variation in when cities adopted clean water technologies. Although some major cities, such as Cincinnati, Philadelphia, and Pittsburgh, began building large filtration plants around the turn of the century, others, such as Chicago and Milwaukee, waited many decades to do so. There was somewhat less variation in when water chlorination was adopted. Following the demonstration of chlorine's use for disinfection in 1908, most major cities began water chlorination within the next decade. Primary sewage treatment and sewage chlorination technologies were generally not introduced until somewhat later, so we could not use our data to investigate their effects.[8] Figure 1 shows the cumulative number of our sample cities that adopted clean water and sanitation technologies from 1900 to 1936.

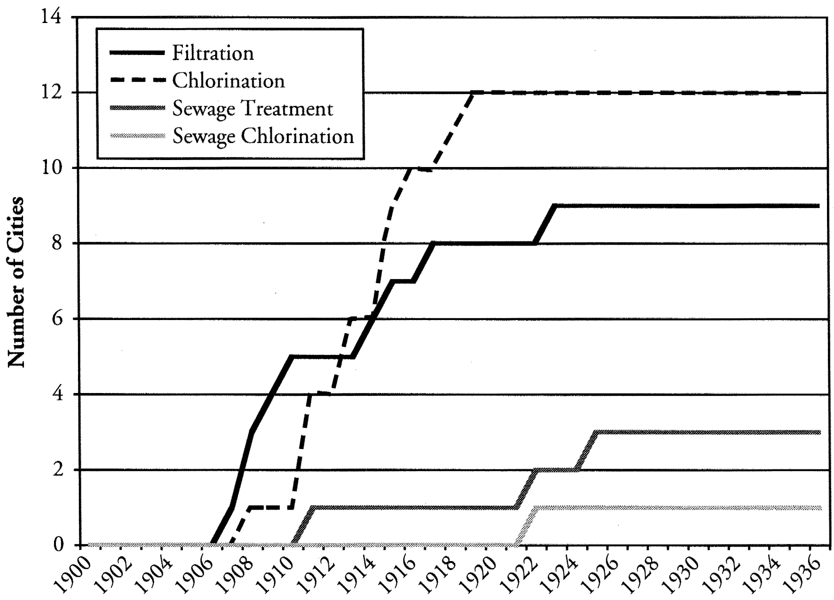
Although probably not complete historical accidents, there was a large random component to the timing of the adoption of clean water technology in American cities. In general, early sanitarians fought uphill battles for many years or even decades to persuade city councils to take action against poor water quality (Cutler and Miller forthcoming). Matters were further complicated by differences in beliefs about the cause of disease (despite the scientific advances of bacteriology) and by debates about the

6. Water filtration was first used in the United States in Poughkeepsie, New York, in 1872.

7. Depending on the clarity and amount of vegetable and particulate matter in a water source, these processes were sometimes seen as substitutes for filtration, too.

8. We know when alternative means of clean were used and when basic sewage treatment technologies were introduced, so we could account for them in our analyses.

Figure 1. Cumulative Number of Sample Cities That Adopted Technologies, 1900 to 1936



government's involvement in water purification.[9] Moreover, even as a consensus about the need to begin filtering or chlorinating municipal water supplies emerged, partisan bickering about how it should be done (by the city directly or by private contract) and the specific technology that should be used (slow or rapid sand filtration, for example) was a problem. Historical accounts have generally suggested that the precise year in which cities ultimately adopted clean water technologies was arbitrary.

The case of Philadelphia provides an illustrative example (McCarthy 1987). More than 20 years passed between the city's initial water-quality studies during the 1880s and the introduction of filtered water. A series of less-costly interventions (like moving the city's primary sewer outfalls to below its water-intake points) were tried first, but they proved to be ineffective. Revelations of corruption and bribery in private water contracts then repeatedly stalled purification efforts during the 1890s (McCarthy 1987). Appropriations for water filtration were finally approved after the turn of the century, but the actual construction of filtration plants took nearly a decade. The story of water politics in Philadelphia mirrors what occurred in most American cities (Cutler and Miller forthcoming). As a result, we take the precise *timing* of the adoption of clean water technology across cities to be largely exogenous and provide statistical evidence to support this assumption. We turn next to the data that allowed us to estimate the impact of these interventions on mortality.

9. Hamlin (1990) presented a detailed account of the complex relationship between science and public policy regarding water in nineteenth-century Britain.

Table 2. The Evolution of Total, Infant, Child, and Typhoid Fever Mortality (Deaths per 1,000) in Major Cities, 1900–1936

	1900		1920		1936	
Mortality	Mean	*SD*	Mean	*SD*	Mean	*SD*
Total Mortality	1,935	316	1,492	222	1,354	287
Infant Mortality	18,931	2,921	11,953	1,752	7,130	2,435
Child Mortality	2,818	1,360	1,260	167	522	267
Typhoid Fever Mortality	47	33	4	2	2	2

Source: U.S. Census Bureau's Mortality Statistics, 1900, 1920, and 1936.

DATA AND SAMPLE SELECTION

To understand how clean water affected mortality, we needed data on sanitary interventions matched to deaths by cause. There was no national system of death records in the United States prior to 1933, however (Haines 2001). Instead, we made use of the substantial data that were collected, beginning in 1900, from an official "death registration area" comprising 10 states, together with a number of "registration cities" outside these states (Haines 2001). Annual mortality statistics collected in these areas by city, cause, and age were obtained from the Census Bureau's Mortality Statistics from 1900 to 1936. We did not include years later than 1936 because a new data series began in 1937. The year 1936 is also a convenient end point for our analysis because it immediately preceded the development of major antibiotics and more modern health care. The precise cause of all deaths from waterborne and diarrheal diseases is difficult to ascertain in the Census Bureau's statistics, and diarrheal disease categories were unfortunately reported inconsistently throughout the 1900–1936 series. However, typhoid fever, a marker for waterborne disease and an important cause of death in its own right, was reported consistently throughout the series. In 1900, the ratio of deaths from diarrheal disease to deaths from typhoid fever in the cities studied was about 3:1. Summary statistics for total, typhoid fever, infant, and child mortality rates per 100,000 population are shown in Table 2. (Throughout the rest of this article, the terms *mortality* and *mortality rates* refer to mortality rates per 100,000 population.)

We matched these municipal-level mortality statistics to knowledge of where and when clean water technologies were in use according to historical engineering and urban planning periodicals. The most comprehensive sources were water-system censuses that were published in the municipal engineering periodicals: two in the *Journal of the American Water Works Association* (in 1924 and 1932) and one in *Water Works Engineering* in 1943. Articles in these and other relevant periodicals, including *American City* and *Engineering News*, contained additional information. Several prominent historical texts on clean water also provided intervention dates (Baker 1948; Blake 1956; Melosi 2000).

Our selection of cities began with all municipalities of at least 100,000 population in 1900; more details on these cities are available in the decennial censuses. A few smaller cities for which unusually good historical information is available were also included. We then sought four dates for clean water intervention for each city: water filtration, water chlorination, primary sewage treatment, and sewage chlorination.[10] Because our

10. In many cases, readily available printed materials did not provide all four intervention dates for each city. Therefore, we made a number of telephone calls directly to municipal water and sewage authorities to request these dates. However, we ultimately question the precision of intervention dates obtained by telephone. In some cases, dates provided by municipal agencies conflicted with published dates; in other cases, the best answers given were of the "circa 1910" sort.

Table 3. Clean Water Intervention Dates

Cities	Water Filtration	Water Chlorination	Sewage Treatment	Sewage Chlorination
Baltimore, MD	1914	1911	1911	>1936
Chicago, IL	>1940	1916	1949	>1949
Cincinatti, OH	1907	1918	>1945	>1945
Cleveland, OH	1917	1911	1922	1922
Detroit, MI	1923	1913	1940	1940
Jersey City, NJ	1978	1908	>1945	>1945
Louisville, KY	1910	1915	1958	>1958
Memphis, TN	>1936	>1936	>1936	>1936
Milwaukee, WI	1939	1915	1925	1971
New Orleans, LA	1909	1915	>1945	>1945
Philadelphia, PA	1908	1913	>1945	>1945
Pittsburgh, PA	1908	1911	>1945	>1945
St. Louis, MO	1915	1919	>1945	>1945

Source: Water system censuses published in the *Journal of the American Water Works Association* (1924, 1932) and *Water Works Engineering* (1943); various articles appearing in *American City, Engineering News, Journal of the American Water Works Association*, and *Water Works Engineering* (available on request).

empirical strategy relied heavily on the accuracy of intervention dates, we chose to include only cities for which readily available published materials provided all four dates. Our final sample comprised 13 cities: Baltimore, Chicago, Cincinnati, Cleveland, Detroit, Jersey City, Louisville, Memphis, Milwaukee, New Orleans, Philadelphia, Pittsburgh, and St. Louis. Even by restricting our analyses to these cities, some measurement error undoubtedly remains. Cities did not always begin clean water interventions in an all-or-nothing manner from one year to the next. However, the dates we used correspond to the year in which the majority of municipal populations were first served by these interventions. Table 3 shows each intervention date for each city. It also makes plain why we could not examine the impact of sewage treatment technologies—few of the 13 cities had adopted these technologies by 1936.

Finally, we obtained data on demographic characteristics and literacy for these populations from the Census Bureau's decennial censuses, 1900–1940. Table 4 summarizes these demographic statistics. For the years between decennial censuses, we estimated the values for these variables by linear interpolation.

EMPIRICAL STRATEGY

Given the importance of cumbersome political processes in determining the precise timing of clean water interventions in cities, our basic empirical strategy was to exploit this plausibly exogenous variation in the timing of intervention to identify the effects of clean water. We used a difference-in-difference approach to estimate the impact of clean water interventions. That is, we examined changes in mortality just around the time that filtration and chlorination were introduced in each city. Given the number of dramatic changes that took place in the early twentieth century, this strategy is attractive for several reasons. First, potentially confounding changes that are common across areas (like knowledge of appropriate personal health practices) would not affect our estimates. Similarly, city-specific conditions that did not change over time (like higher disease rates in warmer

Table 4. Mean Demographic Characteristics of Major Cities, 1900 and 1940

Characteristic	1900	1940
Population	498,259 (467,012)	971,350 (882,250)
% Female	50.5	51.2
% Black	10.6	14.3
% Other Nonwhite	0.1	0.1
% Foreign Born	22.0	11.3
% Younger Than Age 5	10.6	6.5
% Aged 5–14	20.0	14.4
% Aged 15–24	19.8	17.6
% Aged 25–44	32.8	33.8
% Aged 45–64	13.3	21.5
% Aged 65+	3.2	6.3

Note: The standard deviation of the municipal population is shown in parentheses below the mean.

Source: U.S. Census Bureau (1941); U.S. Census Office (1902).

climates) were also controlled for. Only potential confounders (or omitted variables) that varied across cities and over time in the exact way that filtration and chlorination did would be problematic. Because our data capture the sequencing of clean water interventions and mortality, reverse causation was not a concern.

Specifically, we estimated equations for mortality in cities c and years t of the general form:

$$\ln(m_{c,t}) = \alpha + \beta_1 Filter_{c,t} + \beta_2 Chlorine_{c,t} + \beta_3 (Filter_{c,t} \times Chlorine_{c,t}) + \delta_c + \mu_t + \gamma_c l_{c,t} + \sum \rho_d d_{d,c,t} + \sum \lambda_k \ln(m_{c,t-k}) + \varepsilon_{c,t}\,. \quad (1)$$

Log mortality rates[11] (m) were assumed to depend on indicators for water filtration and chlorination and their interaction, city and year fixed effects, city-specific linear time trends (l), demographic characteristics (d), and an error term (ε). The demographic characteristics that we specified were population age structure, sex, racial composition, and share of immigrants. We incorporated an interaction term between filtration and chlorination to test if the two technologies are substitutes ($\beta_3 > 0$) or complements ($\beta_3 < 0$). Lagged mortality (m_{t-k}) was also included to account for the noisy nature of year-to-year mortality, although our results are not sensitive to their inclusion.

Our dependent variables were a variety of mortality measures, including total mortality, infant mortality, child mortality, and cause-specific mortality that were due to a variety of diseases and conditions. It is difficult to determine which infectious diseases should have responded to clean water technologies, however. Hiram Mills, a member of the Massachusetts State Board of Health, and J. J. Reincke, a health officer in Hamburg, Germany, independently observed a marked reduction in overall mortality, not just

11. We used the logarithmic transformation of deaths per 100,000 population, given the right-skewed distribution of mortality rates.

mortality from waterborne diseases, on the introduction of water filtration more than a century ago (Ewbank and Preston 1990; Sedgwick and MacNutt 1910). The biological mechanism underpinning the so-called Mills-Reincke phenomenon would presumably be that contaminated water weakens the immune system, making one more susceptible to other contagions. The scope of the Mills-Reincke phenomenon should at least be limited to infectious diseases other than those directly transmitted by dirty water; chronic diseases, such as cardiovascular disease and cancer, should be less affected (at least initially). We therefore focused on waterborne causes of death and infectious diseases as a whole.

Our intervention variables capture the effect of clean water technologies on some, but not all, people in a city. Although little good historical information is available, there is some suggestion that minority neighborhoods in urban areas received piped water later than did white neighborhoods (Troesken 2002). Our ignorance about the precise share of municipal populations who received piped water in each year should not bias our results unless large-scale infrastructure-improvement projects or a large number of citizen-initiated new household connections were timed to coincide precisely with the introduction of clean water technologies. This possibility seems unlikely, and additional large and expensive infrastructure projects would have probably appeared in the municipal engineering periodicals that we searched for relevant intervention dates. Less than universal access to piped water suggests that we may have an underestimate of treatment effects.

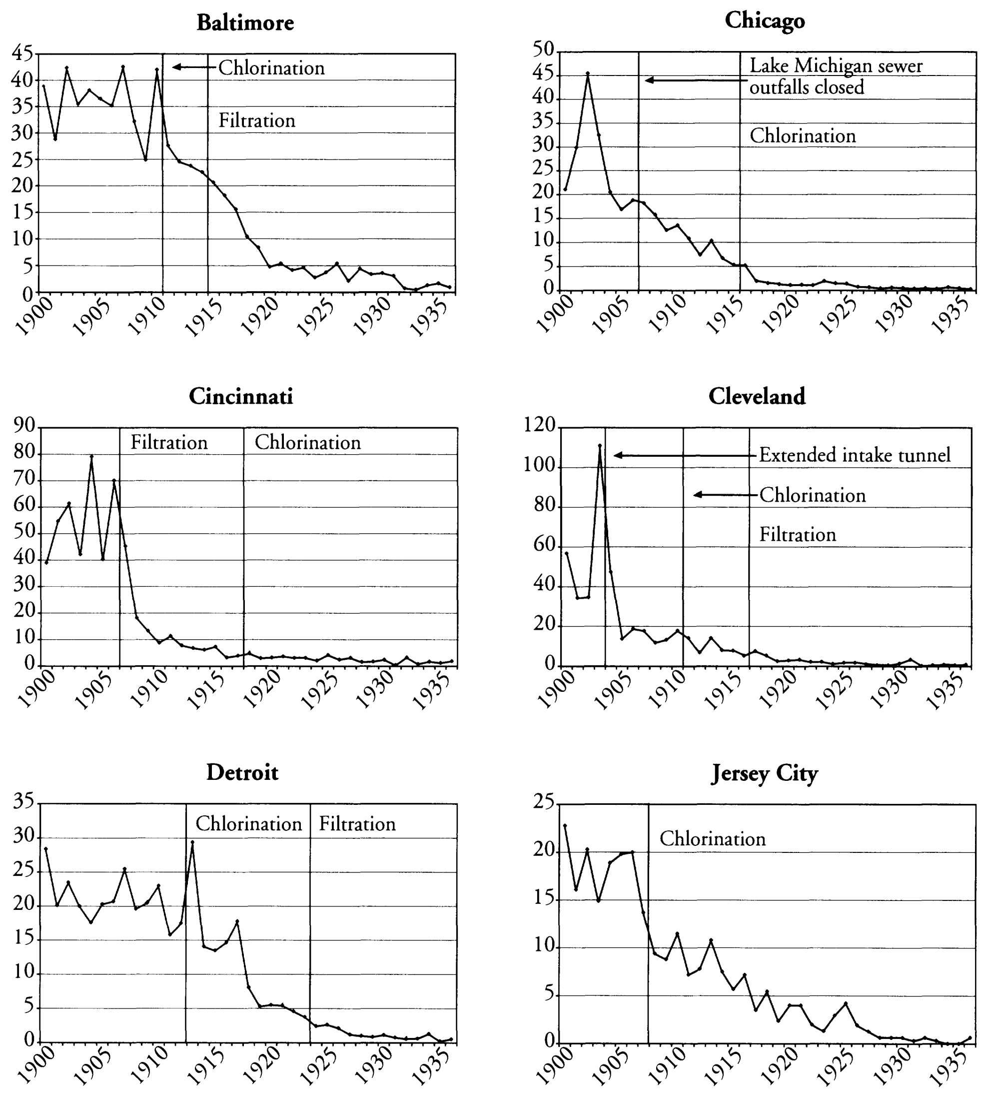
Despite suggestive evidence from historical texts to the contrary, a central concern with this approach is that cities may have begun filtering or chlorinating their water in response to specific events or factors, such as a severe disease environment. Along these lines, relatively high mortality rates just before the introduction of clean water technologies could cause our estimates to capture a process of mean reversion. Alternatively, relative reductions in mortality rates in the years just prior to the adoption of clean water technologies may suggest that our estimates are confounded by secular mortality declines. We addressed these concerns in several ways. First, the inclusion of lagged mortality accounts for differences in preintervention mortality trends, to which our results are not sensitive. In addition, we included leads of the intervention variables in some of our specifications. If the timing of these interventions is truly exogenous, mortality rates should not have been higher or lower just before their introduction. Our results generally hold up to this test.

RESULTS

We begin by illustrating our results with simple time trends. Figure 2 shows trends in mortality from typhoid fever in 12 cities in our sample, depicting the years in which clean water interventions were introduced. Despite considerable year-to-year volatility in typhoid mortality rates, the figure generally indicates that the adoption of clean water technologies was not preceded by increases in death rates. Particularly striking cases are Baltimore, Cincinnati, Philadelphia, and Pittsburgh. There appears, however, to have been a slight preintervention dip in typhoid fever mortality in some cities shortly before clean water technologies were adopted. We pay careful attention to distinguishing preintervention declines in mortality from true program effects in our subsequent analyses. It is also possible that preprogram drops capture program effects resulting from the phase-in of technologies that occurred over several years in some cities.

Table 5 presents the results of estimating Eq. (1). Each column corresponds to a separate regression, with the dependent variable at the head of the column. Because the dependent variable is in logarithmic form, the coefficient estimates can be interpreted roughly as percentage changes. The first row shows estimates of the effects of filtration on mortality. On average, filtration reduced typhoid fever mortality by 46%, total mortality by 16%, infant mortality (ages 0–1) by 43%, and child mortality (ages 1–4) by 46%. These are large effects. The second row shows estimates of the chlorination effects, suggesting that

Figure 2. Typhoid Fever Trends (Mortality per 100,000) and Sanitary Interventions, 1900–1936

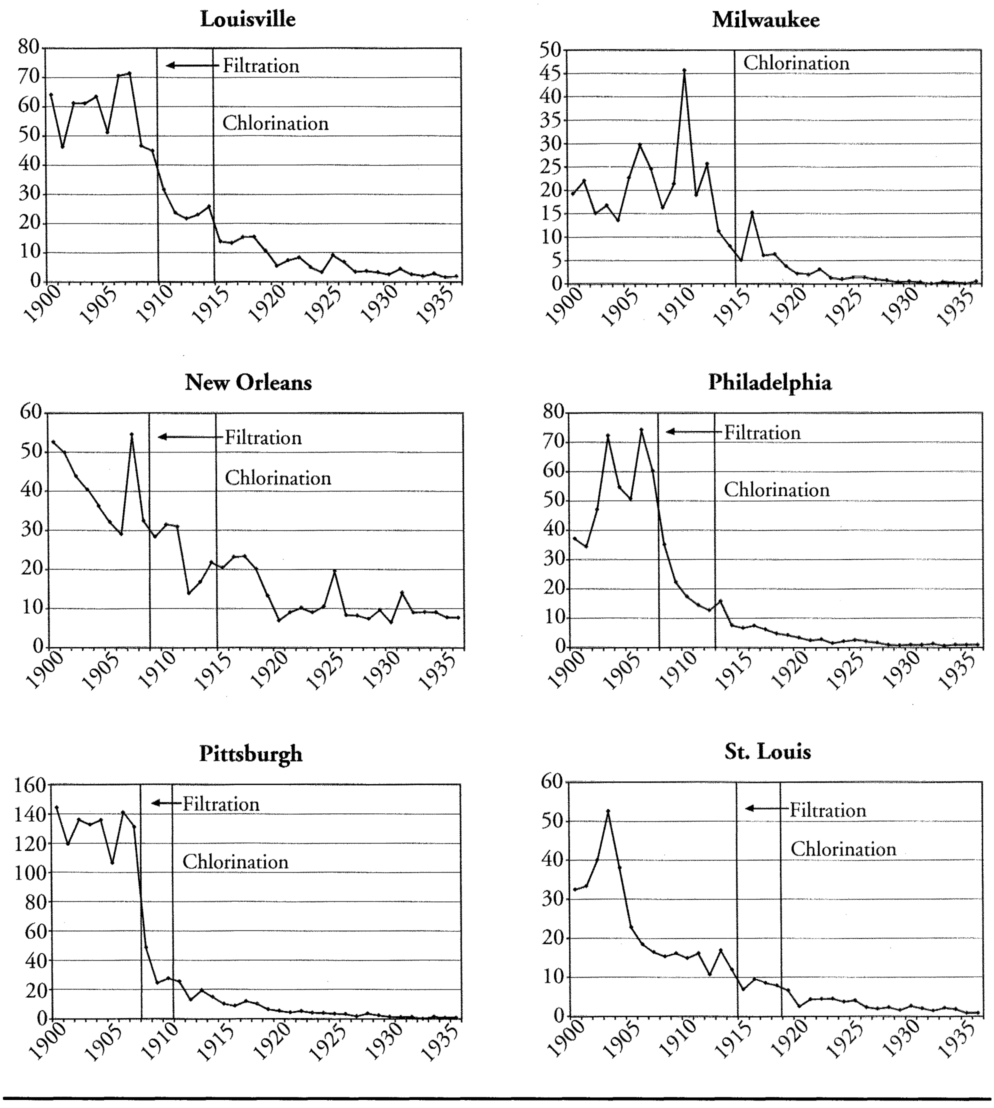


(continued)

chlorination alone had no detectable effect on mortality. The third row shows coefficient estimates for the interaction between filtration and chlorination. These coefficients are positive for typhoid fever mortality and total mortality, suggesting that filtration and chlorination were substitute technologies. We discuss the other coefficients later.

Taken together, the data in Table 5 also indicate that filtration and chlorination were jointly important in reducing mortality. Their combined effects are shown in the fifth row from the bottom, and the corresponding F statistic is shown immediately below. On average, filtration and chlorination together reduced typhoid fever mortality by 25%, total

(Figure 2, continued)



mortality by 13%, infant mortality by 46%, and child mortality by 50%. The finding that filtration was more effective than chlorination is, in some ways, an artifact of the period. Filtration technologies were developed before the health benefits of chlorination were discovered in the United States, so major cities generally adopted filtration before chlorination. As a result, we have little mortality variation with which to identify the chlorination effect if the two technologies are largely substitutable. Another possible explanation for the results is that because it is so cheap, chlorination diffused rapidly across cities after its first large-scale use, leaving less time variation with which to detect an effect.

Table 5. Effect of Clean Water Technologies on Mortality

	Dependent Variable (ln transformation)			
	Typhoid Mortality Rate	Total Mortality Rate	Infant Mortality Rate	Child Mortality Rate
Filter	−0.46*	−0.16**	−0.43**	−0.46**
	(0.23)	(0.04)	(0.09)	(0.11)
Chlorinate	−0.11	−0.02	−0.08	−0.07
	(0.16)	(0.03)	(0.08)	(0.10)
Chlorinate × Filter	0.32*	0.05*	0.06	0.03
	(0.14)	(0.02)	(0.07)	(0.09)
ln(Population)	−0.19	−0.86**	2.78**	1.69*
	(1.49)	(0.23)	(0.66)	(0.77)
Begin Chlorination Within Five Years	0.13	0.02	−0.05	0.00
	(0.10)	(0.01)	(0.06)	(0.07)
Begin Filtration Within Five Years	0.17	−0.09**	−0.18**	−0.14*
	(0.17)	(0.03)	(0.05)	(0.06)
ln(Mortality − 1)	0.02	0.01†	0.04†	−0.02
	(0.03)	(0.01)	(0.02)	(0.02)
ln(Mortality − 2)	0.05†	0.02**	−0.01	−0.02
	(0.03)	(0.01)	(0.02)	(0.02)
ln(Mortality − 3)	−0.17**	−0.01	−0.04*	−0.06**
	(0.03)	0.00	(0.02)	(0.02)
ln(Mortality − 4)	0.06	−0.01†	−0.08**	−0.04**
	(0.03)	0.00	(0.02)	(0.02)
ln(Mortality − 5)	0.02	−0.01†	−0.07**	−0.05**
	(0.03)	(0.01)	(0.02)	(0.02)
Joint Effect	−0.25†	−0.13**	−0.46**	−0.50**
(*F* Statistic)	(2.55)	(7.75)	(10.31)	(7.97)
Total Mortality Change, 1900–1936 (%)	−96	−30	−62	−81
Share of Total Due to Clean Water (%)	26[a]	43	74	62
N	411	415	415	415
R^2	0.94	0.96	0.83	0.88

Note: Huber-White corrected standard errors are in parentheses. All specifications include sewage treatment and chlorination dummy variables; year and city dummy variables; city trends; and demographic characteristics, including population share by gender, race, birthplace, and age.

[a]As shown in Table 8, clean water technologies explain almost all the decline in mortality from typhoid fever when the effects are allowed to vary over time.

†$p < .10$; *$p < .05$; **$p < .01$

The magnitude of these estimated effects is striking. In our sample of major cities, the reduction in mortality from 1900 to 1936 was about 30%. Our results suggest that clean water technologies reduced mortality by 13% during this period, accounting for about 43% (13/30) of the total reduction. Infant and child mortality fell by 62% and 81%, respectively, in these cities during this period. Clean water appears to have been responsible for 74% (46/62) of the reduction in infant mortality and 62% (50/81) of the reduction in child mortality. Similarly, clean water led to the near-eradication of typhoid fever.

The effect of clean water on total mortality is much larger than what can be attributed to typhoid fever alone. Declines in typhoid fever that were due to clean water technologies account for only about 2% of the total reduction in mortality during this period. Although total deaths from waterborne diseases were not reported consistently from 1900 to 1936, we suspect that they were roughly three times as large as deaths from typhoid fever.[12] As a result, reductions in all waterborne diseases account for about 8% of the reduction in total mortality. What of the remaining 35% that is attributable to clean water?

Table 6 presents regression results using the same specification with other causes of death as the dependent variable. Among the causes of death that were reported consistently from 1900 to 1936, the other diseases that responded to clean water were infectious diseases: pneumonia, tuberculosis, meningitis, and diphtheria/croup. As is shown in the last column of Table 6, reductions in pneumonia, meningitis, tuberculosis, and diphtheria/croup account for 9%, 5%, 6%, and 4%, respectively, of the total mortality reduction. Together with typhoid fever and an assumption about unobserved reductions in diarrhea and enteritis, we can identify specific causes of death for 32 percentage points of the 43% decline in total mortality that is attributable to clean water.

An important finding is that clean water technologies had no effect on deaths from noninfectious diseases—in this case, cancer and diabetes (the last two rows of Table 6).[13] In both cases, the coefficient estimates are substantially smaller than those for deaths from infectious diseases, and the estimates are not statistically significant.

Specification Test

One test of our identifying assumption is whether the coefficients on intervention lead dummy variables are different from zero. If we found positive coefficients on the lead dummy variables, we might worry that cities began purifying their water supplies in response to relatively high disease rates or that our estimates mistake a simple process of regression toward the mean for intervention effects. Negative coefficients may suggest that our estimates are confusing secular declines with the effects of clean water.

The coefficients on the five-year lead dummy variables for filtration and chlorination are also shown in Table 5.[14] The coefficient estimates on the intervention lead dummy variables are either insignificantly different from zero or negative. Figure 2 depicts why this is the case. In some of the cities, there is evidence of relative mortality reductions a few years before the interventions. Nevertheless, there is an enormous decline in mortality in the year of the intervention. Furthermore, we coded intervention years to be the years in which the majority of the city populations began benefiting, although in many cases interventions were introduced over a period of several years.

Table 7 shows this result more formally. We parameterized the interventions by particular years on either side of the true year of introduction. There was a large abrupt drop in mortality in precisely the year of the intervention (Time 0), even relative to one year prior to the true intervention (Time –1). Thus, we do not believe that the results are simply capturing preexisting trends.

Long-Run Effects and Behavioral Responses

A central issue is whether the effects of clean water technologies increase or decrease over time. Growing effects over time could be due to learning about how best to use disinfection technologies or to increases in complementary private health behaviors (like

12. Using data from 1900, we calculated that the ratio of deaths from diarrhea and enteritis to deaths from typhoid fever is slightly less than 3:1. Given some assumptions, this ratio can be used to approximate changes in deaths from diarrhea and enteritis from 1900 to 1936 despite the lack of consistent data.

13. These are the only two chronic diseases that were reported consistently from 1900 to 1936.

14. The qualitative results are not sensitive to the choice of length of time before the onset of filtration and chlorination.

Table 6. Other Cause-Specific Mortality Results

Dependent Variable (ln transformation)	Filter	Chlorinate	Filter × Chlorinate	N	R^2	Joint Share of Total Mortality Decline (%)[a]
Infectious Diseases						
Pneumonia	−0.25**	−0.19*	0.15*	415	0.90	9
	(0.08)	(0.08)	(0.06)			
Influenza	0.09	−0.15	−0.03	415	0.93	0
	(0.17)	(0.14)	(0.13)			
Malaria	−0.42	−0.35	0.64**	309[b]	0.95	0
	(0.29)	(0.25)	(0.22)			
Small pox	2.57	−1.13	1.74	95[b]	0.91	0
	(2.63)	(2.79)	(3.30)			
Measles	−0.63	−0.11	−0.10	396[b]	0.52	0
	(0.56)	(0.46)	(0.33)			
Scarlet fever	0.16	−0.24	−0.15	413	0.71	0
	(0.37)	(0.37)	(0.29)			
Whooping cough	−0.06	0.36	−0.42†	414	0.62	0
	(0.29)	(0.27)	(0.22)			
Diphtheria/croup	−0.64**	0.02	0.10	415	0.86	4
	(0.21)	(0.19)	(0.15)			
Meningitis	−0.72**	0.02	0.00	415	0.89	6
	(0.24)	(0.17)	(0.13)			
Tuberculosis	−0.09†	−0.08†	0.02	415	0.97	5
	(0.05)	(0.04)	(0.03)			
Chronic Diseases						
Cancer/Tumor	−0.03	−0.01	−0.02	415	0.98	0
	(0.04)	(0.04)	(0.03)			
Diabetes	−0.12	0.08	−0.06	415	0.90	0
	(0.09)	(0.08)	(0.07)			

Note: Huber-White corrected standard errors are in parentheses. All specifications include five-year intervention leads; sewage treatment and chlorination dummy variables; year and city dummy variables; city trends; and demographic characteristics, including population share by gender, race, birthplace, and age.

[a]As determined by the joint effect of filtration and chlorination and associated F statistics.

[b]Small samples are due to the exclusion of observations with values of zero; regressions using mortality and ln(mortality) as the dependent variable yield similar results.

†$p < .10$; *$p < .05$; **$p < .01$

hand washing, boiling milk, and appropriate food storage) as the expected return to health investments rises (Dow et al. 1999; Murphy and Topel 2003). Alternatively, the effects may diminish over time if major public health interventions "crowd out" costly private preventive measures (Philipson 2000) or if those who were initially saved by interventions were relatively weak and died in greater proportions in subsequent years.

To investigate these competing explanations, we reestimated variants of Eq. (1) including intervention dummy variables that trace out intervention effects five years and nine years after filtration and chlorination were introduced.[15] Table 8 shows that the effects of clean water grew over time. A striking finding is that clean water technologies

15. The estimates presented here are not sensitive to specific lag structure choices.

Table 7. Timing of Intervention Effects

True Intervention: Time 0	Dependent Variable (ln transformation)			
	Total Mortality Rate		Typhoid Mortality Rate	
	Filter	Chlorinate	Filter	Chlorinate
–4	–0.05† (0.03)	0.01 (0.02)	0.37** (0.14)	0.07 (0.10)
–3	–0.07* (0.03)	0.01 (0.01)	0.20 (0.14)	0.07 (0.10)
–2	–0.06* (0.03)	0.01 (0.01)	0.08 (0.11)	–0.06 (0.09)
–1	–0.05* (0.03)	0.01 (0.02)	–0.16 (0.12)	0.14 (0.12)
0	–0.17** (0.04)	–0.02 (0.03)	–0.59** (0.22)	–0.11 (0.16)
+1	–0.15** (0.04)	–0.01 (0.03)	–0.58** (0.21)	–0.15 (0.14)
+2	–0.13** (0.04)	–0.01 (0.02)	–0.45* (0.21)	–0.05 (0.15)
+3	–0.13** (0.04)	0.01 (0.02)	–0.34 (0.21)	–0.09 (0.15)
+4	–0.12** (0.04)	0.01 (0.03)	–0.16 (0.23)	–0.04 (0.15)

Note: Huber-White corrected standard errors are in parentheses. All specifications include five-year intervention leads; five-year intervention lags; sewage treatment and chlorination dummy variables; year and city dummy variables; city trends; and demographic characteristics, including population share by gender, race, birthplace, and age.

†$p < .10$; *$p < .05$; **$p < .01$

appear to have reduced typhoid fever by 26% initially and by another 65% after five years, leading to its near-eradication by 1936. Larger reductions across diseases over time are consistent with delayed intervention effects, learning over time, and a personal health practice multiplier—but not with a crowd-out or a weak marginal survivor explanation. Although not conclusive, these results hint that public health interventions and private health practices may be complements rather than substitutes.

Distributional Effects of Clean Water

The benefits of clean water could differ across the socioeconomic spectrum for a variety of reasons. Because the poor are sicker than the rich, on average, they may have enjoyed greater health improvements from clean water. Alternatively, if the poor were less likely to have household connections to municipal water supplies, they might have benefited less from water filtration and chlorination.

Examining the distributional consequences of clean water empirically is difficult for several reasons. One is that good indicators of who was poor in historical census data are scarce. Income, assets, and consumption are difficult to infer, and other measures that are often used to identify the poor (such as occupation) are not comparable across decades because of the rapid rate of technological change. Furthermore, the best measures of socioeconomic status are only in decennial census data and are therefore not observed as

Table 8. Mortality Results Over Time

	Dependent Variable (ln transformation)			
	Typhoid Mortality Rate		Total Mortality Rate	
Filter	−0.61**	−0.64	−0.14**	−0.12**
	(0.23)	(0.21)	(0.03)	(0.04)
Filter +5	−0.48**	−0.50	−0.04*	−0.03
	(0.12)	(0.13)	(0.02)	(0.02)
Filter +9		−0.25		0.03
		(0.11)		(0.02)
Chlorinate	−0.11	−0.16	−0.02	−0.02
	(0.16)	(0.16)	(0.03)	(0.03)
Chlorinate +5	−0.25*	−0.28	−0.05†	−0.05†
	(0.12)	(0.14)	(0.03)	(0.03)
Chlorinate +9		−0.24		0.01
		(0.12)		(0.02)
Chlorinate × Filter	0.47**	0.49	0.07**	0.07**
	(0.14)	(0.14)	(0.02)	(0.02)
Chlorinate × Filter +5	0.08	0.15	0.08**	0.06*
	(0.13)	(0.15)	(0.03)	(0.03)
Chlorinate × Filter +9		0.30		0.01
		(0.13)		(0.02)
Joint Effect	−0.26**	−0.31**	−0.09**	−0.08**
(*F* statistic)	(5.16)	(5.90)	(6.65)	(5.17)
Joint Effect +5	−0.65**	−0.63**	−0.01*	−0.02
(*F* statistic)	(6.95)	(6.32)	(3.09)	(1.99)
Joint Effect +9		−0.19†		0.04
(*F* statistic)		(2.50)		(1.25)
N	411	411	415	415
R^2	0.95	0.95	0.96	0.96

Note: Huber-White corrected standard errors are in parentheses. All specifications include sewage treatment and chlorination dummy variables; year and city dummy variables; city trends; and demographic characteristics, including population share by gender, race, birthplace, and age.

†$p < .10$; *$p < .05$; **$p < .01$

frequently as annual mortality. We settled for using a measure of illiteracy that was included in the decennial censuses at the municipal level through 1930.[16] We examine the effect of clean water technologies in cities whose residents had various degrees of literacy.

Table 9 shows the results of our base specification with the addition of illiteracy and interaction terms between clean water interventions and illiteracy. Joint effects of filtration and chlorination are shown at the bottom, together with corresponding F statistics. In general, the results are consistent with a steep illiteracy gradient in the impact of clean water on mortality, with larger reductions in mortality for cities with more illiterate residents. This finding is consistent with a greater impact of clean water on the poor, but endogeneity cannot be ruled out in interpreting these results. Mortality changes may lead

16. More desirable measures, such as years of schooling, were not included in the decennial censuses until late in the period we investigated. In addition, we interpolated illiteracy between decennial census years.

Table 9. Distributional Effects of Clean Water

	Dependent Variable (ln transformation)			
	Typhoid Mortality Rate	Total Mortality Rate	Infant Mortality Rate	Child Mortality Rate
% Illiterate	–18.24	1.16	35.85**	28.97**
	(12.41)	(2.13)	(7.00)	(8.96)
Filter	–0.03	–0.18*	–0.16	–0.37
	(0.43)	(0.08)	(0.22)	(0.28)
Filter × % Illiterate	–11.03	0.14	–4.84	–1.49
	(8.24)	(1.22)	(5.36)	(5.53)
Chlorinate	1.13	–0.15	–0.36	–0.27
	(0.92)	(0.13)	(0.38)	(0.47)
Chlorinate × % Illiterate	–29.52	3.14	6.51	4.00
	(19.79)	(2.93)	(8.05)	(10.34)
Chlorinate × Filter	–0.07	0.32*	0.51	0.38
	(0.90)	(0.14)	(0.37)	(0.47)
Chlorinate × Filter × % Illiterate	7.08	–6.67*	–10.37	–8.49
	(19.46)	(3.00)	(8.15)	(10.27)
Joint Effect	1.03**	–0.01†	–0.01	–0.26
(*F* statistic)	(4.51)	(2.30)	(0.88)	(0.65)
Joint Effect × % Illiterate	–33.47**	–3.39**	–8.70*	–5.98
(*F* statistic)	(–4.01)	(–4.20)	(–2.81)	(–0.74)
N	337	337	337	337
R^2	0.95	0.96	0.80	0.81

Note: Huber-White corrected standard errors and *F* statistics are in parentheses. All specifications include sewage treatment and chlorination dummy variables; year and city dummy variables; city trends; and demographic characteristics, including population share by gender, race, birthplace, and age.

†$p < .10$; *$p < .05$; **$p < .01$

to changes in literacy, with greater mortality declines leading to more literacy. Because we found the opposite, we suspect that reverse causation is not a problem in our analysis. We cannot distinguish between the possibility that the poor and illiterate benefited more from clean water and the possibility that those in cities with more poor and illiterate persons benefited more.

SOCIAL RATE OF RETURN TO CLEAN WATER

Our estimates suggest that the benefits of clean water are large. Benefits alone do not justify interventions, however. Costs are important, too.

It is not easy to pinpoint the costs of filtration using historical municipal finance statistics.[17] To be conservative, we used the estimated value of entire municipal water systems, making the assumption that these systems exist only to reduce mortality. We then needed to determine how long a water system lasts. We conservatively chose a horizon of 10 years, assuming that cities must rebuild their entire systems every 10 years. Because cities introduced clean water technologies in about 1915, we used 1915

17. Because our estimates suggest that chlorination alone did not significantly reduce mortality (possibly because it was typically adopted shortly after filtration), we did not estimate a rate of return to water chlorination by itself.

Table 10. Social Rates of Return

	Point Estimate	95% CI Low	95% CI High
% Mortality Reduction Due to Clean Water	0.1326	0.0373	0.2280
1915 Mortality Reduction per 100,000 Population	208	58	357
1915 Deaths Averted	1,484	418	2,551
1915 Person-Years Saved	57,922	16,301	99,543
1915 Annual Benefits in Millions of 2003 Dollars	679	191	1,167
1915 Annual Costs in Millions of 2003 Dollars	29		
Social Rate of Return	23:1	7:1	40:1
Cost per Person-Year Saved in 2003 Dollars	500	1,775	291

values of water systems in our calculations. In 2003 dollars, the available information suggests that the value of a mean big-city water system in 1915 was just under $300 million (U.S. Census Bureau 1916).

Using this rough cost figure, together with our estimates of the mortality benefits of clean water, we calculated some rough rates of return to investment in clean water (see Table 10).[18] We first converted mortality reductions into person-years saved and then valued these person-years saved in dollars. This dollar value of the benefits of clean water can then be compared with the costs incurred in producing them to yield a rough rate of return. The first row of Table 10 shows our regression results indicating that clean water reduced mortality by an average of about 13% (with a 95% confidence interval ranging from about 4% to about 23%). Using the mean population of our sample cities in 1915 (the average year by which clean water technology had been adopted), the third row shows estimates of the mean number of lives saved by clean water per city each year; our point estimate is 1,484 lives. We converted lives saved annually into person-years saved by assuming that individuals who were saved by clean water would otherwise have died at age 27 (roughly half the life expectancy in 1915).[19] This assumption seems reasonable, given that infectious diseases usually hit the very young and very old. Life expectancy at age 27 in 1915 was about 39 years, so we obtained average annual person-years saved by multiplying the number of people saved by that 39 years. These estimates are shown in the fourth row of Table 10; we calculated that, on average, clean water saved 57,922 person-years per city each year.

The next task was to calculate a dollar value of benefits by attaching a dollar value to a person-year. Contemporary research on the value of life suggests that a reasonable dollar value of a person-year today is about $100,000 on average (Viscusi and Aldy 2003). However, there is evidence that the value of life in the United States has changed over time as income has grown (Costa and Kahn 2002). The elasticity of the value of life with respect to the per capita gross national product has been estimated as between 1.5 and 1.7 (Costa and Kahn 2002). In 2003 dollars, the per capita gross domestic product (GDP) grew from $7,496 in 1930 to $37,600 in 2003, a real increase of about 500%.[20]

18. We made a number of simplifying assumptions that are conservative whenever possible.

19. Life tables can be found at http://www.demog.berkeley.edu/wilmoth/mortality/states.html, reprinted from life tables prepared by the Office of the Chief Actuary in the Social Security Administration.

20. Reliable GDP figures are not available much earlier than 1930. This figure may reasonably represent the period of interest because although taken from late in the period, GDP was of course low during the Great Depression. Numbers based on data from the Consumer Price Index were obtained from ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt; GDP data were obtained from http://www.census.gov/prod/99pubs/99statab/sec31.pdf and the authors' calculations.

The implied value of a person-year in 1930 (in 2003 dollars) ranged from $11,723 to $13,280. We used the more conservative figure and assumed that the value of life does not vary with age.

The total annual benefits are therefore a little less than $700 million per city—substantially greater than the $30 million amortized cost. As the second-to-last row of Table 10 shows, the rate-of-return estimate is 23 to 1, with a 95% confidence interval ranging from 7 to 40. Similarly, we obtained a point estimate for the cost per person-year saved in 2003 dollars of $500 and a confidence interval ranging from $1,775 to $291. Even these estimates, large as they are, exclude benefits such as morbidity reductions and productivity gains. Nevertheless, they are tremendous.

CONCLUSION

Our results demonstrate the strikingly large and cost-beneficial role of clean water technologies in reducing mortality in the historical United States. The period examined was the era of the most-rapid documented decline in mortality in American history, and clean water appears to have played as large a role as any force responsible for this rapid progress.

Although the historical United States surely differs from contemporary contexts in other countries in important ways, clean water and adequate sanitation continue to be high on development agendas today.[21] Worldwide, roughly 1.1 billion people lack access to clean water, and about 2.4 billion people do not have adequate sanitation. Cutting the share of people without suitable water and sanitation in half by 2015 is one of the ambitious objectives set by the Millennium Development Goals. The United Nations has declared the years 2005–2015 as the International Decade for Action on Water: "Water for Life." The first international water decade, the 1980s, brought clean water to 1 billion new people and delivered new sanitation services to 770 million people worldwide. However, population growth and rapid urbanization have eroded these gains.

Much of the contemporary investment made in clean water has financed the construction of new water-supply infrastructure. A reason that has been commonly cited for the partial failure of these investments to achieve commensurate health returns is the relative neglect of sanitation. Although certainly not a substitute for an appropriate investment in sanitation, our results from the historical United States suggest that inexpensive water-disinfection technologies can have enormous health returns—returns that reach beyond reductions in waterborne diseases—even in the absence of adequate sanitation services. In 2000, more than one fifth of the samples of drinking water that were taken from existing water systems failed to meet national quality standards for microbiological content and other pollutants (World Health Organization and United Nations Children's Fund 2000).[22] If the Mills-Reincke multiplier found in the historical United States[23] holds and only 1% of the roughly 1.7 million annual deaths from diarrheal diseases worldwide could be prevented by water disinfection, the corresponding social rate of return for one year alone would be about $160 billion.[24]

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21. Information in this paragraph can be found at the Water and Sanitation Program homepage (http://www.wsp.org).

22. The true number is presumably much larger, given that countries voluntarily reported these statistics. Ironically, developing countries also self-reported that more than 90% of their existing water supplies are adequately disinfected (World Health Organization and United Nations Children's Fund 2000).

23. Our conservative estimate of the Mills-Reincke multiplier in the historical United States is about 3.

24. In 2002, there were an estimated 1,767,326 deaths from diarrheal diseases worldwide (WHO 2003). An approximate social rate of return is calculated by taking 1% of these deaths, multiplying by 3 (the Mills-Reincke multiplier), assuming 30 person-years lost per death, and valuing a person-year at $100,000.

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