Public Health Efforts and the Decline in Urban Mortality:
Reply to Cutler and Miller

D. Mark Anderson[*]
Montana State University, IZA and NBER

Kerwin Kofi Charles[†]
University of Chicago and NBER

Daniel I. Rees[‡]
University of Colorado Denver and IZA

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[*] Department of Agricultural Economics and Economics, Montana State University, IZA and NBER. E-mail: dwight.anderson@montana.edu.

[†] Harris School of Public Policy, University of Chicago and NBER. Email: kcharles@uchicago.edu.

[‡] Department of Economics, University of Colorado Denver. E-mail: daniel.rees@ucdenver.edu.

1. INTRODUCTION

This rejoinder is written in response to a comment by Cutler and Miller (hereafter CM-Comment) on our recent NBER Working Paper No. 25027 (Anderson, Charles and Rees 2018, hereafter ACR).

ACR analyze the effect of various public health interventions on mortality using data on 25 major American cities for the period 1900-1940. We study interventions that have received little attention from previous researchers, including treating sewage and setting bacteriological standards for milk. In addition, we provide new evidence on the effects of water filtration and chlorination using a much larger set of cities than were considered in the oft-cited and influential study by Cutler and Miller (2005, hereafter CM-2005).

Like previous researchers (CM-2005; Ferrie and Troesken 2008; Beach et al. 2016), ACR find that filtering the municipal water supply substantially reduced typhoid mortality. More generally, however, our results suggest that public health interventions did not drive the dramatic reductions in infant and total mortality that occurred over the period 1900-1940. Treating sewage and efforts to purify the milk supply appear to have been ineffective. Likewise, chlorinating municipal water supplies appears to have had no impact on mortality. Water filtration is associated with a (statistically insignificant) 1-2 percent decrease in total mortality and an 11-12 percent decrease in infant mortality, but these estimates are considerably smaller than the results reported in CM-2005.

Seeking to reconcile our results with those of CM-2005, we adopted CM's regression specification and restricted our focus to their sample of 13 cities and the period 1905-1936.[1] Two main results emerge from our re-analysis of the CM-2005 data: (1) correcting the infant mortality counts in CM-2005 (79 of 410 infant mortality counts in the paper were incorrectly transcribed)

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[1] Because the inaugural issue of *Mortality Statistics* was published in 1900, and because CM control for 5 lags of the total mortality rate, their analysis is effectively restricted to the period 1905-1936.

reduces the estimated effect of filtration on infant mortality by two-thirds, from -43 log points to -13 log points; and (2) using a consistent method of the calculating the total mortality rate (specifically, using total mortality counts divided by population estimates from the Census and linear interpolation for intercensal years) shrinks the estimated effect of filtration on total mortality in the CM-2005 sample by half, from -16 log points to -8 log points.

The CM-Comment naturally addresses itself only to the ACR water filtration and chlorination results as this is the only part of our paper that is directly related to CM-2005. In particular, CM focus on our re-analysis of the CM-2005 sample. We read the CM-Comment as making two main points. First, CM acknowledge the errors in their coding of infant mortality counts and observe that the estimated effect of filtration on infant mortality indeed becomes "markedly smaller" when these errors are corrected. However, they argue that this new, smaller estimate is not surprising given the "major causes of infant mortality during this era…along with the practice of exclusive breastfeeding."

The second issue addressed in the CM-Comment is how best to measure the total mortality rate, accompanied by various estimates of the effect of filtration on this rate. CM-2005 does not use a consistent method to measure the total mortality rate. For the years 1900-1917, CM directly take mortality rates published in *Mortality Statistics*. For the years after 1917, they divide total mortality counts from *Mortality Statistics* by population estimates from the Census (linearly interpolating population for intercensal years). CM show that the estimated effect of filtration on total mortality goes from -14 log points to -6 log points when, as in ACR, total mortality rates are calculated consistently using the total mortality counts from *Mortality Statistics* and linearly interpolated population estimates. The estimate of -6 log points is similar in magnitude to the estimate reported by ACR. Despite this dramatic reduction in the estimated effect of filtration, CM conclude that filtration was an important contributor to the decline in urban mortality.

We disagree sharply with these two points made in the CM-Comment and do three things in this rejoinder to address them. Specifically, we:

- Argue that the much-reduced estimated effect of water filtration on infant mortality is a dramatic and surprising departure from the consensus view in the literature, which was obviously influenced by the infant mortality estimates reported in CM-2005.

- Show that the estimated effect of water filtration on total mortality is extremely fragile even if one adopts the total mortality rates used by CM for the years 1900-1917. Evidence of this fragility may also be found in recent work by Pr. Cutler, released after ACR. Using the same data as was analyzed in CM-2005, Catillon, Cutler and Getzen (2018) show that water filtration is associated with a 4 percent reduction in the total mortality rate, which is much closer to our estimate than to the preferred estimate in the CM-Comment and CM-2005. We argue, therefore, that there is no basis for altering the conclusions of ACR.

- Provide evidence that the total mortality rates taken directly from *Mortality Statistics* are often inaccurate and should not be used by future researchers.

2. INFANT MORTALITY

CM-2005 show that total mortality in their sample of 13 cities fell by 30% from 1900 to 1936. Over the same period, infant mortality fell by 62%. CM attribute much of this latter reduction to the adoption of filtration technology. They write: "Clean water appears to have been responsible for 74%...of the reduction in infant mortality" (p 13).[2]

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[2] In an erratum, CM revise their calculations and attribute 59% of the reduction in infant mortality to clean water technologies (https://ngmiller.people.stanford.edu/sites/g/files/sbiybj4811/f/erratum.pdf).

As noted above, when errors in CM-2005 are corrected, the estimated effect of filtration on infant mortality goes from -43 log points to -13 log points. Although the CM-Comment does not present new estimates after correcting the coding errors identified by ACR, we read their language (specifically, that the point estimate for infant mortality is "markedly reduced") as agreeing with the point estimate reported in ACR.

We, however, disagree adamantly with CM's contention that this reduction in the point estimate to nearly one-quarter of its original size should not be seen as a departure from the consensus view in the literature. Nor do we agree with the claim that the much-reduced estimate of the effect of filtration on infant mortality should have been expected because there was universal breastfeeding during this period.

Exclusive breastfeeding was not the norm at the turn of the 20th century among American mothers. For example, Wolf (2001, 2003) reports that most mothers in Chicago did not exclusively breastfeed their newborns and, as a consequence, diarrhea was the leading cause of infant mortality.[3] Instead of breast milk, mothers typically fed their infants a gruel that contained water and cows' milk (Alsan and Goldin 2018, p. 22), both of which could carry deadly pathogens including, but certainly not limited to, typhoid. Thus, there was *a priori* reason to suppose that water filtration could have had a large effect on infant mortality. The CM-2005 estimated effect of -43 log points was clearly seen as credible and not unreasonably large by experts in this field, and it has obviously impacted how we think about the urban mortality decline and its causes.

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

CM-2005 has received a large number of citations, and the infant mortality result has been specifically cited by prominent scholars in the field.[4] For instance, Costa (2015, p. 559) used it to support the claim that the "literature has established the importance of water filtration and chlorination as perhaps the biggest contributor to the decline in infant mortality during the health transition..." Specifically, Costa (2015, pp. 545-546) noted that CM-2005 concluded that 74% of this decline can be attributed to clean water.[5]

Given the obviously profound influence of the CM-2005 filtration and infant mortality estimate, we find its dismissal in the CM-Comment to be puzzling.

3. TOTAL MORTALITY

CM-2005 and the CM-Comment do not use a consistent method to calculate total mortality rates. For the years 1900-1917, both take total mortality rates directly from *Mortality Statistics*. For the post-1917 period, CM divide total mortality counts from *Mortality Statistics* by U.S. Bureau of the Census population estimates (linearly interpolating population for intercensal years). In ACR, we use this latter method to consistently calculate mortality rates for the entire sample period. For the years 1900-1909, differences in total mortality rates between ACR and the CM papers are trivial.[6] By contrast, there are often substantial differences in total mortality rates for the period 1910-1917.

The CM-Comment shows that the estimated effect of filtration on total mortality is reduced from -14 log points to -6 log points when total mortality rates are calculated consistently across the

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[4] For examples, see Gordon (2014), Costa (2015), Beach et al. (2016) and Alsan and Goldin (2018). See also the literature reviews by Zwane and Kremer (2007) and Dupas and Miguel (2016), who cite CM's estimate of the effect of clean water on child, rather than infant, mortality.

[5] Costa (2015, pp. 545-546), also cited Ferrie and Troesken (2008), who examine efforts to purify the Chicago water supply over the period 1850-1925. Interestingly, Chicago did not build its first water filtration plant until 1947 (Baylis 1949).

[6] For the period 1900-1909, CM used revised mortality rates published in the 1909 annual *Mortality Statistics* volume.

entire study period. Although CM claim that both methods of calculating total mortality rates are equally valid (something with which we disagree, for reasons detailed below), they nevertheless focus on the estimate of -14 log points and conclude that water filtration "explains 38% of the mortality decline in our sample of cities and study years – a result not dramatically different from the estimated 43% in the original paper."

In Table 1, we explore the robustness of CM's total mortality estimate of -14 log points. We begin by switching from their specification to our, arguably more standard, specification.[7] We also restrict our attention to the sample of cities and years used by CM, use their method for calculating total mortality rates for the period 1910-1917, and use their preferred intervention dates.[8] Switching specifications reduces the estimated effect of filtration on total mortality from -14 log points to -10 log points. Controlling for other public health interventions (i.e., clean water projects, sewage treatment and milk-related interventions), reduces the estimated effect of filtration still further, to -8.3 log points. In column (4) of Table 1, we calculate total mortality rates consistently for the entire period under study (using mortality counts from *Mortality Statistics* and linearly interpolating population). This reduces the estimated effect of filtration to -7.8 log points. In the final three columns of Table 1, we correct CM's intervention dates, expand the period under study to 1900-1940, and expand the sample of cities from 13 to 25. We find that filtration is associated with a (statistically insignificant) decrease in the total mortality rate that ranges from -2.3 to -4.2 log points.

Taken at face value, the last three estimates reported in Table 1 represent only 8 to 14% of the total mortality decline in CM's sample. It is noteworthy that these estimates are of similar

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[7] CM control for 5 lags of the total mortality rate. In his chapter on dynamic panel data models, Baltagi (2013) shows that, in a fixed effects model, controlling for lags of the outcome is problematic and necessitates a GMM approach. CM do not weight their estimates, while we weight by city population. See Appendix Table 4 in Anderson, Charles and Rees (2018) for a detailed comparison of our regression specification with the specification employed by CM.

[8] In the CM-Comment, the authors argue that the filtration date for Philadelphia should be changed from 1908 (the date used in their original study) to 1909. We consider 1909 to be CM's preferred filtration date for Philadelphia.

magnitude to an estimate recently reported by Catillon, Cutler and Getzen (2018). Catillon, Cutler and Getzen (2018) use data for the period 1905-1936 on the same 13 cities considered by CM-2005. These authors also use CM's specification, but omit the city-specific linear trends.[9] They find that filtration is associated with a 4.1 percent ($e^{-.042} - 1 = .041$) reduction in the total mortality rate.[10]

In Table 2, we compare Catillon, Cutler and Getzen's (2018) estimate of -4.2 log points to the much larger filtration effect reported by CM-2005. We begin by replicating the original CM-2005 estimates (with clustered standard errors). In column (2) of Table 2, we correct the Memphis, TN transcription error (described by ACR and acknowledged in the CM-Comment). In column (3), we omit the city-specific linear trends, which reduces the estimated filtration effect from -13.4 log points to -5.8 log points. This latter estimate is similar to, and statistically indistinguishable from, the estimate reported by Catillon, Cutler and Getzen (2018).

Given the wide range of estimated filtration effects reported in the CM-Comment, the wide range of estimates reported by ACR, and the estimates reported by Catillon, Cutler and Getzen (2018), we believe there is little reason to emphasize the estimate of -14 log points in the CM-Comment.

4. MORTALITY RATES USED BY CM FOR THE YEARS 1910-1917: A CAUTIONARY NOTE TO FUTURE RESEARCHERS

The CM-Comment suggests that future researchers should consider a life-table method for computing mortality rates, which CM refer to as a "gold standard." However, this approach is not used by CM-2005 or ACR, nor are we aware of any scholars working in this literature who have used

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[9] Catillon, Cutler and Getzen (2018) also omit the following controls used in CM-2005: ln(Population), Begin Filtration Within Five Years and Begin Chlorination Within Five Years.

[10] This estimate can be found in the first column of Table 2 (Catillon, Cutler and Getzen 2018).

it. One reason for this may be that, to the best of our knowledge, annual city-level data on immigration and emigration are not available for the period under study. We do not discuss this proposed gold-standard approach further as it is not relevant to the analyses discussed in this rejoinder.

We will, however, compare the mortality rates used by ACR with those used by CM for the years 1910-1917, which appear to be inaccurate. We believe that they should not be used by future researchers.

To assess the accuracy of these rates, we "backed out" the population estimates used by *Mortality Statistics* to produce total mortality rates for the period 1910-1917.[11] In Figure 1, these estimates, which were produced before the 1920 census was conducted, are plotted against linearly interpolated population estimates using the 1910 and 1920 censuses. For some cities, the population estimates used by CM are essentially equivalent to the linearly interpolated estimates (e.g., Chicago and Philadelphia). For other cities, however, the estimates used by CM are clearly inaccurate (e.g., Baltimore, Cincinnati and Detroit). For instance, CM's population estimate for Detroit is slightly over 600,000 in 1917, while the linearly interpolated estimate would put Detroit's population at over 800,000 in 1917. To take another example, CM's population estimate for Jersey City in 1917 is over 310,000, yet Jersey City's 1920 census population was less than 300,000.

Finally, we illustrate the pitfalls of taking the mortality rates directly from *Mortality Statistics*. Table 3 shows the mortality rates as used by CM for four selected cities versus mortality rates based on linearly interpolated population estimates. For Chicago, we note that the two sets of rates correspond closely during the 1910-1917 period.[12] By contrast, in Detroit and Baltimore, the

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[11] Specifically, we used the following formula to calculate the population estimates used in *Mortality Statistics*:

$$population = 100{,}000 * \left(\frac{mortality\ count}{mortality\ rate}\right)$$

[12] Recall that, after 1917, CM switch to using mortality counts and the linearly interpolated population estimates.

CM rate is consistently and substantially over-estimated during the 1910-1917 period. For instance, in 1917 the CM total mortality rate for Detroit is 1,894 per 100,000 population while the total mortality rate produced using a linearly interpolated population estimate is 1,405 per 100,000 population. The CM population estimates for cities such as Detroit and Baltimore are obviously too low (Figure 1) and, as a consequence, produce inflated mortality rates. For other cities (e.g., Cincinnati, Louisville and Jersey City), the CM population estimates are obviously too high, which leads to mortality rates that are systematically lower than the rates obtained using linear interpolation.

5. CONCLUSION

Although the water filtration results in ACR necessitate a reassessment of the conclusions in CM-2005, we feel there is much to admire about the paper's approach and analysis. In particular, CM-2005 introduced modern econometric methods to a literature that had been previously dominated by case studies. These methodological contributions alone justify the paper's enduring significance.

We would also like to stress that our finding that municipal public health interventions, including of water filtration, had limited effects on mortality during the years of the "mortality transition" should not be read as a statement that public health efforts are not effective - perhaps even hugely effective - in other places or at other times. ACR study public health interventions in a sample of American cities during an important period and our results concern only that sample.

We note that we are gratified by the description Prs. Cutler and Miller give of our exchanges with them. As we hope the foregoing makes clear, we disagree with the conclusions of the CM-Comment and stand firmly by the conclusions of ACR. While working to reconcile differences between our water filtration results and the results in CM-2005, we updated CM about our results and the explanations we discovered for the discrepancies. We shared a draft of ACR with CM for their thoughts and suggestions, which they graciously provided. We submitted our paper to the NBER Working Series and shared it with scholars in the field only after confirming with CM that it was fine to do so. All of our exchanges have been as professional and cordial as they describe.

Finally, we would like to reiterate that the causes of the urban mortality decline remain only dimly understood. If the municipal public health interventions studied by ACR cannot explain why total and infant mortality fell so precipitously between 1900 and 1940, perhaps other factors such as rising incomes, better living conditions and improved nutrition can (McKeown 1976; Fogel 2004). Yet, well-defined natural experiments that could causally identify these other factors have eluded researchers and significant work remains to be done to understand this profoundly important transition.

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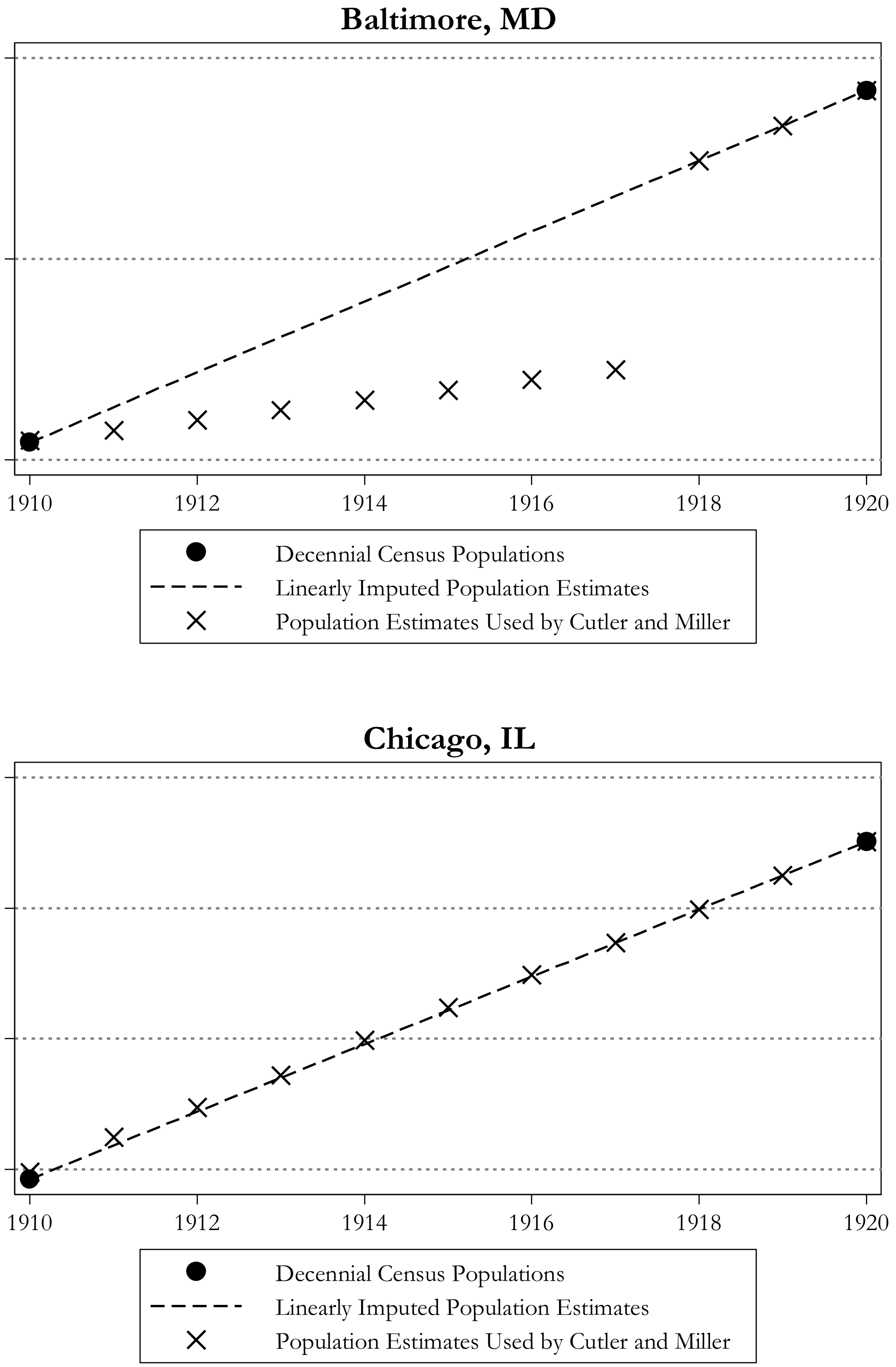
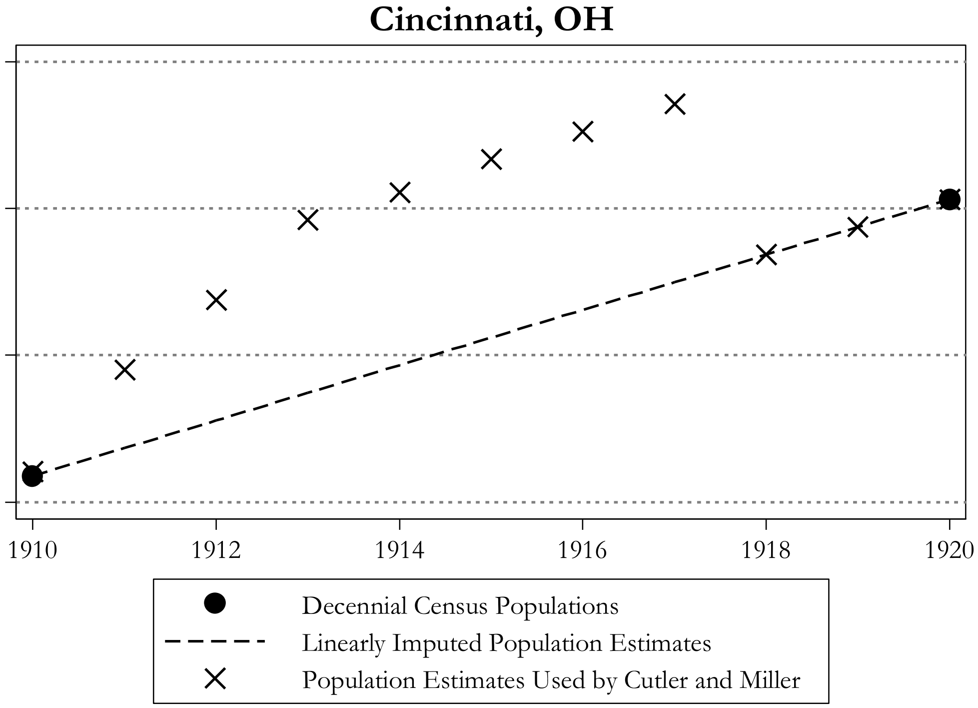
Figure 1. Population Estimates Used by Cutler and Miller




Cincinnati, OH
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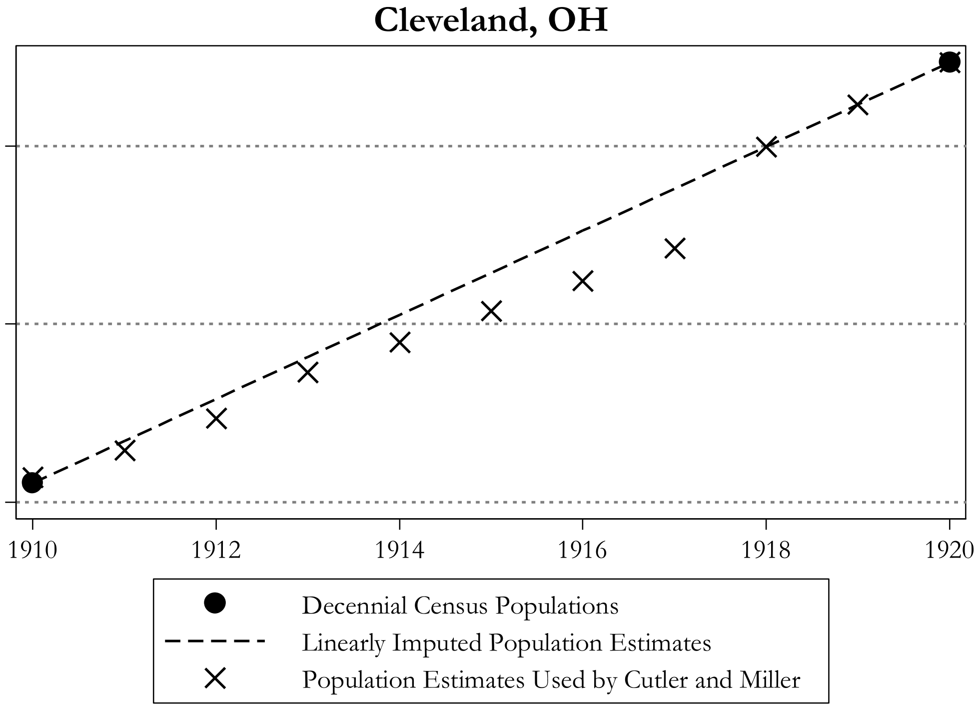
× Population Estimates Used by Cutler and Miller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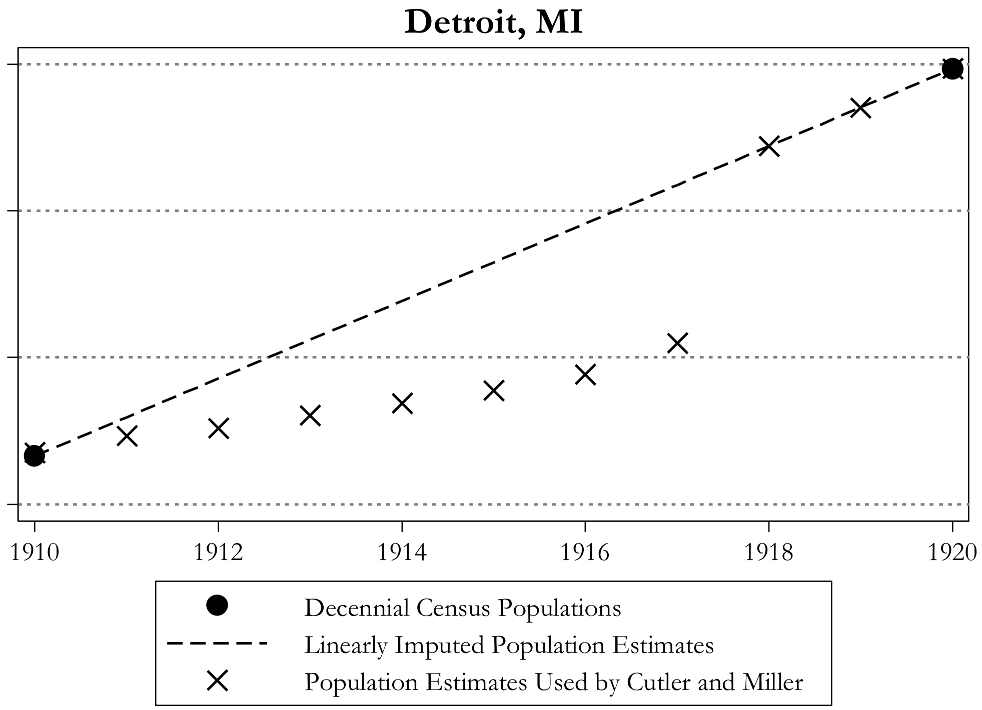
Detroit, MI
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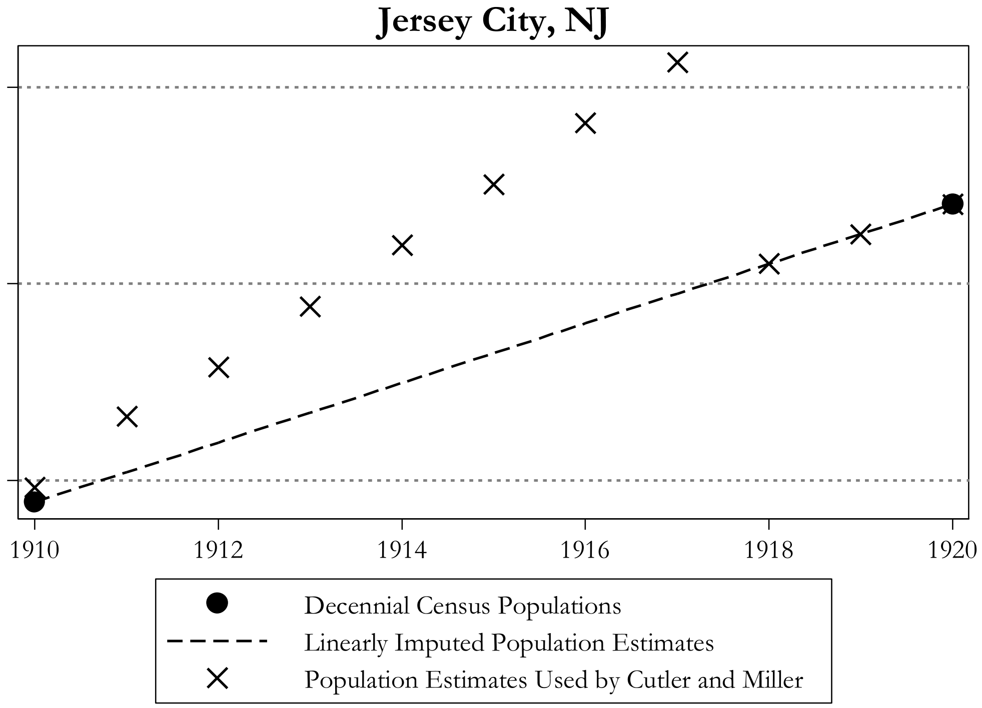
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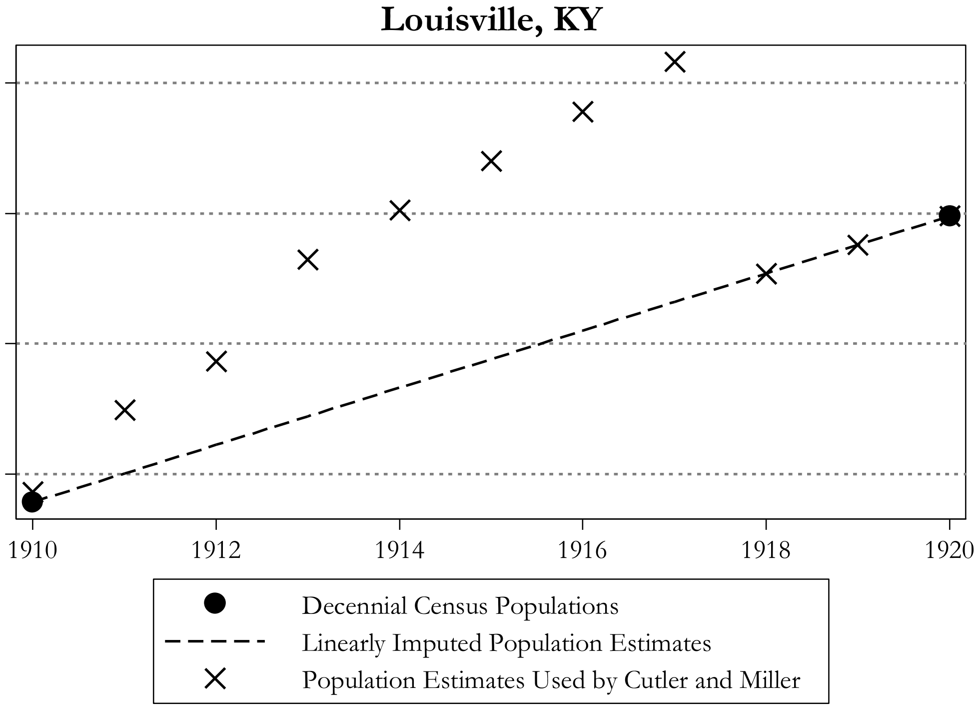
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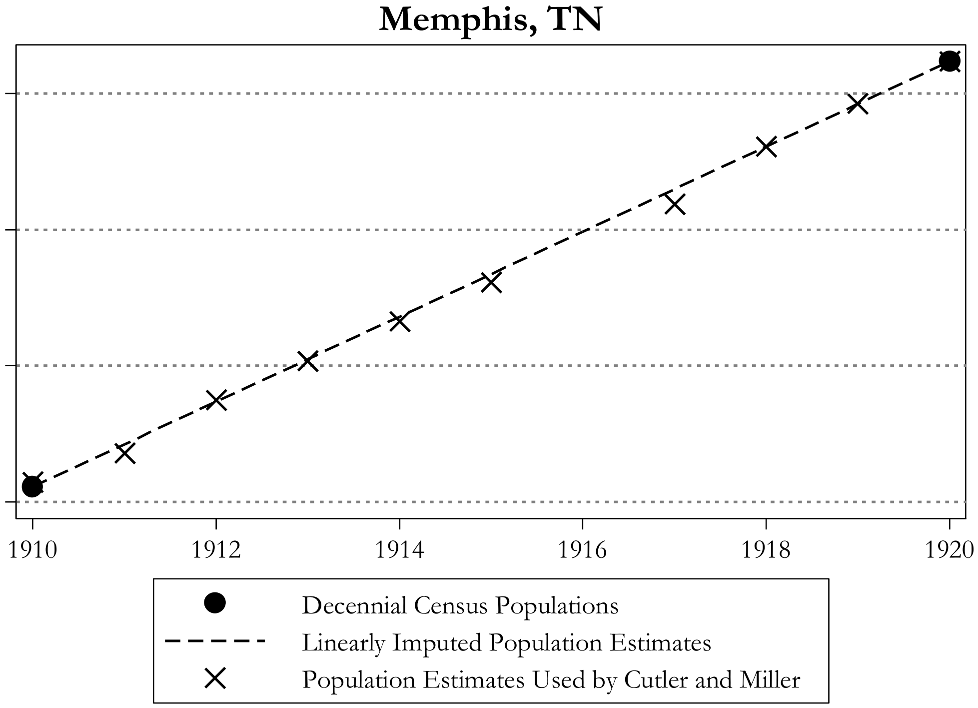
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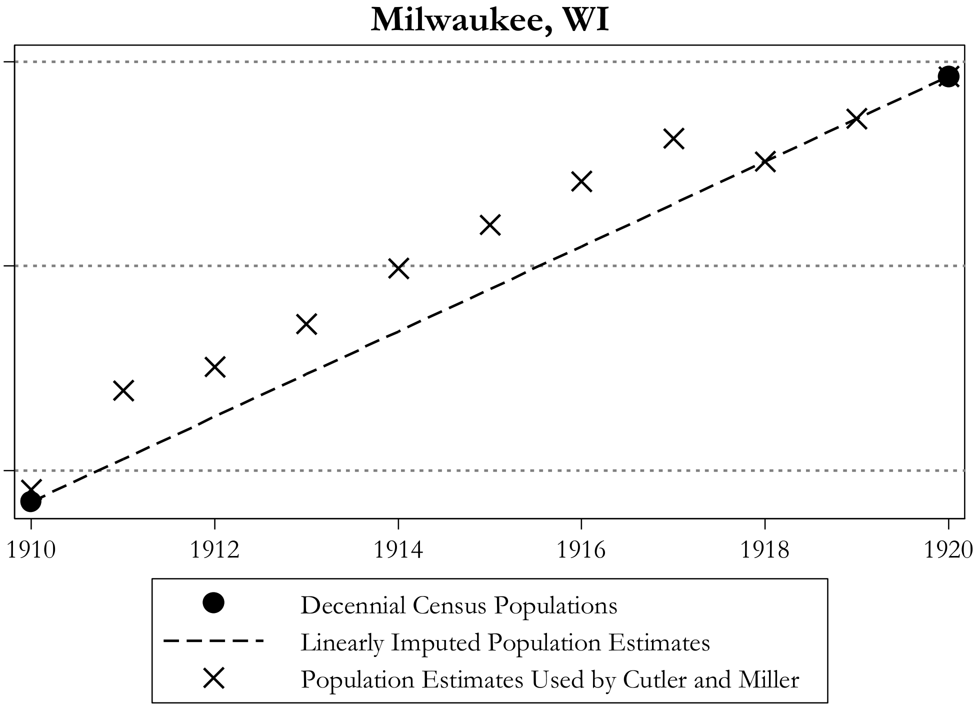
Milwaukee, WI
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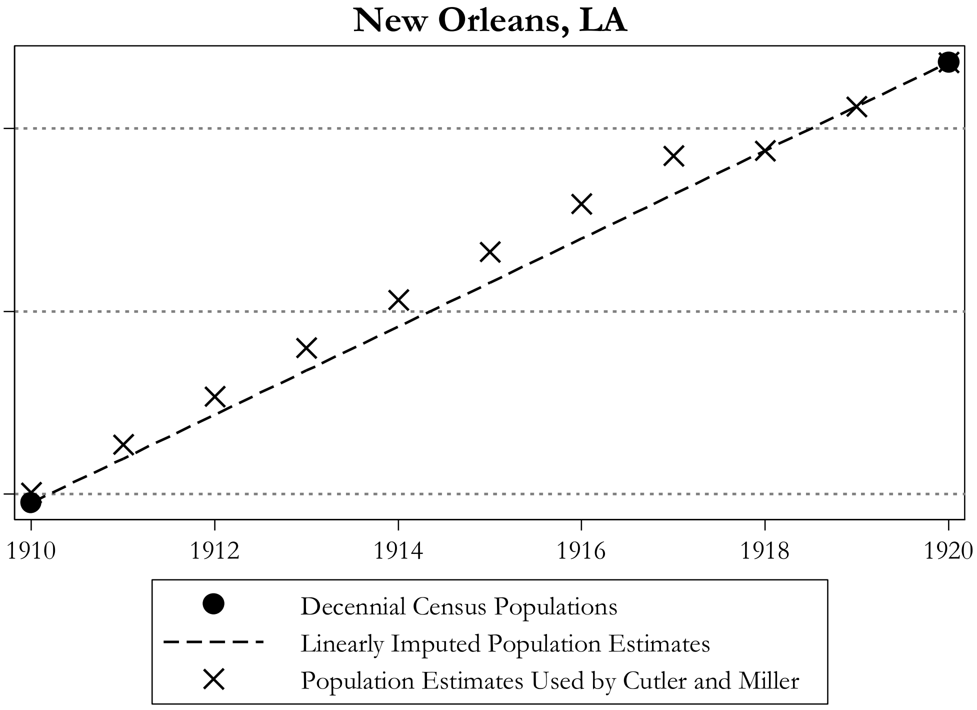
× Population Estimates Used by Cutler and Miller


New Orleans, LA
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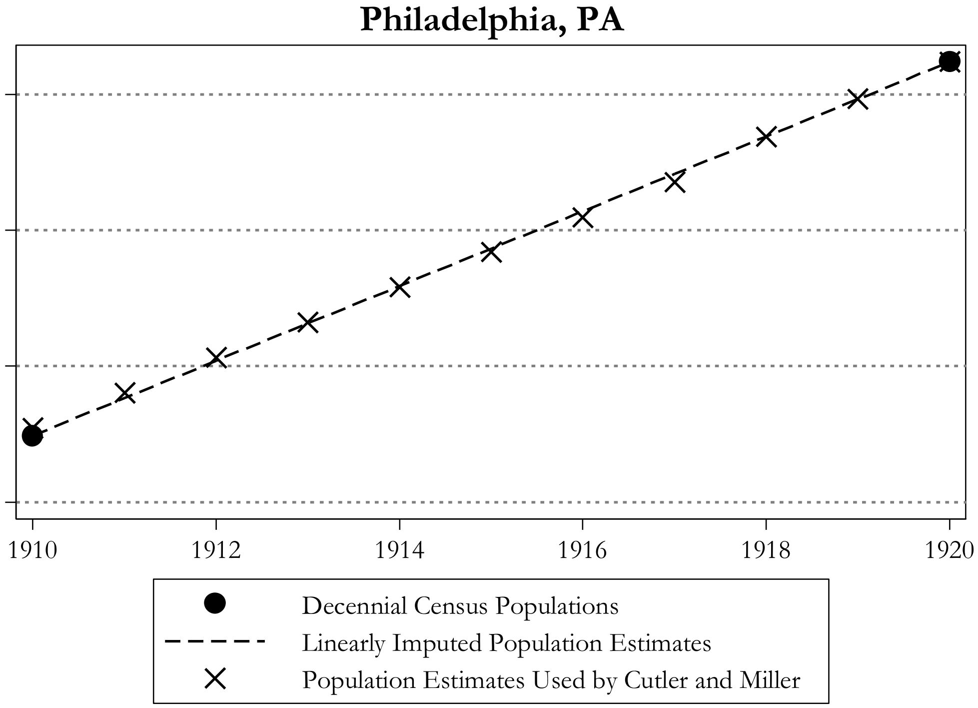
Philadelphia, PA
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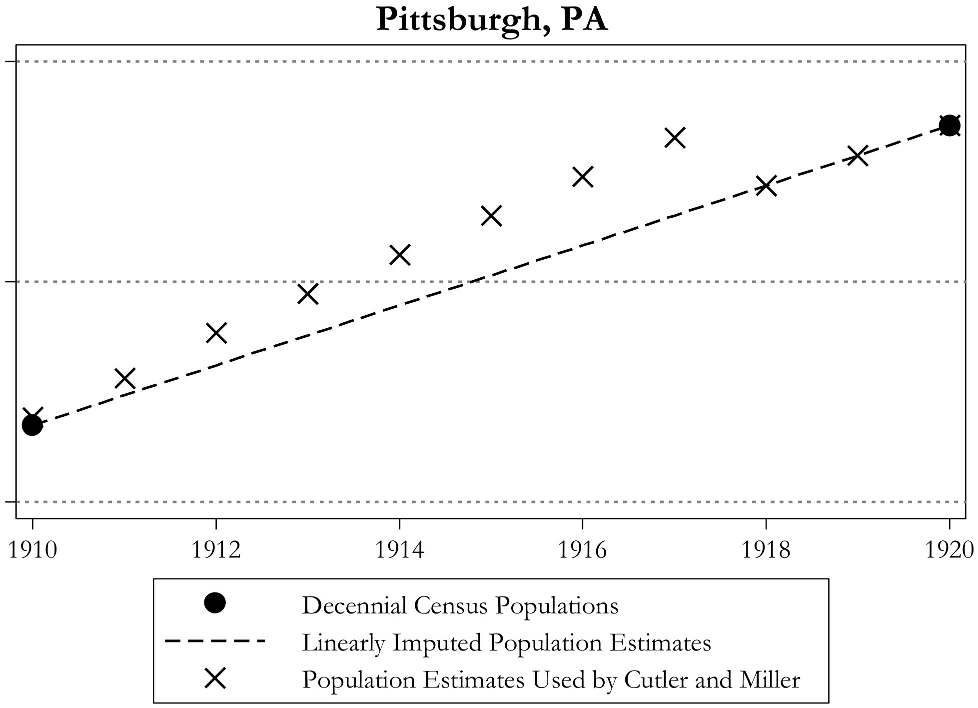
Decennial Census Populations
Linearly Imputed Population Estimates
Population Estimates Used by Cutler and Miller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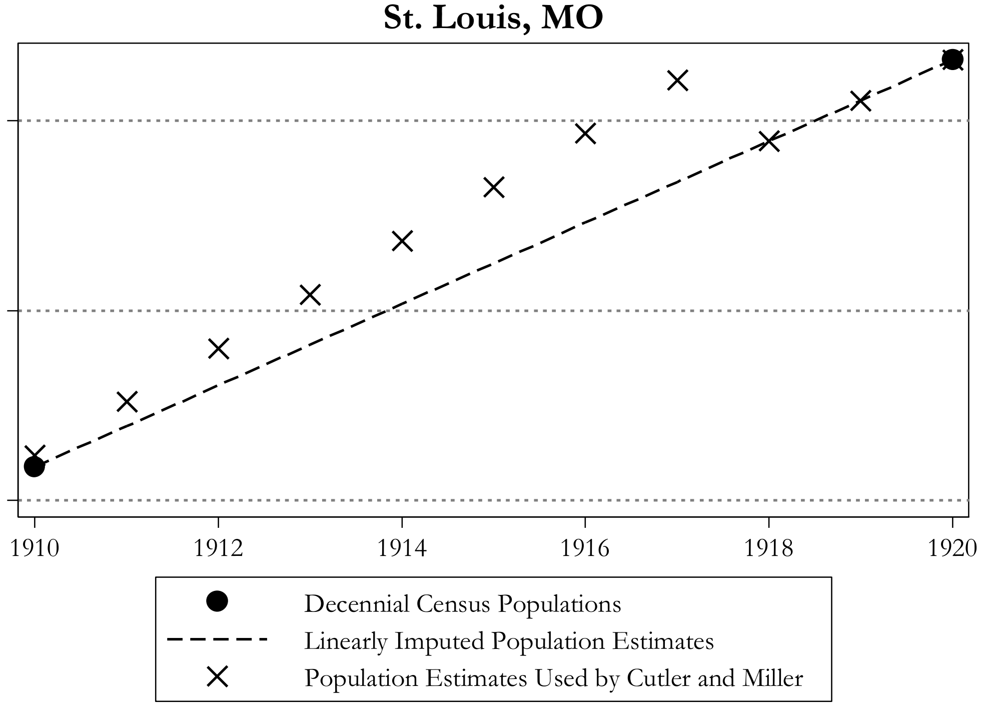
Decennial Census Populations
Linearly Imputed Population Estimates
Population Estimates Used by Cutler and Miller


St. Louis, MO
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Decennial Census Populations
Linearly Imputed Population Estimates
Population Estimates Used by Cutler and Miller

Table 1. Sensitivity of the Estimated Effect of Filtration on Total Mortality

	(1) CM's preferred estimate from their comment for comparison		(2)	(3)	(4)	(5)	(6)	(7)
Filtration	-.14**		-.100***	-.083***	-.078***	-.042	-.037	-.023
	(.054)		(.021)	(.017)	(.016)	(.027)	(.032)	(.019)
Chlorination	-.01		-.018	-.016	-.065**	-.019	-.013	.004
	(.023)		(.038)	(.031)	(.023)	(.029)	(.028)	(.014)
*Filtration*Chlorination*	.03		.050	.044	.075**	.031	.043	.021
	(.025)		(.030)	(.025)	(.027)	(.037)	(.037)	(.024)
Years	1905-1936		1905-1936	1905-1936	1905-1936	1905-1936	1900-1940	1900-1940
N	410		415	415	415	415	532	1,024
R^2	.963		.940	.944	.960	.957	.953	.951
		Control for other public health interventions?	No	Yes	Yes	Yes	Yes	Yes
		Method for calculating total mortality rate for 1910-1917	CM	CM	ACR	ACR	ACR	ACR
		Intervention dates	CM	CM	CM	ACR	ACR	ACR
		Sample of cities	CM	CM	CM	CM	CM	ACR

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

Notes: Based on annual data from *Mortality Statistics*, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the natural log of the number of deaths per 100,000 population in city *c* and year *t*. See Cutler and Miller (2018) for a description of the regression specification in column (1). In columns (2)-(7), controls include the demographic characteristics listed in Table 5 of Anderson, Charles and Rees (2018), city fixed effects, year fixed effects and city-specific linear trends; regressions are weighted by city population. Standard errors, corrected for clustering at the city level, are in parentheses.

Table 2. The Estimated Effect of Filtration on Total Mortality: Cuter and Miller (2005) vs. Catillon, Cutler and Getzen (2018)

	(1)	(2)	(3)	(4)
	Original estimates from Cutler and Miller (2005) with clustered standard errors	Column (1) + Memphis, TN correction	Column (2) + no city-specific linear trends	Estimates from Catillon, Cutler and Getzen (2018)
Filtration	-.162**	-.134**	-.058	-.042*
	(.064)	(.053)	(.034)	(.020)
Chlorination	-.017	-.010	-.009	-.008
	(.034)	(.024)	(.022)	(.011)
*Filtration*Chlorination*	.047	.032	.035	.046**
	(.031)	(.025)	(.020)	(.014)
Years	1905-1936	1905-1936	1905-1936	1905-1936
N	415	410	410	410
R^2	.957	.963	.958	.950

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

Notes: Based on annual data from *Mortality Statistics*, published by the U.S. Census Bureau. Each column represents the results from a separate OLS regression. The dependent variable is equal to the natural log of the number of deaths per 100,000 population in city *c* and year *t*. See Cutler and Miller (2005) or Anderson, Charles and Rees (2018) for further description of the regression specifications in columns (1)-(3). See Catillon, Cutler and Getzen (2018) for further description of the regression specification in column (4).

Table 3. Mortality Rates for Baltimore, Chicago, Detroit and Jersey City, 1910-1920

	Year	Mortality Rate Used by CM	Mortality Rate Calculated Using Linearly Interpolated Population Estimates
Baltimore, MD	1910	1,921.8	1,925.4
	1911	1,843.4	1,806.7
	1912	1,824.0	1,750.3
	1913	1,849.0	1,738.5
	1914	1,809.2	1,668.1
	1915	1,711.9	1,548.9
	1916	1,809.3	1,607.4
	1917	1,909.6	1,666.9
	1918	2,262.6	2,262.6
	1919	1,596.0	1,596.0
	1920	1,547.5	1,547.5
Chicago, IL	1910	1,514.0	1,521.1
	1911	1,446.3	1,454.3
	1912	1,483.1	1,487.1
	1913	1,505.9	1,508.3
	1914	1,416.4	1,419.8
	1915	1,425.5	1,428.0
	1916	1,453.5	1,455.0
	1917	1,492.3	1,492.5
	1918	1,696.0	1,696.0
	1919	1,263.9	1,263.9
	1920	1,289.9	1,289.9
Detroit, MI	1910	1,585.1	1,599.9
	1911	1,442.1	1,371.1
	1912	1,545.7	1,362.0
	1913	1,727.9	1,441.2
	1914	1,562.3	1,240.9
	1915	1,572.0	1,195.0
	1916	1,904.1	1,403.8
	1917	1,894.0	1,405.0
	1918	1,451.3	1,451.3
	1919	1,204.8	1,204.8
	1920	1,378.7	1,378.7
Jersey City, NJ	1910	1,634.4	1,643.5
	1911	1,584.6	1,617.7
	1912	1,400.4	1,439.5
	1913	1,457.7	1,514.8
	1914	1,375.2	1,444.0
	1915	1,448.4	1,536.4
	1916	1,462.4	1,566.6
	1917	1,448.7	1,566.8
	1918	2,082.3	2,082.3
	1919	1,479.3	1,479.3
	1920	1,416.0	1,416.0