Segregation and the Initial Provision of Water in the United States[*]

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Abstract

This paper asks how city demographics and segregation affected the provision of water in 19th century America. We develop a theoretical model to illustrate how the level of segregation and the share of minorities in the city may have affected the extensiveness of water systems. Data from over 1700 cities and towns show that waterworks were built earlier in large, segregated cities and in cities with fewer minorities. These results are consistent with city officials excluding blacks in segregated cities from water provision. Analysis of health outcomes further supports this interpretation. Black and white infant deaths fall when a waterworks is built in an integrated city but the extent of the decline diminishes as the degree of segregation increases. In the most segregated cities the benefits are zero for both whites and blacks, suggesting that by excluding blacks from access to water these cities were unable to eliminate infectious waterborne diseases like typhoid fever and cholera.

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1 Introduction

At the dawn of the 20th century, mortality rates in the United States were much higher in cities than in rural areas. This 'urban mortality penalty' was a common feature among industrial nations during this period (Cain & Hong, 2009; Kesztenbaum & Rosenthal, 2011). As to the causes of this penalty, the literature has settled on three factors: infectious diseases, particularly those associated with unclean water and improper sewage disposal, poor nutrition, and large amounts of air pollution from the burning of coal.[1] Although the precise contribution of each channel remains an open question, the existing literature suggests that investments in water and sewerage played an important role in reducing the urban mortality penalty in the United States and elsewhere. As Cutler & Miller (2005) document, mortality rates fell by about 40 percent between 1900 and 1940 and roughly half of that decline can be explained by the introduction of clean water technologies.

While the results are impressive, this public health movement would not have been possible without earlier infrastructure investment. As Figure 1 illustrates, U.S. cities built waterworks at a tremendous rate during the 1890s: by 1897 there were 3,167 waterworks in the United States with 83% built after 1880 and 46% built between 1890 and 1896.[2] These investments, which occurred before effective water treatment technologies existed, laid the necessary foundation for the elimination of infectious waterborne diseases by connecting households to a centralized water supply. Without these connections, future investments in water filtration would have been much less effective at combatting waterborne disease, as residents with access to clean water would remain at risk through their contact with residents without access.[3]

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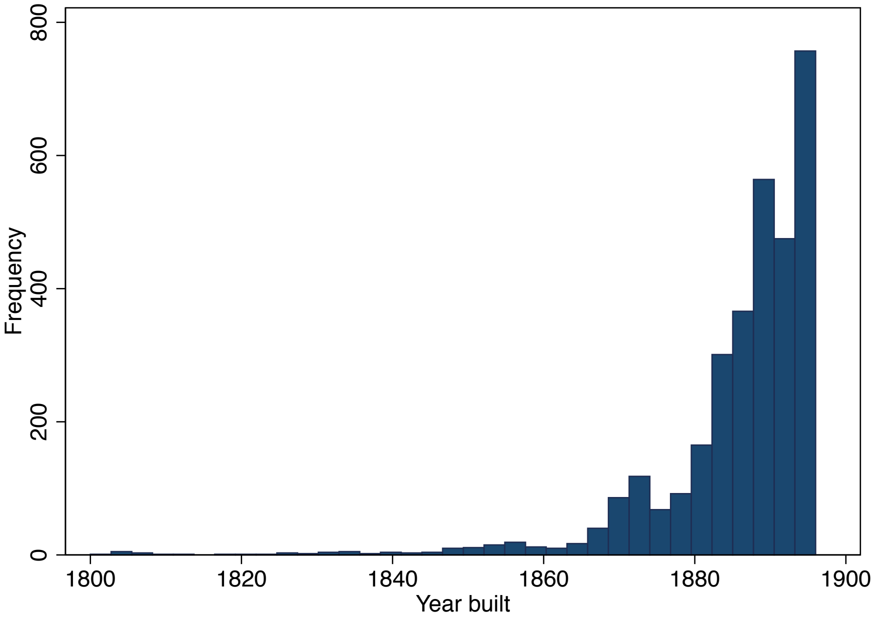
[1] On the role of waterborne diseases see (Cutler & Miller, 2005; Ferrie & Troesken, 2008; Alsan & Goldin, Forthcoming; Antman, 2015). For more on poor nutrition see (McKeown, 1976; Fogel, 2004; Fogel & Costa, 1997). For air pollution see (Beach & Hanlon, Forthcoming; Clay *et al.*, 2015).

[2] This statistic based on data from Baker (1897), the most comprehensive source on U.S. waterworks. Section 3.1 describes this source in more detail.

[3] The waterborne disease Typhoid Fever, for instance, is typically spread through the consumption of water that is tainted from the fecal waste of infected individuals. However, infection from other

Figure 1: Distribution of waterworks construction dates



Data from Baker (1897). Sample includes 3,167 waterworks built between 1800 and 1897.

Given how closely these two movements are linked, it is surprising how little we know about this initial wave of investment. Why American cities decided to build when they did and what determines the extensiveness of the system that they built are both open questions. These questions are also of central importance for understanding the broader success of the movement to filter water and treat sewage. In light of this, we ask whether the ability to exclude lower status groups played a role in shaping investment decisions. Specifically, we examine the extent to which segregation of black households influenced the timing of investment and, conditional on building a waterworks, the overall extensiveness of the system.

Our motivation for considering the role of segregation stems is twofold. First, the initial capital outlays for these waterworks were quite large: in 1890, the median waterworks cost over $700,000 in 1890 dollars, comparable in cost to a $700,000,000 project for a modern city.[4] Since these projects were financed at the local level, investment likely depended on the political will of local residents. This brings us to our second motivation. Since these investments were made before effective water filtration and sewage treatment existed, taxpayers had little incentive to attempt to internalize the future social returns that would be generated from universal access.[5]

We develop a theoretical model to illustrate how segregation might influence water provision. We then draw on full count census data from 1880 to quantify the degree

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forms of contact is also possible. The most well known example of this type of transmission is probably "Typhoid Mary", an asymptomatic carrier of typhoid who is presumed to have infected over 50 people with typhoid fever during her career as a cook.

[4] Median waterworks cost is available from Baker (1897), although the figure we quote is based on the incorporated cities that we use for our analysis. The modern project cost equivalent is based on the economy cost of the project, the relative share of the project as a percent of total economy output, using the calculator at Measuring Worth.

[5] Cutler & Miller (2005) estimate the social rate of return on clean water technologies was greater than 23 to 1. This return only considers life expectancy gains, however, Beach *et al.* (2016) show that early-life exposure to waterborne disease impaired human capital development, affecting earnings and educational attainment. By helping eliminate this exposure, the authors estimate that the gains to future income alone were enough to offset the costs of investment. Specifically, they estimate an additional rate of return (relative to the cost of the building a waterworks) ranging from a low of 4 to 1 to a high of 10 to 1.

of segregation in all incorporated cities.[6] We pair this information with data that we digitize from Baker (1897) – a comprehensive source on the history of American waterworks. These two sources allow us to test the predictions of our model. Consistent with these predictions, we find that segregated cities were quicker to build a waterworks.

While the model and year built results are consistent with an exclusion story, we draw additional support for this interpretation from our analysis of health data. If segregated cities are excluding black households, then this should undermine the city's ability to combat infectious disease. Because comprehensive city-level mortality statistics were not collected during this period, we use information from the 1900 census to generate a proxy for infant mortality.[7] In that census all women were asked the number of children they have given birth to as well as how many of those children were still alive. We use this information to generate an indicator for whether a mother has ever lost a child, which we interpret as a proxy for infant mortality.[8] We then adopt a difference-in-differences empirical specification that exploits variation across cities in the timing of construction as well as variation in the number of fertile years that women within the same city spent exposed to that waterworks.

Results from this specification indicate that waterworks built in integrated cities generated large decreases in infant mortality that did not vary by race. This is consistent with the idea that black households in integrated cities benefited from being located next to white households because, conditional on supplying the white

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[6] Our measure of segregation follows (Logan & Parman, 2017) but is ultimately calculated at the city level rather than the county level. This measure is discussed in more detail in Section 3.2.

[7] In contrast to England, which standardized and mandated the reporting of deaths in 1846, the United States left this decision to state and local governments. Several large cities and states passed mandatory reporting laws by 1900, and in that year the Census Bureau worked with those registration areas to establish uniform reporting standards. The result of this was the adoption of a standardized death certificate and the international classification standard, as well as the distribution of "The Manual of International Classification of Causes of Death", which cross referenced terms appearing in causes of death from 1890 and 1900 reports with the new uniform classification standard.

[8] The dramatic gains in life expectancy that occurred from 1880 to 1950 were largely the result of decreasing mortality for those under the age of five, see Preston & Haines (1991). Life expectancy conditional on surviving to age 20 did not change much during this period.

household with water, the marginal cost of supplying a black household with water was very low. The health benefits of water investment, however, decline dramatically as the level of segregation in the city increases. This is true for both white and black households, which is consistent with the idea that by excluding black households from the initial construction of waterworks, these cities were not able to effectively eliminate waterborne diseases.

These results are largely complementary to previous work by Troesken (2002), on which we extend in several ways. In that paper, Troesken posits that controlling waterborne disease requires comprehensive access, which is more likely in an integrated city rather than a segregated city. Troesken's analysis, however, largely centers on assessing the efficacy of the adoption of clean water technologies. Our paper, however, is much more concerned with assessing the robustness of the link between segregation and the extensiveness of a city's waterworks. To this end, we formalize Troesken's intuition in order to generate a set of empirical predictions, which we subsequently test empirically. A second point of differentiation is that, as a result of recently digitized data, we are able to extend the scope of historical research on waterworks to far more cities than previously possible. The recent release of the complete count federal census data allows us to construct historical segregation estimates for every city in the United States (Logan & Parman, 2017). Troesken, in contrast, was forced to rely on a sample of 33 large cities because of the availability of both segregation and mortality data. Our sample of over 1700 cities captures a much broader range of city sizes, population compositions, and political environments.

2 Modeling the influence of segregation on local water provision

Consider a city with two types of residents. For ease of exposition, we will define the two groups as white and black residents; however, we could consider any minority group that potentially faces discrimination in the provision of public goods. The city lies on a unit interval with $x = 0$ being the whitest part of town and $x = 1$ being the blackest. Without loss of generality, assume the city is one mile long. Each point along the line is a neighborhood. The degree of segregation and the group sizes are characterized by an increasing function $g()$, which indicates the proportion of the neighborhood that is black. For example, if the city is perfectly segregated and each group makes up one half of the city, then:

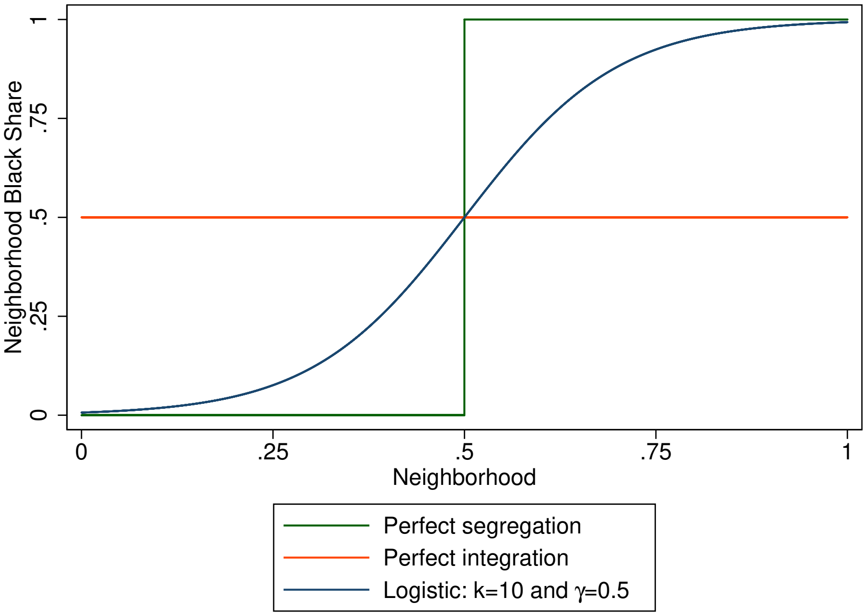
$$g(x) = \begin{cases} 0 & \text{if } x \leq \frac{1}{2}; \\ 1 & \text{if } x > \frac{1}{2}. \end{cases}$$

On the other hand, perfect integration for a city with equal group sizes implies that $g(x) = \frac{1}{2}$. More typically, we would expect $g()$ to be an increasing S-shaped function. Figure 1 graphically depicts $g()$ for our hypothetical city under perfect segregation, perfect integration, and something in between.

Now suppose that city politicians face the budget constraint $B = z + c * m + FC$, where B is the city's budget, z is non-water related public goods with a price normalized to 1, m are miles of water mains, c is the per mile cost of water mains, and FC represents any fixed costs associated with supplying water. If the city does not build any mains, then the constraint is $B = z$.

City officials value non-water related public goods, white residents with access to clean water, and black residents with access to clean water. City officials will place lower value on black resident access to water, which may reflect taste-based

Figure 2: Examples of $g(.)$



Notes: Each line corresponds to the distribution of neighborhoods for a hypothetical city with a total black share of 50%. Neighborhoods are organized based on their black share with 0 being the neighborhood with the smallest black share and 1 being the neighborhood with the largest black share. All neighborhoods are assumed to be of the same size.

or statistical discrimination (e.g., the fact that black residents are more likely to be disenfranchised and thus less likely to help keep city officials in office). Thus, if the city builds a main, it will start at $x = 0$ (the whitest part of town), and keep building the main, possibly stopping before supplying water to the whole city. If a main is built to a particular neighborhood x, then both black and white residents of that neighborhood have access to the main. Now let N_W be the white population that is connected to a water main, N_B be the black population connected to a water main, and $m \in [0, 1]$ be where the city stops building the main. The variable m is the miles of mains and a measure of the water system's size. Then

$$\begin{aligned} N_W &= \int_0^m (1 - g(x))dx \qquad (1) \\ N_B &= \int_0^m g(x)dx \qquad (2) \end{aligned}$$

Now suppose the city's utility function is:

$$U(N_W, N_B, Z) = \alpha N_W + (1 - \alpha)N_B + \beta z \qquad (3)$$

where $\alpha \in (\frac{1}{2}, 1)$. The utility function in (N_w, N_b, z)-space is linear, but since g is nonlinear, the utility function in (z, m)-space is non-linear.

For an interior solution, we need the ratio of marginal utilities of m and z to be equal to the ratio of the costs of m and z. Since $\frac{1-\alpha}{\beta} \leq \frac{MU_m}{MU_z} \leq \frac{\alpha}{\beta}$, an interior solution will require that the per-mile cost $c \in \left(\frac{1-\alpha}{\beta}, \frac{\alpha}{\beta}\right)$. If $c \leq \frac{1-\alpha}{\beta}$, then the city will provide water to all residents. If $c \geq \frac{\alpha}{\beta}$, then the city will not provide water to any residents. For an interior solution, taking the first-order conditions indicates that:

$$m^* = g^{-1}\left(\frac{\alpha - \beta c}{2\alpha - 1}\right) \qquad (4)$$

Since g is an increasing function, it follows that g^{-1} is an increasing function.

Let $\lambda = \frac{\alpha - \beta c}{2\alpha - 1}$. Then $\frac{\partial \lambda}{\partial c} = \frac{-\beta}{2\alpha - 1} < 0$. Thus, an increase in the cost of a water main decreases optimal main mileage. Similarly, an increase in the preferences for non-water public goods decreases optimal main mileage. As for the preferences for whites, $\frac{\partial \lambda}{\partial \alpha} = \frac{2\beta c - 1}{(1-2\alpha)^2}$, which is theoretically ambiguous.

Next, let's characterize the function g to analyze the effects of segregation and group size. Let

$$g(x) = \frac{1}{1 + e^{-k(x-\gamma)}} \tag{5}$$

This is an S-shaped curve in which k measures the degree of segregation. As k goes to infinity, the city becomes perfectly segregated, while $k = 0$ implies perfect integration. The parameter γ (the centering parameter) is the proportion of the city that is white. Then,

$$g^{-1}(x) = \gamma - \frac{1}{k} \ln\left(\frac{1}{x} - 1\right). \tag{6}$$

This implies that m^* increases as white share increases. The effect of segregation on water provision is ambiguous. If $\beta c > \frac{1}{2}$, then segregation increases optimal main mileage. If $\beta c < \frac{1}{2}$, then segregation decreases optimal main mileage.

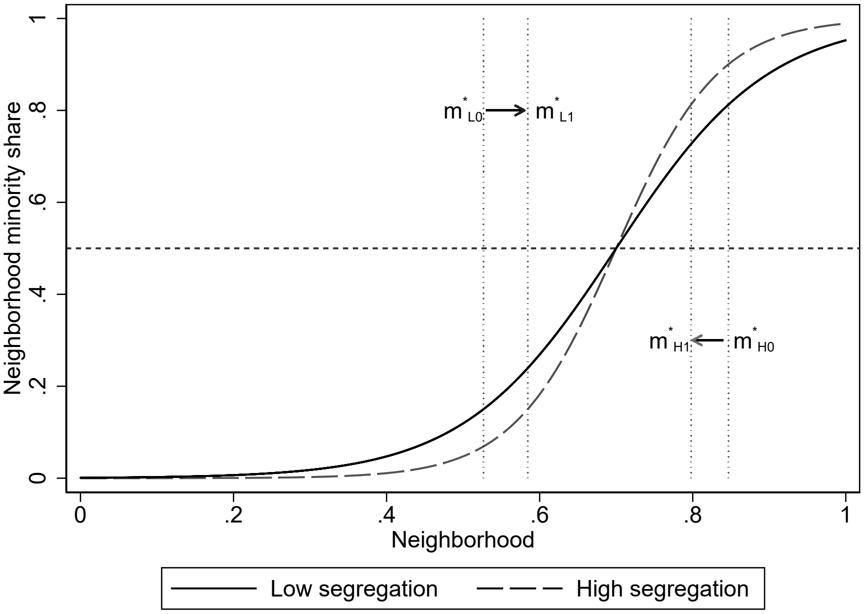
Proposition 2.1 *If the optimal main stops in a neighborhood that is less than one half black, then a marginal increase in either segregation or the preference for whites increases the size of the optimal water system. If the optimal main stops in a neighborhood that is greater than one half black, then a marginal increase in either segregation or the preference for whites decreases the size of the optimal water system.*

Proof A marginal increase in the preference for whites or a marginal increase in segregation increases the size of the water system if and only if $\beta c > \frac{1}{2}$. This implies that

$$\frac{\alpha - \beta c}{2\alpha - 1} < \frac{\alpha - \frac{1}{2}}{2\alpha - 1} < \frac{1}{2}. \tag{7}$$

Since g^{-1} is an increasing function, this implies that $g^{-1}\left(\frac{\alpha-\beta c}{2\alpha-1}\right) < g^{-1}\left(\frac{1}{2}\right)$. Applying g to both sides of this inequality yields the result.

Figure 3: Comparative statics of how changes in segregation influence main provision



Notes: The white share for this hypothetical city is set to 0.7. In both segregation scenarios, $g()$ is modeled as a logistic function. For the low segregation scenario we set k to 10 and in the high segregation scenario we set k to 15. The optimal mains to the left of 0.7 are calculated assuming $\beta = 0.8; c = 0.8$; and $\alpha = 0.7$. The optimal mains to the right of 0.7 are calculated assuming $\beta = 0.5; c = 0.5$; and $\alpha = 0.9$

Intuitively, more segregation decreases the marginal benefit from continuing construction only if the city is already building in a minority neighborhood. If the city has not yet completed construction in the majority neighborhood, more segregation implies there is a higher utility gain to the marginal water main mile. This result is displayed visually in Figure 3, which shows the effects of an increase in segregation on m^*. The vertical line m^*_{L0} shows an optimal main that stops in a majority white neighborhood. After the increase in segregation, the optimal main increases in length to m^*_{L1}. The vertical line m^*_{H0} shows an optimal main for the original level of segregation, but because of different values of α, β, and c, the optimal main stops in a majority black neighborhood. After the increase in segregation, the optimal main decreases to m^*_{H1}.

Thus far we have considered a model where city officials place lower weight on black access to water. This is reflected in the preference parameter α, which can be thought of as capturing local officials' need to cater to likely voters, desire to focus provision of public goods on those most able to finance those goods, or discriminatory preferences for a particular group. Since roughly half of local waterworks were privately owned during this period, a natural question is whether private provision affects the predictions of our model. As private firms should be motivated by profits, one would expect that private firms would not face the same pressure to discriminate. In practice, however, private firms would still likely treat potential white and black customers differently. In particular, if white residents have higher ability or willingness to pay for water service on average, the firm's profit function will effectively place greater weight on neighborhoods with more white residents as those neighborhoods would contain more paying customers and could thus be served with far lower average costs per customer. Accordingly, private provision does not affect the comparative statics of our model. These results are available in Appendix A.

3 Taking the model to the data

Our model of water provision leaves us with several testable predictions. First, the size of the optimal water system increases with the size of the majority group. Second, in a city in which the last water main stops in a neighborhood less than one half minority, an increase in segregation should lead to an increase in the size of the optimal water system. Third, in a city in which the last water main stops in a neighborhood more than one half minority, an increase in segregation should lead to a decrease in the size of the optimal water system.

The ideal dataset to examine these predictions would include: city-level variation in black share, city-level variation in the segregation of the black population, and high quality data that allows us to identify access to water and racial composition at the neighborhood level. Our primary data constraint is that we are unaware of any dataset that would allow us to take a comprehensive look at variation in access to water at the neighborhood level. Instead, the bulk of our analysis will be conducted at the city level.

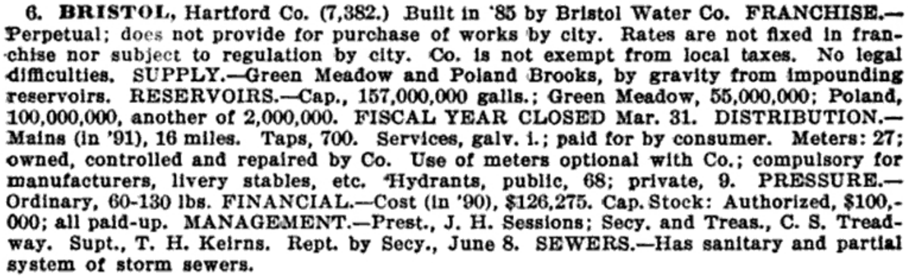
3.1 Water provision data

Our primary source for information on water provision comes from the 1897 edition of Moses Nelson Baker's *Manual of American Waterworks*. Baker's first volume of the Manual of American Waterworks was published in 1888. As is made clear from his introduction, Baker's efforts were inspired by his frustration with the fact that essential data on America's waterworks (e.g., the number of waterworks, the location of each waterworks, and when each waterworks was built) were not accurately known. Baker attempted to remedy this situation by surveying local officials and companies to obtain accurate histories and continuing to follow up with these individuals until he received the requested information. Subsequent editions focused on standardizing the information obtained from those surveys so that the information could be included in future editions. Baker also incorporated information on works built since the initial survey. For these reasons, we focus on digitizing the 1897 edition of the manual as it is the most comprehensive of the four volumes.

For each waterworks, the manual includes information on "its history, general character, the capacity of the pumps, reservoirs, stand-pipes, or filters; the extent of the distribution system; and the most important figures relating to the finances of each system" (Baker (1897), preface). A representative example of one these descriptions is provided in Figure 4. The main piece of information we focus on is the year the waterworks was built. We digitize this information for all 4,207 cities appearing in the 1897 manual.

It is worth pointing out why we prefer to use year built instead of other measures, such as miles of mains or number of taps, which relate directly to the measures

Figure 4: Example entry from Baker (1897)



6. **BRISTOL**, Hartford Co. (7,382.) Built in '85 by Bristol Water Co. FRANCHISE.—Perpetual; does not provide for purchase of works by city. Rates are not fixed in franchise nor subject to regulation by city. Co. is not exempt from local taxes. No legal difficulties. SUPPLY.—Green Meadow and Poland Brooks, by gravity from impounding reservoirs. RESERVOIRS.—Cap., 157,000,000 galls.; Green Meadow, 55,000,000; Poland, 100,000,000, another of 2,000,000. FISCAL YEAR CLOSED Mar. 31. DISTRIBUTION.—Mains (in '91), 16 miles. Taps, 700. Services, galv. i.; paid for by consumer. Meters: 27; owned, controlled and repaired by Co. Use of meters optional with Co.; compulsory for manufacturers, livery stables, etc. Hydrants, public, 68; private, 9. PRESSURE.—Ordinary, 60-130 lbs. FINANCIAL.—Cost (in '90), $126,275. Cap. Stock: Authorized, $100,000; all paid-up. MANAGEMENT.—Prest., J. H. Sessions; Secy. and Treas., C. S. Treadway. Supt., T. H. Keirns. Rept. by Secy., June 8. SEWERS.—Has sanitary and partial system of storm sewers.

considered in our model. The model uses miles of mains to illustrate which neighborhoods will get access and which neighborhoods will not. The prediction of the model is that, depending on the demographic mix of the final neighborhood that receives water, an increase in segregation can either increase or decrease the extensiveness of the system. Specifically, we saw that when the marginal neighborhood is majority black then an increase in segregation will decrease water provision. Conversely, we saw that when the marginal neighborhood was mostly white an increase in segregation would increase the extensiveness of the waterworks. Unfortunately, when miles of mains are reported at the city-level it is not possible to identify the demographic mix of the final neighborhood that receives water. This is problematic because if we don't observe the demographic mix of the final neighborhood receiving water then we don't have a clear empirical prediction that can be validated with the data.

To overcome this issue we note that the model does offer clear predictions for how segregation should influence the city's decision of when to build. Because the construction of a waterworks involves large fixed costs, the rational city will only begin construction when there are enough neighborhoods to justify the initial investment. That is, the first wave of construction has a marginal cost that is equal to the initial fixed costs as well as the variable costs of supplying each neighborhood (up until the optimal stopping point). As a city becomes more segregated, then all else equal there should be more neighborhoods in that initial wave of construction to spread those fixed costs across. As a result, more segregated cities should begin construction earlier than integrated cities.

3.2 Demographic data

With our empirical prediction in hand, we now set out to attach demographic characteristics to our waterworks data. Our demographic data come from the complete count 1880 census as maintained by the Integrated Public Use Microdata Series (IPUMS) (Ruggles *et al.*, 2015). We rely on this dataset to identify: number of households residing in the city, the black share, and the level of segregation in the city. We begin with the sample of individuals residing in an incorporated place in 1880. By using incorporated places we are not restricted to the sample of large cities that are typically reported in census publications, but are instead able to obtain demographic data for roughly 5,400 cities and villages.

We measure segregation using the neighbor-based segregation index developed by Logan & Parman (2017). This measure exploits the public availability of complete census returns for any census over 72 years old and the door-to-door enumeration process by which census information was collected. Given that enumerators visited each household in sequential order down a street, the households appearing before and after an individual on the census manuscript page correspond to that individual's next-door neighbors. It is therefore possible to see how often individuals live next to a person of a different race, providing a very simple and intuitive way to think about the level of residential integration in a community.

The neighbor-based segregation index compares the number of black households in a given area living next to white neighbors to the number expected under complete integration and under complete segregation. Formally, the index is given by

$$\text{Neighbor-based segregation} = \frac{E(\overline{x_{Min}}) - x_{Min}}{E(\overline{x_{Min}}) - E(\underline{x_{Min}})} \tag{8}$$

where x_{Min} is the number of minority households with majority neighbors, $E(\overline{x_{Min}})$ is the expected number of minority households with majority neighbors under complete integration (the group membership of neighbors are completely independent) and $E(\underline{x_{Min}})$ is the expected number of minority households with majority neighbors under complete segregation (only the minority households on either end of the minority neighborhood have majority neighbors). This index equals zero under complete integration, increases as the number of minority households with a majority neighbor decreases, and equals one in the case of complete segregation. What is particularly appealing about this measure of segregation in our context is that it effectively matches the relevant geography for water provision: street segments.

Because we are examining cities and villages before the Great Migration there are a number of cities in our sample that don't have meaningful black population sizes. We restrict our sample to cities with at least 11 black households, which corresponds to the 50th percentile of all incorporated places that have at least 1 black household. This leaves us with a sample of 1,754 cities and villages, 876 of which appear in the Baker Manual. Note that because of the comprehensiveness of the Baker manual we classify the remaining 878 cities and villages as not having a waterworks. Some of these waterworks could simply be non-responders, but Baker suggests that the amount of non-responders is actually quite small.

4 Main results

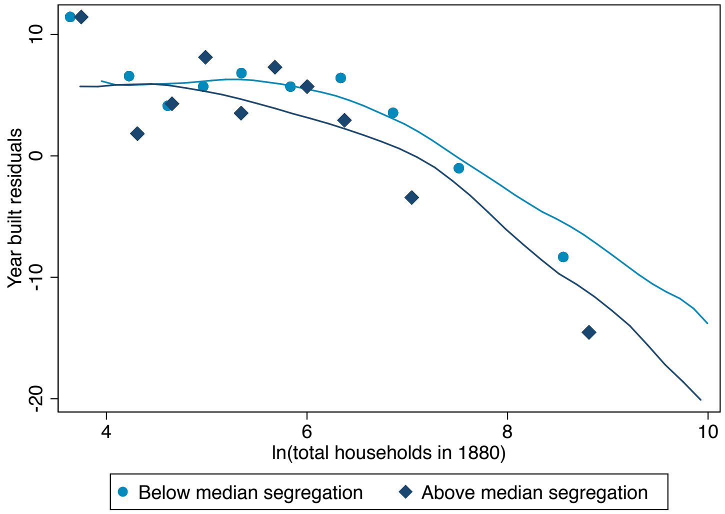
4.1 Segregation and water provision

Figure 5 visually displays our first result. We begin by first regressing year built on a series of census region indicators in order to tease out geographic variation in year built as well as black shares. By construction, this sample is restricted to those that ultimately build a waterworks before 1897. From that regression we take the residuals and plot them against ln(number of households in the incorporated place). We then fit two separate local polynomial regressions, one for the sample of cities with above median segregation and one for the sample of cities with below median segregation. Finally, we include a binned scatter plot for these two groups to illustrate the overall fit of our polynomials.

There are three main takeaways from Figure 5. First, we see a clear downward trend, which illustrates that larger cities tend to built waterworks earlier than smaller cities. This is not too surprising given the inherent fixed costs associated with building a waterworks and the fact that larger cities will be able to spread those costs over more households. The second takeaway, however, is that in the largest cities, those with higher levels segregation tend to build their waterworks about 5 years earlier than cities with lower levels of segregation. This is consistent with the empirical predictions of the model outlined above. Finally we see that this difference converges towards zero as the city size decreases. We hesitate to over interpret what convergence might mean given the simplicity of this specification, but it could suggest that systematic exclusion of blacks from water provision was only possible in larger cities.

Next we incorporate information from our cities that did not build a waterworks by 1897. Specifically, we estimate a cox proportional hazard model, taking year of construction as our "failure." These results are presented in Table 1. In column 1 we examine the full sample and find that segregated cities are building their waterworks at a rate about 70 percent higher than integrated cities. We also see that cities with larger black shares are building at a much smaller rate. In columns 2 through 5 we restrict the sample based on city size. These results indicate that the impact of segregation is most pronounced in larger cities. For cities that fall in the 80 to 95th percentiles (so 995 to 4474 households) we see that segregated cities are building at a rate that is roughly 3.5 times higher than integrated cities. In the top 5th percent of the city size distribution we see that segregated cities are building waterworks 12.7 times faster than integrated cities.

Figure 5: Non-parametric estimates of the relationship between city size and year built for high and low segregation cities



Year build residuals obtained by regressing year built on a series of census region fixed effects. The median level of segregation is 0.28.

Table 1: Examining the relationship between segregation and the timing of construction in a cox proportional hazard model

		City size restrictions			
	All cities	Bottom 50th percentile	50th to 80th percentile	80th to 95th percentile	95th and up
ln(total households)	3.342***	5.491***	5.850***	2.886***	1.632***
	(0.177)	(1.596)	(0.902)	(0.569)	(0.280)
Segregation	1.714**	1.795	1.385	3.553**	12.696***
	(0.401)	(1.085)	(0.408)	(1.799)	(10.203)
Black pop. share	0.247***	0.066***	0.102***	0.075***	0.104
	(0.099)	(0.052)	(0.047)	(0.054)	(0.256)
Observations	1663	866	485	241	71
Failures	737	82	348	236	71

*** p<0.01, ** p<0.05, * p<0.1. Coefficients reported in the table are hazard ratios. Each regressions includes census region fixed effects. Robust standard errors in parentheses. The median city in our sample has 253 households, while the 80th percentile had 995 households, and the 95th percentile had 4474 households.

4.2 Exploring the health consequences of this relationship

The previous results indicate that segregated cities tended to build their waterworks much earlier than integrated cities. In the framework of our model, these results are consistent with a story where segregation makes construction of a waterworks more attractive because, all else equal, segregated cities will have more neighborhoods that are suitable candidates for connection and thus more neighborhoods to spread the fixed costs over. If true, then blacks may have been less likely to have access to water in segregated cities, particularly with respect to the initial wave of provision.

In this section, we set out to understand whether this potential lack of provision might have had any health consequences. During the first half of the twentieth century, the adoption of water filtration technologies would ultimately generate large reductions in mortality (see Cutler & Miller (2005), Ferrie & Troesken (2008)). In this sense, the initial wave of waterworks construction laid the necessary foundation for this public health movement. That is, once filtration technologies were developed, it would be possible to eliminate typhoid fever and other waterborne diseases by increasing household access to clean water.

While much has been written about this mortality transition, which occurred between 1900 and 1950, it is important to note that the primary motivation of construction was not to purify the water. This is because effective water filtration technologies did not exist during the 1880s. The nation's first filtration plant aimed at treating tainted water was the "Lawrence Experiment Station", which was built in 1886 in Lawrence, MA (Alsan & Goldin, Forthcoming). Other filtration plants existed during this period, but they were aimed at combatting turbidity, discoloration, and bad taste rather than disease (Cutler & Miller, 2005). Baker's comments on the rapid expansion of waterworks during the 1890s are consistent with the interpretation that purification was not the primary motivation. As Baker writes:

> "Think of the effect upon the standard of living caused by the introduction

> of a public water supply! In place of the labor attendant upon lifting water by the old oaken bucket, the more prosaic hand pump, or of carrying water in pails from some spring or stream, only a turn of the faucet is now necessary in hundreds of communities to secure either hot or cold water on any floor of a dwelling. The labor saving thus secured, together with the increase in convenience, comfort and cleanliness, is too evident to need detailed mention, especially as both the old and the new are within the experiences of so many."

Largely due to the technological constraints of the time, initial water investment decisions were motivated by convenience rather than the control of disease. The systematic exclusion of blacks makes much more sense when the goal is to increase convenience rather than when the goal is to combat disease. When the goal is to combat disease, there is a stronger motivation to increase black household's access to water. Humans can be carriers of waterborne diseases like typhoid fever, and so black households without access to clean water may still contract the disease and spread it to white households. In the context of our model, local officials interested in combating typhoid fever and other waterborne diseases may value black household and white household access equally ($\alpha = 0.5$), which would undermine any empirical predictions about how segregation should affect the city's overall health. When investment decisions are motivated by convenience, however, it is much more likely that local officials will undervalue black access. This is important because it suggests that $\alpha > 0.5$, and so we should expect the level of segregation in the city to generate variation in black vs. white household provision.

While purification was not the primary motivation, for many cities the construction of a waterworks allowed residents to access water sources that were less likely to be tainted by improper sewage disposal, thus limiting exposure to waterborne diseases (see, for instance, Alsan & Goldin (Forthcoming) on water and sewerage access in Massachusetts). This, combined with the fact that initial provision decisions were motivated by convenience rather than disease, generates the following empirical prediction. In an integrated city, the construction of a waterworks will provide black and white households with better access to clean water, which will in turn is likely to lower the incidence of waterborne disease. In a segregated city, however, blacks are more likely to be excluded from access to clean water, which will undermine the city's ability to control waterborne diseases like typhoid fever.

To test this empirical prediction, we draw on data from the IPUMS 5% sample of the 1900 census. In that census, each woman was asked about how many children they have had and how many of those children are still living today. As in Logan & Parman (2018), we use this information to construct an indicator variable for whether an individual ever lost a child, which we interpret as a proxy for infant mortality. We rely on this proxy because comprehensive city-level data on black and white mortality by age and cause does not exist for this time period.[9]

Figure 6 displays our main result with raw data. Specifically, we plot our indicator for losing a child against city-level segregation. We plot this relationship separately for white mothers (left panel) and black mothers (right panel). We also plot the relationship separately for those who were less than the age of 18 when the waterworks was constructed and those who were over the age of 45 when the waterworks constructed. We interpret those who were under the age of 18 as those who spent all of their fertile years in the regime where the city was providing its residents with water. Conversely, we interpret those were over the age of 45 as those who spent all of their fertile years without a waterworks.

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[9] In contrast to England, which standardized and mandated the reporting of deaths in 1846, the United States left this decision to state and local governments. Several large cities and states passed mandatory reporting laws by 1900, and in that year the Census Bureau worked with those registration areas to establish uniform reporting standards. The result of this was the adoption of a standardized death certificate and the international classification standard, as well as the distribution of "The Manual of International Classification of Causes of Death", which cross referenced terms appearing in causes of death from 1890 and 1900 reports with the new uniform classification standard. While the registration area would expand dramatically over the next 30 years, the city-level tabulations simply do not include the necessary detail for our analysis.

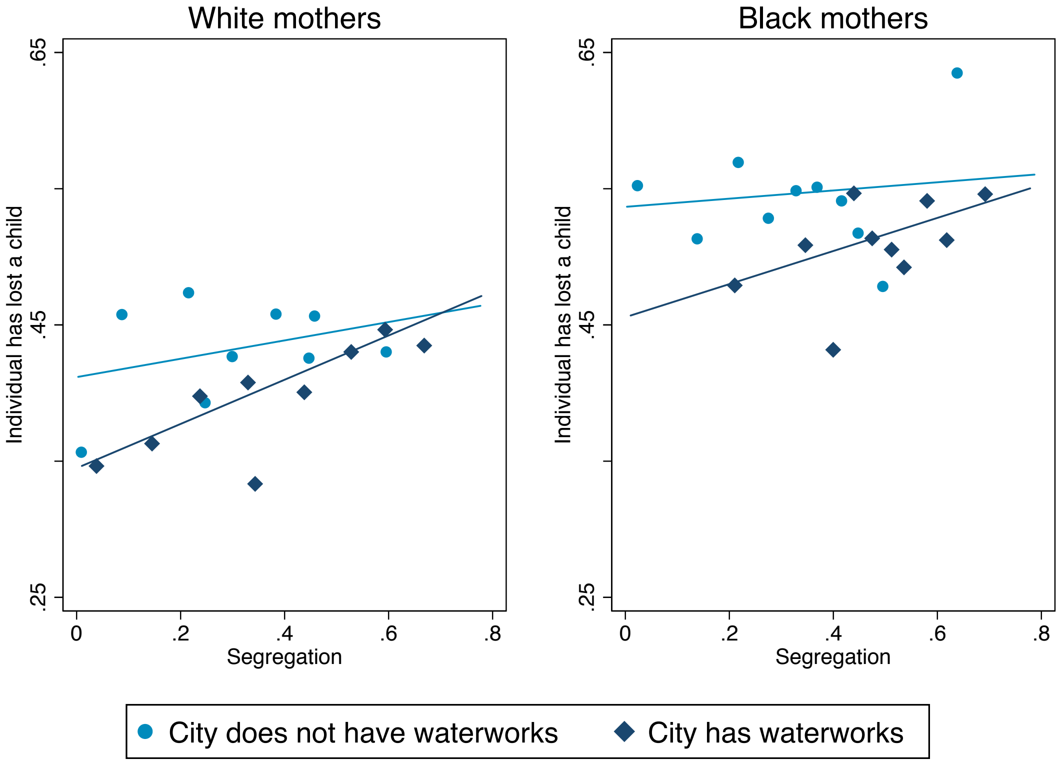
The results of Figure 6 are as follows. In an integrated city, the share of mothers that lost a child is about 5 percentage points lower for mothers who spent their fertile years in a city with a waterworks vs mothers who spend their fertile years in a city without a waterworks. Notably, this decline is roughly the same size for both black and white mothers, which is consistent with black households gaining access to water at the same rate that white households are gaining access to water. However, we also see that these benefits decline as the level of segregation increases, which is consistent with the exclusion of black households hindering the city's ability to control waterborne disease rates.

Next we analyze this relationship in a formal difference-in-differences specification. Specifically we estimate variations of the following equation:

$$Lost_{iac} = \alpha_0 + \beta_a + \gamma_c + \delta * Exposure_{iac} + \psi * White + \epsilon_{iac} \tag{9}$$

where $Lost_{iac}$ is an indicator that equals 1 if individual i, who is age a and resides in cit c at the time of census enumeration has ever lost a child. The parameters β_a and γ_c are age and city fixed effects, respectively. The variable $Exposure_{iac}$ captures the share of fertile years (ages 18-45) that the individual spent in a city with water access. This is calculated by taking the individual's age at the time of enumeration and backing out how old they would have been at the time the waterworks was built. If the individual was under the age of 18 when the waterworks is built then they are assigned a 1. If the individual was 45 or older then they are assigned zero. The remaining individuals receive partial exposure corresponding to $\frac{45 - age\ at\ time\ of\ construction}{45-20}$. Finally, we include an indicator for whether the individual is white or not since black and white mothers lost children at different rates. In some specifications we will interact our exposure variable by race and by the degree of segregation in the city. Standard errors are clustered at the city level. Identification of δ comes from the fact that different cities built their waterworks at different times and that, within a city, the construction of a

Figure 6: Binned scatter estimates of the relationship between water access, segregation, and infant mortality



Notes: This 5% sample of black and white mothers between the ages of 18 and 45 who resided in an incorporated place at the time of enumeration in 1900 comes from IPUMS.org. Sample is restricted to those who either spend all or none of their fertile years (18-45) in a city with a waterworks.

waterworks generates differential exposure to water access based on the individual's age when the waterworks was built.

Column 1 of Table 2 presents estimates of equation 9. In this specification we find that investment in water decreased the likelihood of losing a child by roughly 4 percentage points, which is broadly similar with the results depicted in Figure 6. Note that our estimating equation includes city fixed effects, which absorbs the average effects of segregation, city size, and year built. In column 2 we interact our exposure variable with an indicator for whether the mother is black. Here we see little evidence that water investments differentially benefit white households. In column 3 we include an interaction with our segregation variable. In this specification, "Water Exposure" is interpreted as the effect of building a waterworks in an integrated city. There we see that the likelihood of losing a child fell by roughly 10 percentage points for mothers that spent their entire fertile years in a city that had a waterworks and that the degree of segregation in the city mitigates this effect. This effect is both practically and statistically significant such that moving from perfect integration to a segregation index of 0.5 generates no measurable decline in infant mortality. In column 4 we fully interact both "Water Exposure" and "Water Exposure × Segregation" with an indicator for whether the mother is black. Again, we cannot reject that the effect for white mothers is different from the effect for black mothers.

Table 2: Difference-in-differences estimates of the relationship between waterworks construction and infant mortality

DV: Whether the mother has ever lost a child	(1)	(2)	(3)	(4)
Water Exposure	-0.042**	-0.043**	-0.101***	-0.101***
	(0.017)	(0.017)	(0.026)	(0.027)
Water Exposure × Black	0.007		0.005	
		(0.016)		(0.029)
Water Exposure × Segregation			0.217***	0.216***
			(0.070)	(0.071)
Water Exposure × Segregation × Black				-0.006
				(0.047)
Observations	170,514	170,514	170,514	170,514
R-squared	0.087	0.087	0.087	0.087

*** p<0.01, ** p<0.05, * p<0.1. Robust standard errors (clustered at the city level) are reported in parentheses. Sample is restricted to black and white women between the ages of 18 and 55 who have had given birth to at least one child (at the time of 1900 census enumeration). Water exposure is the share of fertile years (ages 18 to 45) that the mother resided in a city with a constructed waterworks. Each regression includes city fixed effects, cohort fixed effects, and an indicator for whether the individual is white or not. Segregation is measured using the Logan-Parman segregation index.

5 Concluding remarks

During the first half of the twentieth century, the United States experienced a dramatic decline in mortality as cities invested in clean water technologies. However, this public health movement would not have been possible without prior infrastructure investment, which connected households to a centralized water supply. In this paper, we ask whether the segregation of blacks might have influenced municipal investments, and in turn influenced this public health movement. We find evidence consistent with the narrative that segregated cities were quicker to build their waterworks and more likely to exclude households. This exclusion may not have been rational, however, as we also find that segregated cities experienced much smaller declines in infant mortality, perhaps because by excluding black households they were unable to effectively control waterborne disease.

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A Extending the model

A.1 Private provision without price discrimination

Suppose that the city is on a unit interval and the degree of segregation is described by the g function from the previous subsection. However, instead of public officials deciding water provision, suppose water is provided by a profit maximizing firm. The profit maximizing firm must decide what price to charge and how many miles of mains to build. Assume the firm cannot price discriminate, and must charge a single price for connecting to the water system. Further assume that all whites are willing to pay δ to connect to the water system, whereas all blacks are willing to pay θ, and that $\delta > \theta$. Since whites are willing to pay more, the firm will start construction of the mains in the whitest part of town, indexed by 0 on the unit interval.

The firm will either charge δ or θ to hook up to the water system. If the price were set below δ and above θ, then the firm could raise prices without losing any customers; the firm would never charge below θ because it is the minimum willingness to pay in the model. If the firm charges δ, then profits are

$$\Pi_\delta = \delta \int_0^m (1 - g(x))dx - pm - C, \tag{10}$$

where m is the miles of mains, p is the per unit cost of mains, C is the fixed cost of building the mains. The first order condition yields:

$$m^* = g^{-1}\left(1 - \frac{p}{\delta}\right). \tag{11}$$

This implies that miles of mains decrease as the price per main increases and that miles of mains increases as the willingness of whites to pay increases. Furthermore, mains increase with the share of whites. Segregation decreases water provision if the mark up is sufficiently low ($2p > \delta$). This is because if the mark up is low, then the private firm will stop constructing mains when it reaches the black neighborhood. If the mark up is sufficiently high, however, it will be worth constructing mains in the black neighborhoods to reach the few white customers that do exist. For this equilibrium, only whites connect to the water system.

The second possible price strategy is if the firm charges θ so that both black and white customers connect to the main. In this case,

$$\Pi_\theta = \theta m - pm - C \tag{12}$$

So long as the price per unit of main is smaller than θ, this will give us a corner solution of providing water to the whole city. In this equilibrium, the firm is already covering the whole city and segregation and the share of whites have no effect on main mileage.

Letting m^*_δ be the optimal miles of main under the δ pricing strategy, then the firm will pick the δ pricing strategy so long as:

$$\delta \int_0^{m^*_\delta} (1 - g(x))\, dx - \theta > pm^*_\delta - p. \tag{13}$$

Of course fixed cost must be sufficiently small so that profits are non-negative.

A.2 Private provision with price discrimination

Now suppose the firm can price discriminate, so that the firm charges all blacks θ and all whites δ so long as the firm builds a main to that particular neighborhood. Then profits become:

$$\Pi = \delta \int_0^m (1 - g(x))dx + \theta \int_0^m g(x) - pm - C \tag{14}$$

The first order conditions give us that:

$$m^* = g^{-1}\left(\frac{\delta - p}{\delta - \theta}\right) \tag{15}$$

Therefore, mileage of mains decreases with costs p. The comparative statics reveal that mileage increases with the WTP of whites if the costs per unit is greater than the WTP of blacks ($p > \theta$). Notice that if $p > \theta$, then whites are effectively subsidizing blacks. In the absence of whites in the neighborhood, building in the black neighborhood would not be profitable. An increase in the WTP of blacks increases main mileage so long as $\delta > p$, which is necessary for the water provision to be profitable. Water provision increases with the share of whites γ. An increase in segregation increases water provision so long as $\delta - \theta > 2(\delta - p)$ (or, alternatively, $2p > \delta - \theta$), which is to say if WTP of whites over blacks is at least twice as large as the mark up for whites. This result is similar to the role of segregation without price discrimination. In the case of no price discrimination, if the mark up for whites is high ($2p > \delta$), it is worth extending mains to neighborhoods with even a small number of whites. In the case of price discrimination, this logic still holds except except that the threshold is lower given that the firm receives revenues from the black households ($2p$ must be greater than $\delta - \theta$ rather than just δ).