Segregation and the Initial Provision of Water in the United States

By BRIAN BEACH, JOHN PARMAN, AND MARTIN SAAVEDRA*

* Beach: Vanderbilt University, VU Station B, Box #351819, 2301 Vanderbilt Place, Nashville, TN 37235 (brian.beach@vanderbilt.edu). We are grateful for feedback from Mark Anderson, Francisca Antman, Jonathan Chapman, Walker Hanlon, Randy Walsh, seminar participants at George Mason University and University of Tennessee Knoxville, and conference participants at the UC Davis' Geographies of Poverty Conference, the Western Economic Association's annual meeting, the American Historical Association's annual meeting, the Cliometric Society, the World Economic History Congress.

A key pillar of standard of living in today's developed countries is widespread access to safe water and sanitation. When access is incomplete, communities are left vulnerable to typhoid fever, cholera, and other water-related illnesses. To this point, nearly one-third of the world's annual 1.6 million diarrheal deaths are thought to result from contaminated water.

Water and sewer infrastructure have historically played a crucial role in eliminating waterborne threats. Alsan and Goldin (2019), for instance, provide compelling evidence that infant mortality rates in late 19th century Massachusetts were highly responsive to improved access to clean water and sewerage.[1] While the gains are impressive, infrastructure rarely arrives all at once, and so it can take decades for outcomes in low and high-income neighborhoods to converge (Costa and Kahn, 2015; Kesztenbaum and Rosenthal, 2017).

Werner Troesken's seminal work (2002 and 2004) argued that, relative to other public services, Black households in the late 19th and early 20th centuries were much less likely to be denied access from water and sewer infrastructure. The logic underpinning this argument is that water and sewer mains can accommodate many houses, and so when a main arrived, low connection costs and the presence of disease externalities provided an incentive to extend access to both Black and White households.

This paper documents two new empirical facts that suggest a more nuanced picture: U.S. cities with higher rates of residential segregation built their waterworks earlier but were slower to eliminate typhoid fever and had fewer households with running water and access to flush toilets in 1940.

We offer a theoretical model that reconciles these seemingly paradoxical findings. Because of the high variable costs of infrastructure (laying new mains), segregation allows discriminatory city planners to exclude some

[1] Urban mortality rates in the United States and elsewhere fell dramatically between 1880 and 1940 but the share of the decline due to water and sanitary interventions remains debated. Key papers include Cutler and Miller (2005) and Anderson et al. (Forthcoming). See also Beach (Forthcoming) for a summary of this literature.

neighborhoods as a way of lowering provision costs. By making it cheaper to provide access to the targeted subpopulation, segregation also makes it more likely that planners are willing to incur the high fixed costs of infrastructure (e.g., pumping stations and water towers). But these forces that lead a discriminatory city planner to build earlier and in predominantly White neighborhoods also leave discriminatory city planners reluctant to invest in predominately Black neighborhoods. This undermines the elimination of waterborne disease, as residents with infrastructure access remain vulnerable to disease spillovers arising from neighborhoods with more limited access.

I. Background

Like many residents in today's developing countries, 19th century American city dwellers suffered the consequences of a poor sanitary environment in large numbers. Typhoid fever offers some insight on the scale of the problem, since it originated almost exclusively from contaminated water until the early 20th century. The 1890 vital statistics indicate that typhoid fever killed 3.9 of every 1,000 U.S. residents. For comparison, the U.S. COVID death rates in 2020 and 2021 were about 1.2 and 1.3 deaths per 1,000 persons, respectively. Importantly, 1890 was not an outlier (see Figure 2).

Figures 1 and 2 provide an incomplete picture of the issue for several reasons. First, typhoid mortality was likely underestimated as the varied and indistinct nature of typhoid's symptoms made it difficult to diagnose. Second, there is evidence that those that survived the initial infection faced an elevated mortality risk and other health issues. Finally, Beach et al. (2016) provide evidence that exposure to typhoid lowered human capital accumulation, and those productivity gains alone were large enough to justify the capital investments needed to eliminate typhoid fever.

Eliminating typhoid fever was not easy. Most large- and medium-sized cities started building their networks when water quality was judged primarily by its taste, smell, and clarity. The bacteriological revolution of the 1870s and 1880s offered a more objective measure of water quality, but by then a sizeable amount of infrastructure was already built. This motivated cities to make investments to purify the water running through their mains, albeit with mixed results (Anderson et al., Forthcoming).

II. Data

Our sample contains 72 U.S. cities. This sample is informed by the availability of 19th century typhoid mortality data. The mean city had a Black population share of 8% in 1880. All but 3 of our cities are ranked among the 100 largest cities in 1880 and the sample includes 49 of the 50 largest cities. In terms of geography, 36 cities are in the New England and Middle Atlantic divisions, 19 are in the North-Central divisions, 12 are in the South Atlantic and South-Central divisions, and the remaining 5 are located in the West.

Our measure of segregation comes from Logan and Parman (2017). This measure leverages the fact that enumeration occurred "door-to-door," and so households adjacent on the census manuscript are often next-door neighbors. The Logan-Parman index compares the actual number of Black households with White next-door neighbors to the number expected under complete segregation and complete integration given the racial proportions of the area. It equals zero in the case of complete integration, increases as the number of Black households with White neighbors declines, and equals one in the case of complete segregation.

A key advantage of this segregation measure is that it captures the local forms of segregation present in 19th century cities, including Black households residing in alleys and cases of small Black enclaves in cities with small Black populations overall (Logan, 2017). We follow Logan and Parman's methodology to generate city-level measures from the 1880 census. This census reflects the postbellum segregation patterns that were relevant for initial infrastructure decisions. The first wave of the Great Migration would alter these patterns, but not until after initial construction took place.

III. An Empirical Puzzle

Figure 1 displays average typhoid fever deaths per 1,000 residents from 1880 to 1930 for cities with above and below median levels of segregation. The figure reveals two facts. First, typhoid fever mortality fell considerably during this period. Relative to 1880, typhoid fever rates were about 35% lower by 1900 and 90% lower by 1920. Second, more segregated cities took longer to control typhoid fever. Typhoid fever death rates in any given year were approximately twice as high in cities with above median segregation. 1897 was the first year in which typhoid fever mortality in below-median segregated cities fell below 1 death per 1,000 persons. Above-median segregated cities would not reach that milestone until 1912.

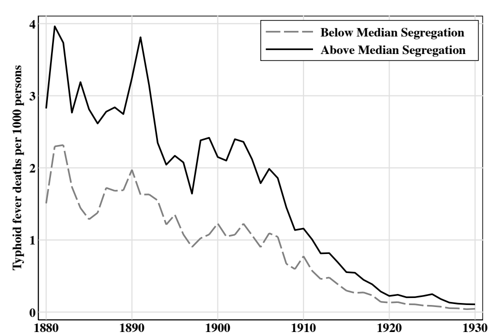


FIGURE 1. TYPHOID FEVER MORTALITY. 1880-1930

Note: Mortality counts for 1880-1900 are from Whipple (1908). Remaining data from the U.S. Mortality Statistics. Mortality rates based on linearly interpolated populations between census years.

While Figure 1 is consistent with the hypothesis that segregated cities invested less in their water systems, Figure 2 reveals a more nuanced story.

Figure 2 displays the cumulative share of cities that have started constructing their waterworks. We plot this separately for cities with above- and below-median levels of segregation. More segregated cities built their water system earlier than less segregated cities. Among cities with higher levels of segregation, the median city built a waterworks in 1854. In cities with lower levels of segregation, the median city built its waterworks in 1869. This result does not appear to be driven by compositional differences. Regressing year of construction on our above-median segregation indicator as well as a set of region fixed effects, ln(city population in 1880), and the city's Black population share suggests that more segregated cities built their waterworks 13.4 years earlier (p-value of 0.001).

These facts represent an empirical puzzle. Why would a set of cities that built their water systems earlier be slower to eliminate typhoid fever?

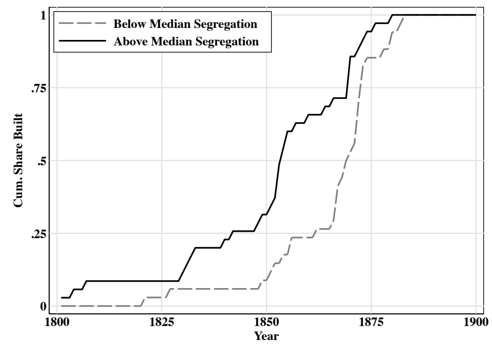


FIGURE 2. WATERWORKS CONSTRUCTION BY SEGREGATION

Note: Data from Baker (1897), which reports the year that a city started construction on their waterworks.

IV. A Model of Water Provision

Consider a city with two types of residents: White and Black, however, we could consider any group that faces discrimination in the provision of public goods. The city lies on a unit interval in which each point along the line represents a neighborhood of equal size. In addition, order the neighborhoods such that $x = 0$ is the neighborhood with the highest White share and $x = 1$ is the neighborhood with the highest Black share.[2]

The degree of segregation and 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 $g(x) = 0$ if

[2] This implies that neighborhood racial composition is fixed. This seems reasonable as racial segregation during the 19th century was primarily the result of racial discrimination coupled with low incomes restricting Black households to the areas of lowest residential quality (Kellogg, 1977). With that being said, Coury et al (2021) provide evidence that property values in Chicago more than doubled after receiving piped water and sewers, raising the possibility that neighborhood investments may have induced a sorting response. We expect such a response to reinforce existing segregation patterns.

$x \leq \frac{1}{2}$ and $g(x) = 1$ otherwise. A perfectly integrated city with equal group sizes implies that $g(x) = \frac{1}{2}$. More typically, we expect g to be an increasing S-shaped function. Appendix Figure A.1 depicts g for our hypothetical city under perfect segregation, perfect integration, and something in between.

The city planner faces the budget constraint $B = z + c * m + F$, 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 a main, and F represents any fixed costs associated with supplying water. If the city does not build any mains, then the constraint is $B = z$.

The city planner is racist in that their objective function values White residents with access to the water system more than Black residents. Thus, if the city builds a main, it will start at $x = 0$ (the Whitest part of town), and keep building mains, possibly stopping before supplying water to the whole city. Once a main reaches a neighborhood, x, both White and Black residents of that neighborhood have access to the main. Let N_W be the White population connected to a water main, N_B be the Black population connected to a water main. The variable $m \in [0,1]$ reflects where the city stops building. Thus $N_W = \int_0^m \left(1 - g(x)\right) dx$ and $N_B = \int_0^m g(x) dx$.

Suppose the objective function is: $U(N_W, N_B, z) = \alpha N_W + (1 - \alpha) N_B + \beta z$ where $\alpha \in \left(\frac{1}{2}, 1\right)$. For an interior solution, we need the ratio of the marginal value of m and z to be equal to the ratio of prices. 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 $c < \frac{1-\alpha}{\beta}$, then the city will provide water to all residents, assuming fixed costs are sufficiently small. If $c > \frac{\alpha}{\beta}$, then the city will not provide water to any residents. The first-order conditions for an interior solution indicate: $m^* = g^{-1}\left(\frac{\alpha - \beta c}{2\,\alpha - 1}\right)$, which yields the following proposition.

Proposition 1: For an interior solution, the size of the system decreases in the cost of mains and the preference for non-water public goods.

Next, let's characterize the function g to analyze the effects of segregation, group size, and preferences for Whites. Let $g(x) = \frac{1}{1+e^{-k(x-\gamma)}}$. 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 is the centering parameter, reflecting the location of the neighborhood that is equally split between the two groups, if such a neighborhood exists. Thus, $g^{-1}(x) = \gamma - \frac{1}{k}\log\left(\frac{1}{x} - 1\right)$.

Proposition 2: The size of the system m^* increases as γ increases.

A city with a higher value of γ has more White residents and since the planner places a higher weight on White households with water they will build a more extensive system.

Proposition 3: If the optimal main stops in a neighborhood that is less than one-half Black (i.e., $m^* < \gamma$) then a marginal increase in either segregation (k) or the preference for Whites (α) increases the size of the optimal water system. Conversely, if $m^* > \gamma$, then a marginal increase in either k or α decreases the size of the optimal water system.

The intuition here is what matters is how segregation affects the marginal neighborhood, not the city as a whole. If segregation increases, then the Black share increases in majority Black neighborhoods and, from the perspective of a racist city planner, the marginal payoff of mains in that neighborhood declines. Similarly, the Black share decreases in majority White neighborhoods and the marginal payoff of the main increases. A consequence is that the most segregated cities have the highest incentives to start constructing their waterworks (since at first the system will serve nearly all-White neighborhoods) and the least incentive to complete the water system (which would serve nearly all-Black neighborhoods).

This issue is similar to the "last-mile problem" documented in Ashraf et al (2016), in which the last user is the most difficult to connect to the water system. Ashraf et al present a theoretical model in which the cost of connecting to the water system is below the social benefit of doing so, but above the private cost. Thus, to achieve optimal connectivity, Pigouvian subsidies or fines are necessary.

We describe an alternative last-mile problem where the final connections occur in the neighborhood with the least political power. This neighborhood may impose a disease externality on the rest of the city, which explains why highly segregated cities would be slower to eliminate typhoid fever.

V. Revisiting *Water, Race, and Disease*

In *Water, Race, and Disease* Troesken (2004) argued that, relative to other public services, Black Americans were much less likely to be excluded from water and sewer infrastructure. Because drinking contaminated water has diffuse health effects that likely interact with nutritional deficits or disparities in health care, Troesken argues that this relatively equal access helps explain why some of the greatest reductions in racial health disparities occurred at the height of the Jim Crow era.[3]

A representative example of the role of segregation in Troesken's narrative appears in his case study comparing Memphis, TN, and Savannah, GA. During the late 19th century, Memphis was far more integrated when compared with Savannah. Memphis also built a sewer system that more uniformly connected Black and White households. Troesken estimated that 86% of White households and 72% of Black households had access to sewers in Memphis in the years following construction. However, if the outlying and majority Black neighborhood of Chelsea is omitted from the analysis, Troeksen estimated that 93% of Memphis residents had access to sewers, regardless of race. In Savannah, 88% of White households but only 59% of Black households had access to sewers.

Troesken's work helps validate our characterization of the city planner. That the majority Black neighborhood of Chelsea lacked access to Memphis' sewer system indicates that Memphis was operating at an interior solution where neighborhoods with higher White shares were prioritized.

While Troesken focused on the limited ability to exclude households residing on the same street from accessing nearby mains, our paper focuses on when and where water and sewer mains are built. By formalizing the problem facing a discriminatory city planner, our work explains why more segregated cities would be quicker to begin construction but slower to provide comprehensive access.

To explain the substantial lags in controlling typhoid that were documented in Figure 1, then in addition to Troesken's evidence that cities were reluctant to expand into predominantly Black neighborhoods we also need to show that this disparity in access was persistent.

Figure 3 makes this point by drawing on city-level data from the 1940 census of housing. The top panel examines households connected to running water while the bottom panel examines households with a flush toilet. Both panels plot the distribution across cities in above vs below-median levels of segregation. In both panels we see that more segregated cities had lower levels of infrastructure access. These data are not available by race, but Troesken's case studies of Memphis and Savannah suggest that these city-level averages only tell part of the story and racial disparities likely exist.

[3] Anderson et al. (2021) provide mixed support for this idea. They find that water filtration lowered Black and White mortality proportionately but chlorination resulted in a net decline in the Black-White mortality gap. This may reflect underlying differences in residential segregation, but the authors note the variation in their sample is not well-suited for exploring those interactions (pg. 5).

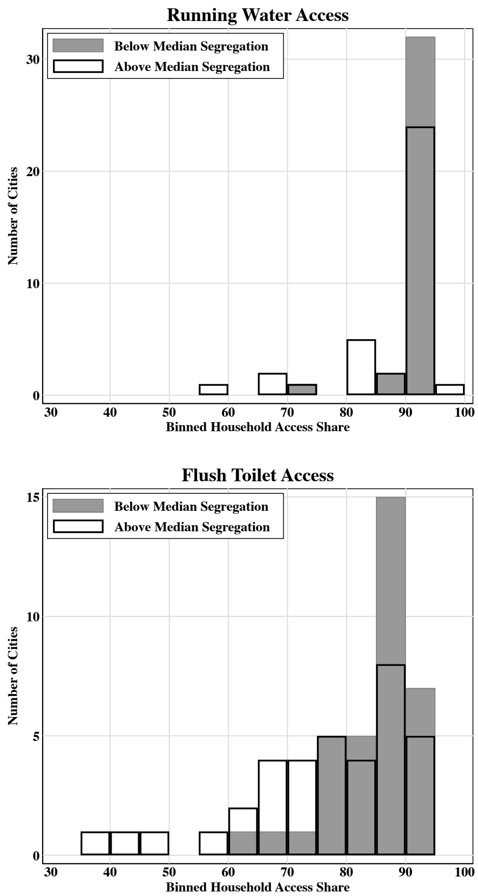


FIGURE 3. WATER AND SEWER ACCESS IN 1940

Note: City-level data are from the 1940 census of housing. Among above-median-segregation cities, average household running water and flush toilet access was 94% and 81% in 1940. In below-median-segregation cities, these figures were 98% and 90%, respectively.

VI. Conclusion

During the first half of the twentieth century, the United States experienced a dramatic decline in waterborne illness as cities invested in clean water technologies. This public health movement would not have been possible without earlier investments connecting households to a centralized water supply.

We provide evidence consistent with the narrative that more racially segregated cities were quicker to build their waterworks and more likely to exclude Black households. This exclusion appears to have come at a cost: more segregated cities were much slower to eliminate waterborne diseases like typhoid fever. These results are consistent with segregation-induced exclusion undermining the city's ability to control waterborne disease.

REFERENCES

Alsan, Marcella, and Claudia Goldin. "Watersheds in child mortality: The role of effective water and sewerage infrastructure, 1880–1920." *Journal of Political Economy* 127, no. 2 (2019): 586-638.

Anderson, D. Mark, Kerwin Kofi Charles, and Daniel Rees. "Re-examining the contribution of public health efforts to the decline in urban mortality." *American Economic Journal: Applied Economics* (Forthcoming).

Anderson, D. Mark, Kerwin Kofi Charles, Daniel Rees and Tianyi Wang. "Water purification efforts and the black-white infant mortality gap" *Journal of Urban Economics*, 122 (2021): 103329.

Ashraf, Nava, Edward L. Glaeser, and

Giacomo AM Ponzetto. "Infrastructure, incentives, and institutions." *American Economic Review* 106, no. 5 (2016): 77-82.

Baker, Moses Nelson, ed. *The Manual of American water-works*. Vol. 4. Engineering News, 1897.

Beach, Brian, "Water Infrastructure and Health in U.S. Cities." Regional Science and Urban Economics, (Forthcoming).

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

Costa, Dora and Matthew Kahn. "Declining Mortality Inequality within Cities during the Health Transition." *American Economic Review* 105. No. 5 (2015): 159-180.

Coury, Michael, Toru Kitagawa, Allison Shertzer, and Matthew Turner. "The Value of Piped Water and Sewers: Evidence from 19th Century Chicago." Working Paper, 2021.

Cutler, David and Grant Miller. "The role of public health improvements in health advances: The twentieth-century United States." *Demography* 42 (2005): 1-22.

Kellogg, John. "Negro urban clusters in the postbellum South." (1977): 310-321.

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

Logan, John. "Racial segregation in postbellum Southern cities: The case of Washington, DC." *Demographic Research* 36 (2017): 1759.

Logan, Trevon, and John Parman. "The national rise in residential segregation." *Journal of Economic History* 77.1 (2017): 127-170.

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

Troesken, Werner. "The limits of Jim Crow: race and the provision of water and sewerage services in American cities, 1880–1925." *The Journal of Economic History* 62, no. 3 (2002): 734-772.

Online Appendix for "Segregation and the Initial Provision of Water in the United States"

Brian Beach
Vanderbilt University
and NBER

John Parman
William & Mary
and NBER

Martin Saavedra
Oberlin College

January 12, 2022

Derivation of the Interior Solution

The city planner wishes to maximize $U(N_W, N_B, z)$ subject to budget constraint, which for an interior solution is $B = z + c \times m + F$. This implies that:

$$\begin{aligned}
U(N_W, N_B, z) &= \alpha N_W + (1-\alpha)N_B + \beta z \\
&= \alpha \int_0^m (1 - g(x))dx + (1-\alpha)\int_0^m g(x)dx + \beta z \\
&= \int_0^m \left[\alpha(1-g(x)) + (1-\alpha)g(x)\right] dx + \beta z \\
&= \int_0^m \left[\alpha + (1-2\alpha)g(x)\right] dx + \beta z \\
&= \int_0^m \left[\alpha + (1-2\alpha)g(x)\right] dx + \beta(B - c \times m - F)
\end{aligned}$$

Then $\frac{\partial U}{\partial m} = \alpha + (1-2\alpha)g(m) - \beta c$, which implies that the optimal main is when:

$$\begin{aligned}
(1-2\alpha)g(m^*) &= \beta c - \alpha \Rightarrow \\
g(m^*) &= \frac{\beta c - \alpha}{1 - 2\alpha} \Rightarrow \\
m^* &= g^{-1}\left(\frac{\beta c - \alpha}{1-2\alpha}\right) \\
&= g^{-1}\left(\frac{\alpha - \beta c}{2\alpha - 1}\right).
\end{aligned}$$

Proof of Propositions

Proposition 1 *For an interior solution, the size of the system decreases in the cost of mains and the preference for non-water public goods.*

Proof 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, $\frac{\partial\lambda}{\partial\beta} = \frac{-c}{2\alpha-1} < 0$ and an increase in the preferences for non-water public goods decreases optimal main mileage. ■

Proposition 2 *The size of the system m^* increases as γ increases.*

Proof This result follows immediately from the fact that

$$\begin{aligned} m^* &= g^{-1}\left(\frac{\alpha-\beta c}{2\alpha-1}\right) \\ &= \gamma - \frac{1}{k}\ln\left(\frac{2\alpha-1}{\alpha-\beta c}-1\right).\blacksquare \end{aligned}$$

Proposition 3 *If the optimal main stops in a neighborhood that is less than one-half Black (i.e., $m^* < \gamma$) then a marginal increase in either segregation (k) or the preference for Whites (α) increases the size of the optimal water system. Conversely, if $m^* > \gamma$, then a marginal increase in either k or α decreases the size of the optimal water system.*

Proof Note that $\frac{\partial m^*}{\partial k} = \frac{1}{k^2}\ln\left(\frac{2\alpha-1}{\alpha-\beta c}-1\right)$, which implies that $\frac{\partial m^*}{\partial k} > 0$ if and only if

$$\begin{aligned} \frac{2\alpha-1}{\alpha-\beta c}-1 &> 1 \Leftrightarrow \\ \frac{2\alpha-1}{\alpha-\beta c} &> 2 \Leftrightarrow \\ 2\alpha-1 &> 2\alpha-2\beta c \Leftrightarrow \\ \beta c > \frac{1}{2}. \end{aligned}$$

Now suppose that the optimal main stops in a majority White neighborhood. This implies that

$$
\begin{aligned}
m^* &< \gamma \Leftrightarrow \\
g^{-1}\left(\frac{\alpha-\beta c}{2\alpha-1}\right) &< \gamma \Leftrightarrow \\
\gamma - \frac{1}{k}\ln\left(\frac{2\alpha-1}{\alpha-\beta c}-1\right) &< \gamma \Leftrightarrow \\
0 &< \frac{1}{k}\ln\left(\frac{2\alpha-1}{\alpha-\beta c}-1\right) \Leftrightarrow \\
1 &< \frac{2\alpha-1}{\alpha-\beta c}-1 \Leftrightarrow \\
\frac{1}{2} &< \beta c,
\end{aligned}
$$

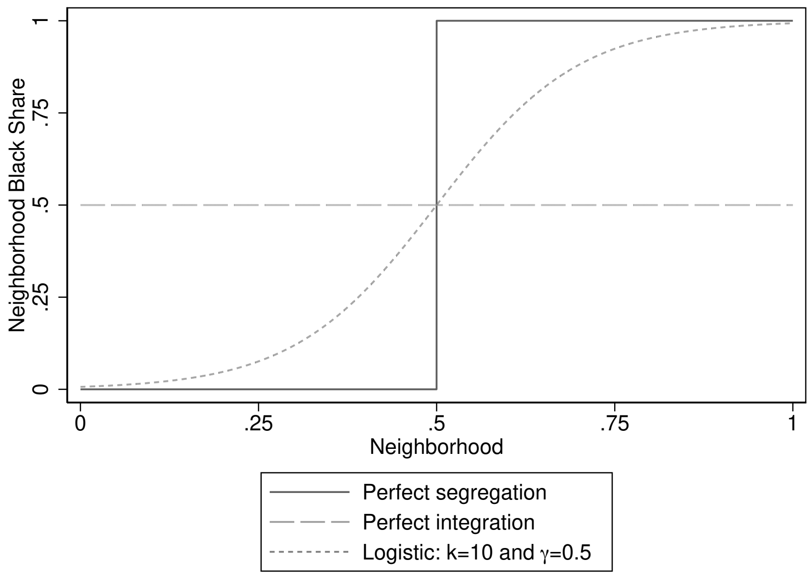
which implies that $\frac{\partial m^*}{\partial k} > 0$.

A symmetric argument will show that if the optimal main stops in a majority Black neighborhood, then $\beta c < \frac{1}{2}$ and $\frac{\partial m^*}{\partial k} < 0$.

As for the preferences for Whites (α), continue to let $\lambda = \frac{\alpha-\beta c}{2\alpha-1}$. Then $\frac{\partial \lambda}{\partial \alpha} = \frac{(2\beta c-1)}{(1-2\alpha)^2}$. This derivative is positive if $2\beta c - 1 > 0 \Rightarrow \frac{1}{2} < \beta c$ (when the optimal main stops in a majority White neighborhood) and negative when $\beta c < \frac{1}{2}$ (when the optimal main stops in a majority Black neighborhood). $\blacksquare$

Appendix Figures

Figure A.1: Examples of $g(.)$



Notes: The lines corresponds to hypothetical cities with the same Black share (50% in this case), but differ in their level of segregation. Neighborhoods are ordered 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.