Economic Consequences of Childhood Exposure to Urban Environmental Toxins*

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Abstract

During the late nineteenth century, half of all municipalities in the U.S. installed lead water pipes, exposing millions of people to harmful levels of lead consumption. This paper explores the long-term effects of waterborne lead exposure on men's labor market outcomes using linked samples drawn from the full count 1900, 1910 and 1940 censuses. For identification, we leverage variation in lead pipe adoption across cities and differences in the chemical properties of a town's water supply, which interact to influence the extent of lead leaching. Results show adult men with higher levels of waterborne lead exposure as children have lower incomes, worse occupations, and lower levels of completed education compared to adult men who had lower levels of waterborne lead exposure as children. In addition, men who are exposed to higher levels of waterborne lead have a significantly decreased probability of improving their income rank relative to their fathers, which is consistent with lead exposure behaving like a negative place-based shock that constrains upward mobility.

KEYWORDS: LEAD EXPOSURE, EDUCATION, EARNINGS, INTERGENERATIONAL MOBILITY

JEL CLASSIFICATION:

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1 Introduction

People around the world have experienced consequential levels of lead exposure throughout much of the nineteenth and twentieth centuries. Lead exposure has come through a variety of sources including occupational exposure, lead contaminated drinking water, fuel emissions, lead-based paint, and contaminated soil. The medical and epidemiological evidence is now explicitly clear that lead is harmful at any level of exposure, and can adversely affect an individual's health, especially when exposed to lead as a child (Bellinger et al., 1992; Borja-Aburto et al., 1999; Hu et al., 2006; Needleman, 2004). For young children, these adverse health effects have resulted in worse birth outcomes, impaired cognition, and higher rates of mortality (Dave and Yang, 2022; Aizer et al., 2018; Clay et al., 2014). Among adolescents, this has led to lower test scores, behavior problems, and lower levels of educational attainment (Hollingsworth et al., 2022; Aizer and Currie, 2019; Grönqvist et al., 2020), and new research is emerging to show lasting mortality and cognitive impacts in older adults from childhood lead exposure (Lee et al., 2022; Hollingsworth and Rudik, 2021).

What remains an open puzzle is how childhood exposure to lead impacts an individual's labor market outcomes in adulthood. Prior work by Grönqvist et al. (2020) has begun to explore this link by imputing earnings losses based on returns to education for individual's exposed to lead in Sweden. Our paper pushes this research agenda forward by using individual-level US census data linked from 1900 to 1940 for the continental U.S. to directly estimate the impact of childhood exposure to lead-contaminated water on long-run labor market outcomes, including income, unemployment status, occupational choices, and intergenerational income mobility. Additionally, we consider the impacts of lead exposure on educational attainment to explore a potential mechanism for the labor market findings.

In the late nineteenth and early twentieth century, the dominant form of lead exposure for children in the US was waterborne lead. Over this period, many towns constructed water infrastructure systems that included lead service pipes which connected main water lines to individual residences and businesses.[1] Lead leached from these lead pipes and was introduced into drinking water, representing substantial exposure to this environmental toxin.

Our empirical strategy leverages variation in the intensity of waterborne lead exposure due to the pipe material (lead vs. non lead) used and the chemical properties of the local water supply. More acidic water increases the amount of lead leached from lead pipes, which exposes individuals to higher levels of waterborne lead (Schock, 1990). Our approach builds on a rich literature that exploits similar differences in water source chemistry to identify the causal impacts of water-borne lead exposure. Troesken (2008) and Clay et al. (2014) leverage variation in waterborne lead exposure to show a strong link between lead exposure and elevated infant mortality. Ferrie et al. (2012) and Lee et al. (2022) both find a negative relationship between lead exposure and cognition measured at different stages of life. Work in contemporary settings exploits changes in chemistry from changes in municipal water sources and finds worse birth outcomes, lower education scores, and lower housing prices (Dave and Yang, 2022; Zheng, 2021; Christensen et al., 2023).

The causal interpretation of the relationship between waterborne lead exposure and long-run adult labor market outcomes relies on the central assumption that variation in water chemistry is plausibly exogenous to the outcomes of interest. Critical for identification purposes, the chemistry of the local water source was exogenously determined by local geology and was not a consideration when towns chose whether or not to use lead service pipes. This helps alleviate the selection concerns where lead pipe adoption was more likely among larger and wealthier towns (Clay et al., 2014; Feigenbaum and Muller, 2016).

[1] Experts and government officials now recognize that the use of lead as material in water infrastructure systems significantly increases exposure to the toxin. Amendments to the 1986 Safe Drinking Water Act prohibit the use of lead as a material in public water systems and residential plumbing.

For our analysis, we build an individual-level dataset from the full count U.S. population censuses in 1900, 1910, and 1940 (Ruggles et al., 2021). We link individuals between 1900 and 1910 and then to 1940, and combine this with town-level information on the type of service pipes and local water chemistry. We construct our linked samples using young men between the ages of 0 and 20 in 1900 linked to their census records in 1910 and in 1940 (Price et al., 2021). We focus on young men because female labor force participation and earnings were still limited in 1940 with only 20% of linked women reporting any positive wage and salary income. The full count censuses in each decade identify a limited number of larger cities and town. We supplement the existing town information with additional location matching from Berkes et al. (2023) to dramatically increase the number of towns that can be identified in the full count censuses. Similar to prior literature, we digitize town water system information from Baker (1897), and water chemistry information for the US Geological Survey in 1952 (Lohr and Love, 1954).

Findings show a strong negative relationship between childhood waterborne lead exposure and long-run labor market outcomes. Individuals exposed to a higher intensity of waterborne lead, driven by the combination of acidic water and lead service pipes, experienced 7% lower wage and salary incomes in 1940 compared to individuals not exposed to these acidic conditions. These same individuals experience a 1.5 percentage point increase in the probability of being unemployed. Evidence suggests that individuals with more childhood waterborne lead exposure are sorted into occupations with lower median earnings. Education appears to be the main driver of these findings, as years of education is approximately 0.2 years lower for individuals exposed to a higher intensity of waterborne lead.

We use family information within the 1900 and 1910 censuses to consider whether lead exposure affects intergenerational mobility. Our measures of intergenerational mobility focus on changes in the income rank of sons relative to their fathers. Results reveal a sharp negative relationship between lead exposure and the likelihood of the son having an improved income rank relative to their father. Consistent with other literature showing that higher socio-economic status can mitigate the negative impacts of lead exposure (Ferrie et al., 2015; Grönqvist et al., 2020; Hollingsworth et al., 2022), heterogeneity analysis shows that young men whose fathers were in the upper part of the income distribution did not experience lower rates of economic mobility. The results demonstrate how local shocks, like lead exposure, can behave like a negative place-based shock that constrains upward mobility.

This paper makes key advancements in three different strands of literature. First, this paper complements the literature on lead exposure among adolescents and adults. Our findings reinforce the educational attainment results in Grönqvist et al. (2020) while sharpening our understanding of the impacts on earnings, by directly estimating the effects on income. We do this by leveraging a unique and rich dataset that encompasses nearly 1,000 cities in the U.S., and approximately 1.2 million young men linked between 1900 and 1940. Our paper is also the first to examine occupational sorting, where we find that lead exposure, and subsequent education decisions, induced young men to sort into lower paying occupations.

Second, our paper builds on the existing work that assesses the impact of lead exposure in historic contexts (Troesken, 2008; Clay et al., 2014; Feigenbaum and Muller, 2016). Most of the prior work relies on comparisons of town-level outcomes over time, whereas our paper takes advantage of the availability of individual-level data.[2] In this way, we complement recent work that uses granular data to evaluate the impact of the introduction of water systems in the early twentieth century (Beach et al., 2016; Beach, 2022; Coury et al., 2022).

Finally, we add to the literature on intergenerational mobility. Our paper builds on a growing literature that considers how policies and other local shocks contributed to changing intergenerational mobility over time and across locations (Olivetti and Paser-

[2]For exceptions that use linked individual-level data see, Ferrie et al. (2012) and Lee et al. (2022).

man, 2015; Tan, 2023; Ward, 2022). Our findings are consistent with lead exposure behaving like a local shock that produced local differences in intergenerational mobility. This highlights the potential role of infrastructure in shaping patterns of mobility and relates to recent work on the importance of place for explaining differences in economic mobility (Chetty et al., 2014; Chetty and Hendren, 2018).

2 Pathways Linking Lead and Adult Outcomes

It is now well known that lead is highly toxic to humans, and absorption interferes with the body's normal processes (Bradbury and Deane, 1993; Needleman, 2004).[3] Exposure to lead starts as early as *in utero*, when a mother's lead levels can affect fetuses, as lead can cross the placenta and be absorbed by the fetus (Needleman, 2004; Manton et al., 2003). Exposure and absorption of lead continue throughout life as breast milk contains lead leached from the mother's bones (Gulson et al., 1998), and the toxin is directly ingested via lead-contaminated substances.

For this paper, there are two salient characteristics of how lead impacts individuals. First, lead affects children differently than it does adults. Children absorb lead five times more efficiently than adults (Hammond, 1982; Bellinger, 2004) and children have immature central nervous systems that are more vulnerable to lead poisoning than mature adults (Needleman, 2004). For this reason, we focus on a sample of individuals who were exposed to lead-contaminated drinking water between the ages of 0 - 20.

The second salient characteristic is that the body does not expel lead quickly. Repeated exposure to the toxin accumulates in an individual's bones, which can impact the level of lead in their blood years later (Troesken, 2006; Ferrie et al., 2015). Therefore, we would expect childhood exposure to the toxin may have both immediate and lasting impacts. Prior literature has documented the lasting impacts of childhood exposure to lead, this is

[3]For a summary of the medical literature see Needleman (2004).

summarized in Grönqvist et al. (2020).

2.1 Lead Exposure in the Nineteenth Century

In the late nineteenth century, a common form of lead exposure was from ingesting lead-polluted water (Troesken, 2006).[4] As the population began to grow and urbanization occurred in the latter half of the nineteenth century, towns began to implement organized water infrastructure systems. Lead was a common choice of material to use for water pipes because it was durable and cost-effective in the long run, with lead pipes typically lasting twice as long as iron or steel pipes (Troesken, 2008). Pipes that connected main water lines to individual residences, commonly known as service pipes, were often made of lead.[5] Water that runs through lead pipes leaches lead from the pipe into the water, causing town inhabitants to drink lead-polluted water.

The pH of the water passing through lead pipes influences the amount of lead that can be leached into the water (Schock, 1990).[6] Figure **??** depicts the relationship between the amount of lead in water, caused by running through a lead pipe, and the pH of the water.[7] Highly acidic water, with a pH below 6.5, is associated with more lead leaching from the pipes into the passing water. As the pH increases, less lead is leached into the passing water. This relationship between a given water supply's chemical properties and it's ability to leach lead from service pipes has been well documented and used in other research designs (Ferrie et al., 2012; Lee et al., 2022).

Engineers and health officials in the nineteenth century encouraged the use of lead plumbing, not understanding how much lead leaches into the water via lead service pipes and the risks of low-level lead exposure (Troesken, 2006; Committee on Service Pipes,

[4]In the late twentieth century, common forms of lead exposure shifted to be from the inhalation of dust and fumes containing lead, and the ingestion of lead-tainted paint.

[5]In addition to lead service pipes, lead solder was also commonly used to join segments of piping.

[6]The diameter and length of pipe can also influence how much lead was leached into drinking water (Schock, 1990). However, this information is not available for the sample used in this paper.

[7]This figure is based on Schock (1990) and Clay et al. (2014).

1917; Journal of the American Medical Association, 1942).[8] The scientific community at the time focused on the effects of very high levels of lead exposure, due mainly to occupational exposure. A common engineering principle at the time, known as the Doctrine of Protective Power, informed engineers and public health officials that lead pipes were safe to use if the water supply was not corrosive (Troesken, 2006). While this advice was correct, it was not followed. Many city officials and water supply companies ignored the portion of the Doctrine of Protective Power that considered the chemical properties of the water supply, and universally assumed lead pipes were safe to use everywhere (Troesken, 2006).[9] It was commonly argued that a protective coating quickly formed within a lead pipe, removing the risk of lead leaching into water (Adams, 1852; Lindsay, 1859). While a protective coating can form, it can take decades to do so and may not completely mitigate the risk of lead leaching into the water (Troesken, 2006; Ferrie et al., 2012).

Contemporaneous evidence demonstrates that lead was indeed being leached into drinking water in the late nineteenth century, at what is now considered dangerous levels. In 1900, the Massachusetts State Board of Health calculated the lead content in water for twenty-two towns in Massachusetts. For the ordinary use of water, the average lead content was 51 times the current EPA threshold.[10] If water was allowed to stand in the pipes for a few hours, the average lead content was 114 times the current EPA threshold.

2.2 Pathways Linking Lead Exposure and Long-Run Labor Market Outcomes

There are three main pathways linking lead exposure and long-run labor market outcomes. The fist pathway through which lead may impact long-run labor market out-

[8] One notable exception was Swann (1892), who postulated that lead leaching from lead plumbing was a problem, but he did not have robust scientific evidence to prove it.

[9] Clay et al. (2014) also notes an article from *Engineering News* in 1916, stating that concerns over lead pipes were inflated. Similarly, several articles from the *Journal of the American Medical Association* in the 1940s argue lead pipes were safe for consumers.

[10] The current EPA threshold for lead in drinking water is 15 parts per billion. Some researchers are calling on the EPA and the CDC to reduce this threshold even more, see Bellinger (2008).

comes, is lead's negative impact on cognition and intelligence. Decreased cognitive functioning and intelligence may influence one's earning power and occupation. There is a large body of literature documenting that lead exposure, even at very low doses, decreases test scores, cognitive functioning and intelligence (Needleman and Gatsonis, 1990; Canfield et al., 2003; Dorsey et al., 2006; Stewart and Schwartz, 2007; Ferrie et al., 2012; Aizer et al., 2018; Lee et al., 2022). While much of this evidence is based on present day data and blood lead levels, Ferrie et al. (2012), use data on WWII U.S. Army enlistees, to show that enlistees exposed to more waterborne lead, measured by using the type of water pipes and the pH of the water an enlistee was exposed to, had lower scores on the Army General Classification Test, a proxy for intelligence. In a similar spirit, Ferrie et al. (2015), shows that WWII draftees were less likely to be assigned to the Army Air Corps, where the most intelligent and disciplined recruits were assigned, with increased exposure to waterborne lead. Using data a nationally representative sample of older adults in the US from the Health and Retirement Study, Lee et al. (2022) finds that individuals who were exposed to cities with lead pipes and acidic or alkaline water conditions as children had worse cognitive functioning.

Second, lead exposure negatively impacts one's health, leading to a variety of conditions such as anemia, kidney failure, renal failure, nerve disorders, irregular red blood cells, hypertension and decreased fertility (Needleman, 2004; Clay et al., 2014; Borja-Aburto et al., 1999). Being in worse health impacts an individual's ability to work full time, the type of occupation they can get and their performance. Being in worse health as a child may also influence an individual's ability to attend school, as they may not physically be able to go to school every day and may drop out of school sooner than they otherwise would have.

Third, lead exposure may influence long term labor market outcomes by increasing the likelihood of behavior and conduct problems. In a meta-analysis by Marcus et al. (2010), a review of 19 studies shows increased exposure to lead is associated with conduct disorder, oppositional defiant disorder, aggressive and violent behavior, and delinquent, antisocial and criminal behavior.[11] Lead exposure is also strongly associated with Attention Deficit/Hyperactivity Disorder (ADHD) in children and adolescents.[12] Neuroanatomical findings support the association between lead exposure and behavior and conduct problems (Cecil et al., 2008). Using whole brain MRI scans, childhood blood lead levels are found to be linked to a loss of gray matter in the brain. The loss of brain matter occurs specifically in the anterior cingulate cortex (ACC), which is associated with mood regulation, executive functioning, and decision-making. These neuroanatomical findings were more pronounced for males than for females, suggesting heterogeneous impacts by sex (Cecil et al., 2008).

One consequence of the behavior and conduct problems caused by lead has been an increase in crime. Using variation in exposure to lead via lead polluted water and leaded gasoline several papers have found increased lead exposure is linked to increases in criminal behavior (Reyes, 2007, 2015; Feigenbaum and Muller, 2016).[13] In particular, Feigenbaum and Muller (2016) look at exposure to waterborne lead and find cities' use of lead service pipes increased homicide rates in the early twentieth century.

This paper identifies the reduced form impact of exposure to waterborne lead on adult labor market outcomes; it does not identify the importance, or weight given, to each pathway. Focusing on exposure to waterborne lead, rather than contemporary diagnoses of lead poisoning, incorporates the fact that the scientific community now knows that even extremely low levels of lead can have adverse effects on individuals (Bellinger et al., 1992).

[11] More recent studies, such as Reyes (2015) have also shown a strong causal link between lead exposure and delinquent behavior.

[12] Goodlad et al. (2013) provides a meta-analysis of this relationship, synthesizing 33 studies on this topic.

[13] Looking specifically at blood lead levels, Needleman et al. (2002), found lead levels were four times higher among convicted juvenile offenders than among other high school students not convicted of a crime.

3 Data, Sample Selection, and Summary Statistics

Our data construction process focuses on measuring labor market outcomes in adulthood and water-borne lead exposure during childhood for males in the continental U.S. To do this, we construct a unique and rich dataset that contains 1.2 million young men found in the U.S. censuses, from all 48 Continental states and from over 950 unique towns that constructed their water systems after 1850.[14]

We construct the individual-level dataset by linking the full population census in 1900 to the full census in 1910 and then to the full census in 1940.[15] We link individuals from 1900 through to 1940 because higher rates of mobility in the first half of the twentieth century imply we cannot infer lead exposure based on the place of residence in 1940, but instead need to determine an individual's place of residence during childhood. The 1940 census was the first census to record the labor market outcomes of interest, namely wage and salary earnings. In this data construction endeavor, we build on two recent advancements that increase access to the person-level full population censuses between 1900, 1910, and 1940. First, we follow young men, between the ages of 0 - 20, in 1900 into adulthood in 1940 using linked crosswalks developed by Price et al. (2021). Second, we assign lead exposure using location information in the 1900 census. Location information in publicly available samples was limited to larger cities, but recent work by Berkes et al. (2023) significantly expanded location availability in the individual-level data. We apply their location crosswalks to our linked sample, resulting in specific place assignments for over 90% of our dataset. We evaluate labor market outcomes in 1940. Our primary outcomes of interest are total wage and salary income and unemployment status. Additionally, we consider education and occupational sorting as two channels that could explain the difference in labor market outcomes.[16]

[14]Nearly all systems built prior to 1850 used lead. We focus our sample to decades with balanced adoption.

[15]Connecting to the 1910 census allows us to condition our results on individuals who were in the same places in 1900 and 1910, which minimize mobility during childhood.

[16]The 1940 census was the first to include completed years of education.

Taken together, these two advancements allow us to assign lead exposure to young men based on their place of residence in 1900 and then evaluate the long-term effects of this lead exposure in later adulthood. In order to mitigate mismeasurement concerns, we *exclude* anyone captured in the following conditions: 1) birthplace does not match their state of residence in 1900 2) recorded year of birth differs significantly from a birth year inferred from their reported age 3) relationship to the household head in 1900 is not a child 4) the individual lives in a rural household in 1900,[17] 5) individuals that move towns between 1900 and 1910, and 6) exclude any individuals not living in urban areas.

We combine this individual-level census data with information on the type of pipes used in an individual's town water infrastructure and the chemical properties of the water supply. Town water system information was recorded in *The Manual of American Water-Works* Baker (1897). The manual reports service pipe information for all major cities and many smaller locations, as well as the year of system construction. We categorize lead towns as those locations reporting any use of lead service pipes. Town water chemistry information was published by the United States Geological Survey in "The Industrial Utility of Public Water Supplies in the United States, 1952" (1954). From this report, we record the pH of the historical water sources for every available town.

Figure 2 plots the location of each town in our dataset with water system information from Baker (1897). Our present sample is constrained by the availability of water chemistry information. When we restrict our sample to locations with pH information, we have a final sample of roughly 1.01 million adult men in 1940 drawn from over 560 towns where we observe water system pipe information in 1900 and the pH of the water supply.

Table 1 illustrates the characteristics of the matched men in the sample within the set of observed towns with service pipe information. Panel A reports characteristics from childhood in 1900 and panel B reports outcomes of interest in 1940. On average, the

[17] Despite being assigned to a town, these households are unlikely to be connected to the local water system.

children are eight years old and their families have six people present. By construction, the population includes nearly no immigrants because we required they were classified as born in the US. The sample includes very few non-white individuals in the sample, and 93% live in a household with a male head. These same individuals in 1940 have an average wage and salary income of $1,824 USD, and 31% have completed high school.[18]

Our fundamental empirical comparisons are between individuals exposed to lead through their water systems to individuals whose water system did not expose them to lead leaching. This comparison raises concerns regarding the selection into the types of cities that chose to incorporate lead pipes into their water systems. Section 2 highlights that health concerns did not influence the adoption of lead pipes. Both Clay et al. (2014) and Feigenbaum and Muller (2016) show that population and wealth were the predominant factors contributing to lead adoption.

Table 2 presents town-level summary statistics aggregated from the 1900 individual-level census for the sample of 960 towns with water system information. Columns 1 and 2 present the means and standard deviations of each measure split by lead and non-lead status. Column 3 reports the unconditional differences in means with the standard errors reported in brackets. The results reveal the strong population differences highlighted in prior work, along with differences in industrial composition as well. The results indicate that lead towns were significantly larger, had higher shares of manufacturing and retail employment, and had a smaller fraction of the population employed in farming and mining. These towns were also home to more immigrants and fewer non-white individuals.

Column 4 reports conditional differences between lead and non-lead cities. The column introduces region fixed effects, town population fixed effects, and decade fixed effects for the year of construction. The fixed effects restrict the comparisons to towns of similar size making construction decisions along similar time horizons. The models also include decile fixed effects for the share of the population working in each of the listed

[18] The 1940 census top-coded incomes above $5,000 and we exclude those individuals from any specifications that rely on income. We did not find evidence of differences in the likelihood of being top-coded.

industries. Figure 1 illustrates the variation in construction timing by the type of water system for those systems built between 1850 and 1900. The differences in column 4 are substantially smaller in magnitude after conditioning on the fixed effects. Column 5 repeats the same conditional comparison for the 564 towns where we observe chemistry information. Within this sample of towns, we no longer observe statistically significant differences in demographic or economic conditions between lead and non-lead towns.

4 Persistence of Lead into Adulthood

4.1 Estimating Equation

Our empirical approach and predictions are motivated by how lead is transmitted under different water chemistry conditions as described by Clay et al. (2014) and Troesken (2008). First, we expect individuals exposed to waterborne lead during childhood to face worse long-term economic outcomes on average than individuals not exposed to waterborne lead. Second, we expect individuals exposed to lead pipes with acidic water should have worse average long-run outcomes than those exposed to lead pipes with less acidic water because lead leaching is worse in the more acidic conditions. Figure 3 illustrates the town-level variation in pH of the water supply and reveals that lead and non-lead towns faced similar distributions of pH, with similar density in the acidic tails below a pH of 6.5.

We test these predictions by estimating the following equation:

$$y_{it} = \beta_1 lead_t + \beta_2 lead_t \times (LowPHt) + \beta_3 lead_t \times (MediumPHt) + X'\delta_i + \rho_t + \psi_r + \epsilon_{it} \quad (1)$$

where y_{it} is the outcome of interest for individual i who lived in town t in 1900. A town's lead status, $lead_t$, equals 1 if the town's service pipes included lead. We step in two binary measures of water chemistry to capture different degrees of the acidity of water. $LowPH$

equals one if the town's water had a pH lower than 6.5, which is classified as strongly acidic. $MediumPH$ captures if the town's water was between 6.5 and 7.25, which would be weakly acidic. We include a vector of individual-level controls taken in 1900, including race, immigrant status, parent's immigrant status, sex of the household head, metropolitan status, and age.[19] Each element of X enters the model as a separate fixed effect. The specification includes the town-level controls from the person's childhood town in 1900 as discussed in section 3. These include town population fixed effects, a set of industry fixed effects, and year of construction decade fixed effects, ρ_t. The specifications also include region fixed effects, ψ_r. Finally, the models include fixed effects for the different pH bins, which focus the identification on places with similar underlying chemical environments. Standard errors are clustered by town $\times$ 5-year age bins, to allow for correlations between similarly aged individuals within the same towns in 1900. From our predictions, we expect β_1 to be associated with worse outcomes, with weaker negative effects for β_2.

4.2 Lead and Adult Outcomes

Findings show that exposure to lead service pipes in combination with acidic water leads to reduced wage and salary income as an adult well as an increased likelihood of unemployment. Table 3 presents results from estimating equation 1, where the outcomes of interest are wage and salary income and unemployment. These two outcomes allow us to evaluate the impact of lead exposure on the intensive and extensive margins of the labor market. Each column presents a slight variation of equation 1 for the two outcomes. Column 1 presents results from a specification with a single binary lead exposure treatment over the full sample of individuals and includes the complete set of covariates and fixed effects described above. The resulting coefficient of interest indicates that childhood exposure to lead service pipes is not associated with any changes in wage and salary income as an adult. However, column 2 interacts the presence of lead service pipes with

[19] See Table 1 for more information about each variable.

the local water having low pH, and we find that wage and salary income decreases by an average of 7%. Next, we include a measure of medium pH in the model (Column 3) and find that the negative effects of exposure to lead service pipes are concentrated in those that had the most acidic water.[20]

Earnings differences of 7% are larger in magnitude than those associated with other public health interventions, like reducing typhoid (Beach et al., 2016), but are in line with historic benefits from developing public health programs (Hoehn-Velasco, 2021). They are also slightly larger than contemporary estimates of the imputed wage effects of lead exposure in Sweden (Grönqvist et al., 2020).

Differences in wage income illustrate one way that lead could negatively impact an individual in the labor market. Another is through their ability to remain working. Columns 4–6 repeat the analysis but focus on whether the individual is unemployed. The results reveal a similar for unemployment across all three specifications. There is no impact of lead service pipes on their own, but in combination with acidic water, there is a 1.4–1.5 percentage point increase in the likelihood of unemployment in 1940.[21]

Table 4 provides some insight into the channels that could explain these results. Columns 1–3 introduce completed years of education as the outcome of interest and columns 4–6 focus on enrollment in high school. The results suggest that lead exposure during childhood is associated with lower completed years of education and lead exposure induces exit before high school. The results suggest that total years of education decline by nearly 0.2 years. The results in columns 5 and 6 highlight that most of those differences emerge prior to high school. The estimates suggest that these adults 0.05 percentage points less likely to start high school.

These reductions in educational attainment coincided with the rapid secular rise in

[20]The results from columns 1–3 reveal a marginally significant positive main effect on lead, but once we include the two-part chemistry interaction this effect is no longer significant.

[21]We repeated the above specifications while looking at labor force participation and whether the individual reports themselves as self-employed and find not statistical differences by lead status. Suggesting the effects are not driven by participation, but by realized labor market outcomes.

education levels, as high school attendance and completion rates grew considerably over this period (Goldin, 1998). Given the high returns to education during this period, a large fraction of the income result is likely explained by lower educational attainment (Goldin and Katz, 1999; Feigenbaum and Tan, 2020; Clay et al., 2021).

Figure 4 directly explores differences in occupational sorting by estimating the effect of lead exposure on whether an individual's occupation was in one of the ten single-digit occupational categories in the census. Each point estimate in the figure is from a separate regression of the chemistry interacted specification that exploits low pH (column 2 from prior models). The ten occupational categories are sorted from the lowest average income to the highest average income, which helps illuminate a pattern where men facing higher levels of lead exposure were more likely to be working in lower paying occupations like laborers and operatives and were less likely to be working in professional occupations. Many of these white collar positions included educational requirements, making them inaccessible to the young men that did not complete high school, and included relatively high wage premiums (Goldin and Katz, 1995).

5 Lead and Intergenerational Mobility

Education and occupation are two key channels that influence intergenerational mobility Parman (2011); Long and Ferrie (2013); Olivetti and Paserman (2015); Tan (2023); Ward (2022). Section 4 documents that lead exposure is associated with lower earnings, reduced educational attainment, and increased likelihood of sorting into lower paying occupations, all of which could affect upward mobility. In this section, we evaluate whether lead exposure altered the intergenerational mobility between fathers and sons and whether the initial income rank of fathers enhances or suppresses these effects.

5.1 Measuring Intergenerational Mobility

In order to measure intergenerational mobility, we use the household information in 1900 from our main sample to identify the fathers of our sample of young men. Income information was unavailable prior to the 1940 census. To determine income ranks for fathers in 1900, we follow the approach in Abramitzky et al. (2021) and Collins and Wanamaker (2022) of imputing income ranks for each individual using the father's occupation, race, age, state of residence, and which IPUMS metropolitan category they reside in. We use these characteristics to predict an individual's income in 1900 and 1910 and rank the incomes from 0 (lowest) to 100 (highest). To address the issue of measurement error in income identified by Ward (2021), we average the father's rank in 1900 and 1910. Similar to prior work that has applied this approach, the specific values of predicted incomes are less important than their rank order. We determine the rank order of sons based on their reported wage and salary income in 1940. Panel C of Table 1 shows overall summary statistics for the sample of father-son linked individuals between 1900 and 1940. Within this sample, roughly 49.5% of children had improved their income rank relative to their fathers.

5.2 Estimation and Results

We estimate the effect of lead exposure on intergenerational mobility by modifying estimating equation 1 to include additional covariates for the linked father.

$$y_{ift} = \beta_1 lead_t + \beta_2 lead_t \times (LowPHt) + X'\delta_i + \rho_t + \psi_r + Z'\mu_f + \epsilon_{ift} \tag{2}$$

We focus on whether the son's rank improved relative to their father's rank as our preferred measure of mobility, y_{ift}, between son i and father f.

Figure 5 presents the key estimate of interest from the interaction term in equation 2. The estimate suggests a weak, positive relationship between lead exposure and upward mobility. However, contemporary work examining the consequences of lead exposure finds that family socioeconomic status can exacerbate the negative consequences of lead Grönqvist et al. (2020); Zheng (2021). A fundamental challenge in evaluating the moderating role of socioeconomic status is separating lead exposure from other risk factors facing economically disadvantaged households. Historic, town-level exposure helps alleviate these concerns because lead exposure did not vary along neighborhoods or by racial groups, which gives us the ability to evaluate the effects of lead by different measures of socioeconomic status.

The additional estimates plotted in Figure 5 presents results from a series of specifications that estimate the effect of lead exposure within different quartiles of the father's income rank, where the first quartile estimates the relationship between lead and mobility within the lowest 25% of average income ranks.

The estimates reveal a consistent pattern, where the sharpest negative relationship between lead exposure and economic mobility occurs in the central two quartiles. The bottom quartile suggests a weak negative relationship. These suggest that lead exposure slowed economic mobility between fathers and sons for the children of low and middle income households. Interestingly, the highest quartile reveals a weak positive relationship consistent with higher socioeconomic status households being able to mitigate the negative effects of lead exposure.

Taken together, the results are consistent with lead exposure behaving like a negative place-based shock that constrains upward mobility. This type of place-based shock relates to recent work documenting the regional differences in historic mobility Tan (2023) and the significant role that places play in shaping contemporary estimates of intergenerational mobility (Chetty et al., 2014; Chetty and Hendren, 2018).

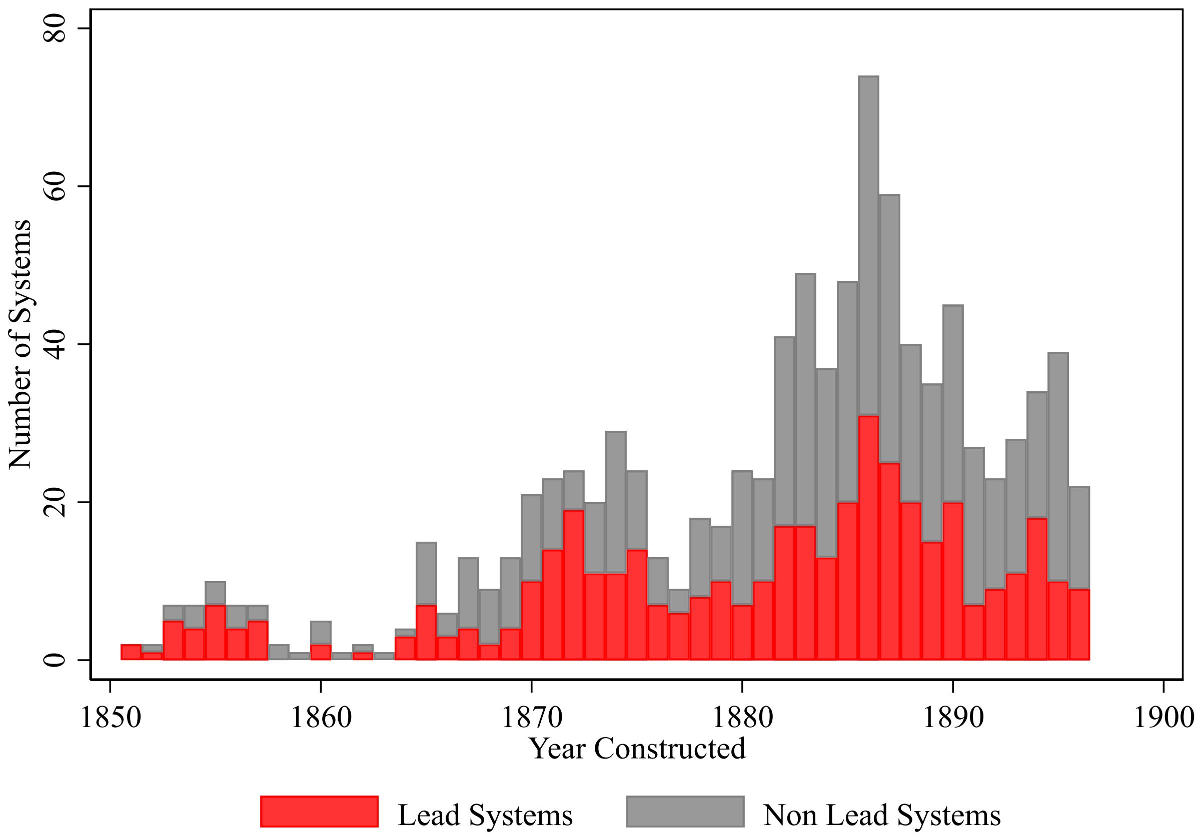
6 Conclusion

Municipal decisions in the late nineteenth and early twentieth century exposed millions of people to harmful levels of lead exposure. Unfortunately, the negative consequences of lead water pipe exposure are still a pressing issue today. The Environmental Protection Agency estimates that there are six - ten million active lead service lines in the United States (Environmental Protection Agency, 2021). In response, the Biden Administration recently approved legislation with the goal of replacing all lead pipes over the next decade (The White House, 2022).

This paper provides empirical evidence that lead service pipes had detrimental effects on exposed individuals into adulthood. This resulted in lower earnings, worse occupations, fewer years of education, and less intergenerational mobility. Earnings differences of 7% in 1940 correspond to differences of over $2,000 per person today. Given the historic prevalence of exposure, these differences aggregate to large negative economic impacts.

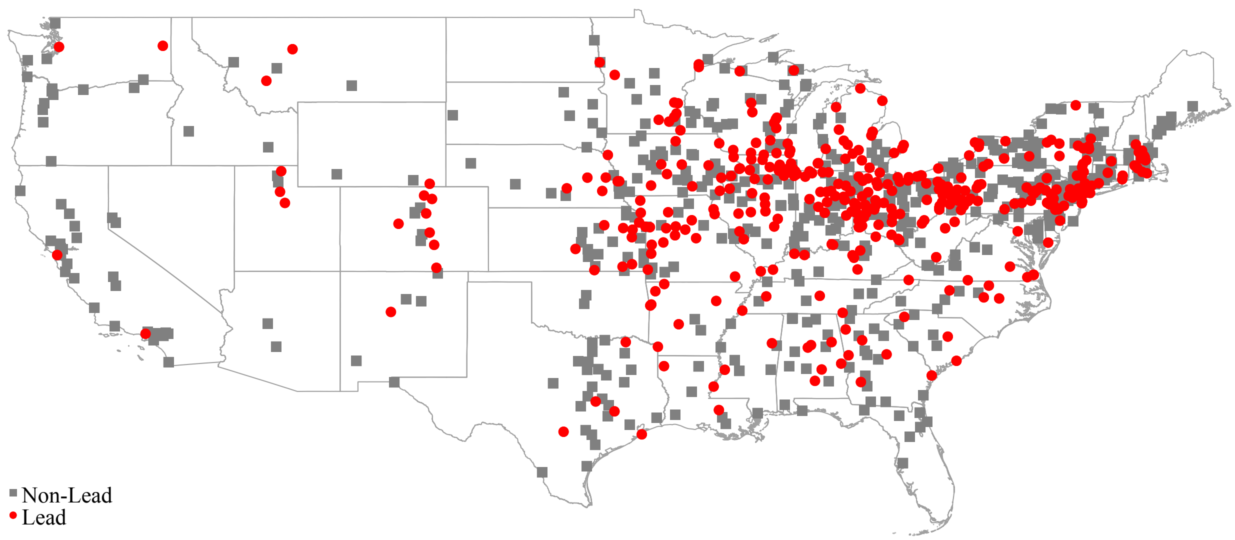
7 Figures

Figure 1: Water System Construction



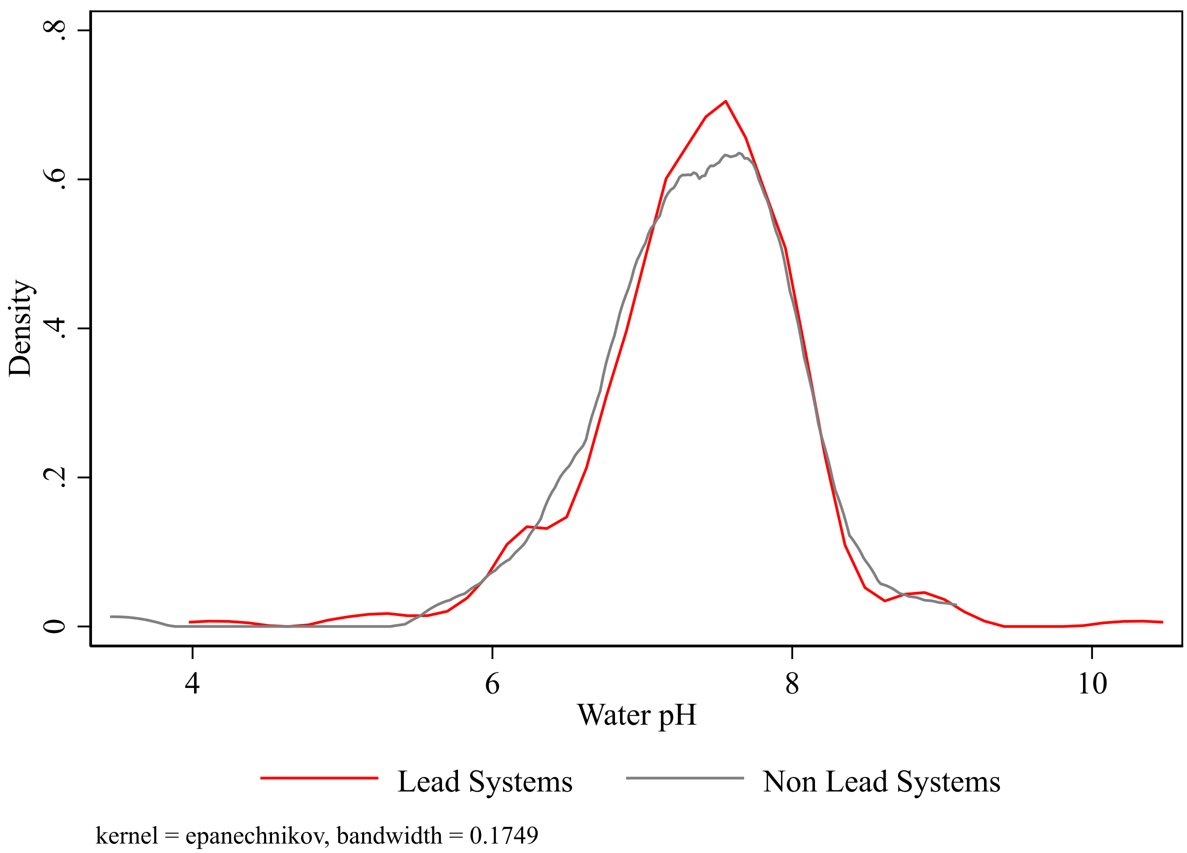
Notes: The figure plots the construction dates for water systems from Baker (1897).

Figure 2: Map of Lead Service Pipe Status by Location



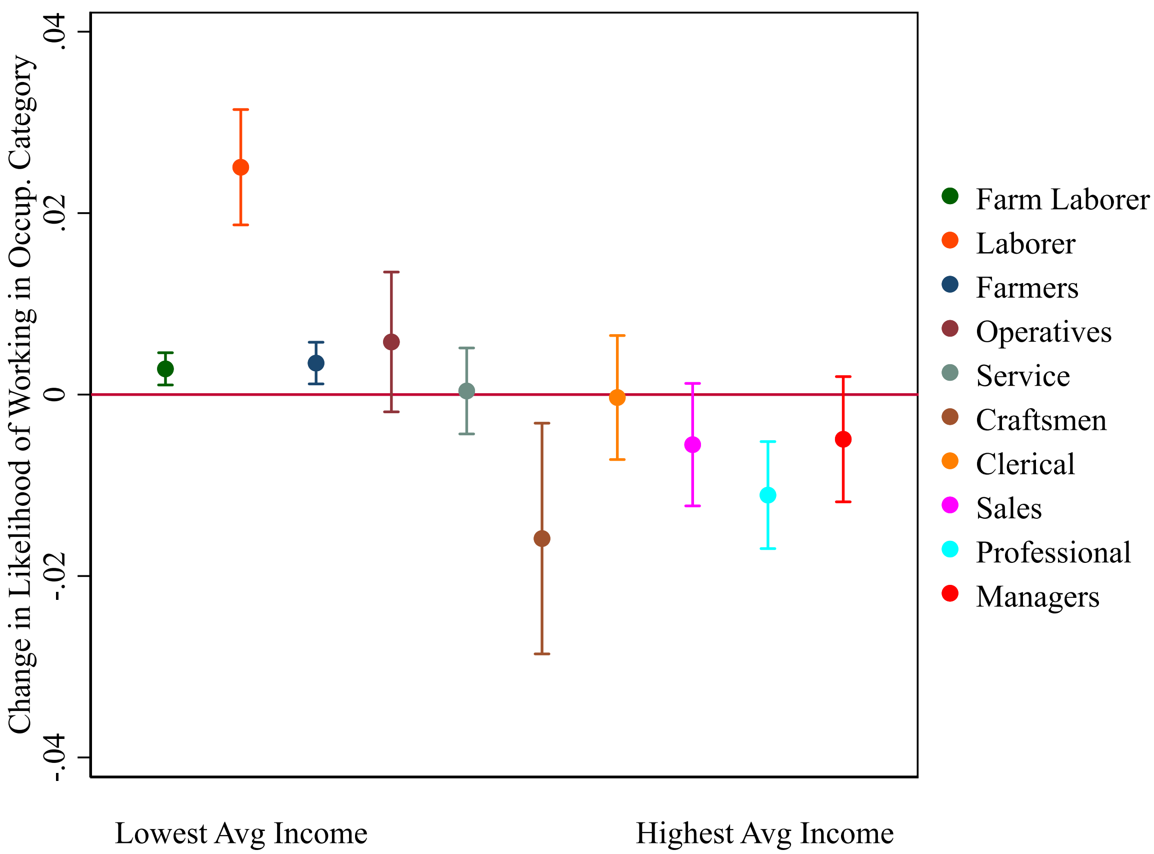
Notes: The figure plots the location of each town in the linked sample with water system information from Baker (1897). The figure distinguishes towns by whether they used any lead (red) or no lead (grey) for the town service pipes.

Figure 3: Water Chemistry Density Plot



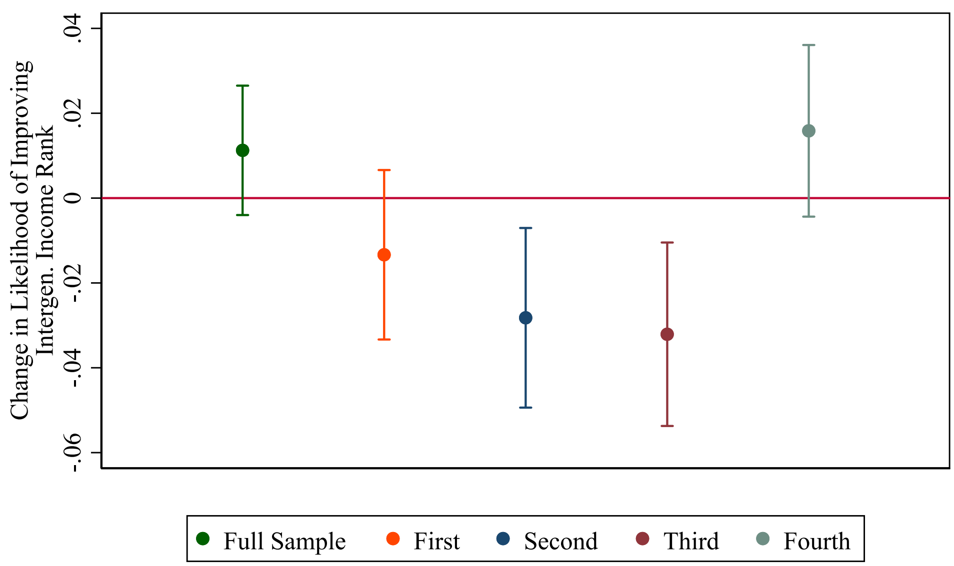
Notes:

Figure 4: Lead and Occupational Differences



Notes:

Figure 5: Lead and Intergenerational Mobility by Father's Income Quartile



(a) Lead and Change in the Likelihood of Improving Intergenerational Mobility Ranking

Notes:

8 Tables

Table 1: Individual Summary Statistics

	(1) Mean	(2) SD	(3) Min	(4) Max	(5) Count
Panel A: 1900 Census					
Age	7.898	5.599	0	20	1,192,189
Non-White	0.024	0.152	0	1	1,192,189
Family Size	6.071	2.125	1	56	1,192,189
Immigrant	0.004	0.061	0	1	1,192,189
Father Immigrant	0.031	0.174	0	1	1,192,189
Not in Metro	0.382	0.486	0	1	1,192,189
In Central City	0.487	0.500	0	1	1,192,189
Male Head of HH	0.931	0.254	0	1	1,192,189
Panel B: 1940 Census					
Wage and Salary Income	1824.428	1197.103	1	5,000	873,559
Occupational Prestige Score	30.253	10.614	3	80	1,111,595
Not in Labor Force	0.078	0.268	0	1	1,183,361
Completed Years of Education	10.627	3.303	0	21	1,169,882
Never Start High School	0.514	0.500	0	1	1,169,882
Completed High School	0.311	0.463	0	1	1,169,882
Any Post-Secondary Education	0.155	0.362	0	1	1,169,882
Panel C: Intergenerational Mobility					
Improved Income Rank	0.495	0.500	0	1	679,611
Change in Income Rank	-0.965	33.867	-99	99	679,611
Son Rank 1940	56.184	27.432	1	100	679,611
Father Rank 1900	57.604	26.146	1	100	925,561

Notes: Significance levels are denoted by * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 2: Differences in Town Characteristics by Lead Status in 1900

	(1)	(2)	(3)	(4)	(5)
	Non-Lead	Lead	Difference: Lead - Non Lead		
Chemistry Data (0/1)	0.56	0.63	0.07**	0.01	0.00
	(0.50)	(0.48)	[0.03]	[0.03]	[.]
pH	7.36	7.37	0.02	0.04	0.04
	(0.69)	(0.67)	[0.06]	[0.07]	[0.07]
Population (in 000s)	12.19	30.73	18.54***	1.23*	2.08
	(16.36)	(109.52)	[5.37]	[0.70]	[1.35]
Pct. Emp in Manuf	17.97	22.05	4.09***	0.40**	0.25
	(13.09)	(13.99)	[0.88]	[0.18]	[0.22]
Pct. Emp in Retail	13.30	14.28	0.98***	0.07	-0.05
	(3.77)	(4.02)	[0.25]	[0.09]	[0.06]
Pct. Emp in Service	26.87	27.04	0.17	-0.17	-0.03
	(9.16)	(8.63)	[0.58]	[0.15]	[0.19]
Pct. Emp in Mining	4.23	2.42	-1.82***	-0.92***	-0.40
	(11.93)	(7.70)	[0.64]	[0.35]	[0.32]
Pct. Emp in Farming	13.50	8.97	-4.53***	0.27	0.22
	(12.73)	(10.53)	[0.75]	[0.19]	[0.22]
Pct. Female	49.93	50.28	0.35*	0.09	0.22
	(3.31)	(2.85)	[0.20]	[0.17]	[0.22]
Pct. Immigrants	14.06	15.70	1.64**	0.23	-0.08
	(11.49)	(11.41)	[0.74]	[0.67]	[0.90]
Pct. Non-White	10.01	8.02	-1.99*	-0.90	-1.12
	(16.84)	(14.90)	[1.03]	[0.78]	[1.16]
Observations	537	423	960	959	564
Incl. Controls			No	Yes	Yes
Town Sample			Full	Full	Chemistry

Notes: This table reports on baseline differences in town characteristics. Columns 1–2 present mean and standard deviations by lead status. Column 3 reports differences unconditional differences, column 4 reports differences conditional on town controls, column 5 reports differences for the subset of towns with water chemistry information conditional on town controls. Significance levels are denoted by * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Lead and Labor Market Outcomes

	(1)	(2)	(3)	(4)	(5)	(6)
	Ln(Wage and Salary Income)			Unemployed=1		
Lead	0.011**	0.012*	0.011	-0.000	-0.000	0.001
	(0.005)	(0.006)	(0.007)	(0.001)	(0.001)	(0.002)
Lead × Low pH		-0.072***	-0.070***		0.015***	0.014***
		(0.017)	(0.018)		(0.003)	(0.003)
Lead × Medium pH			0.003			-0.002
			(0.012)			(0.002)
Observations	633,436	557,817	557,817	785,175	689,836	689,836

Notes: Significance levels are denoted by * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Lead and Educational Accumulation

	(1)	(2)	(3)	(4)	(5)	(6)
	Years of Educ			Did Not Start High School=1		
Lead	-0.045*	-0.064**	-0.034	0.019***	0.023***	0.015***
	(0.026)	(0.031)	(0.033)	(0.004)	(0.005)	(0.006)
Lead × Low pH		-0.188**	-0.226***		0.040***	0.050***
		(0.076)	(0.080)		(0.012)	(0.013)
Lead × Medium pH			-0.065			0.021**
			(0.058)			(0.010)
Observations	842,567	740,339	740,339	842,567	740,339	740,339

Notes: Significance levels are denoted by * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

References

Abramitzky, R., L. Boustan, E. Jácome, and S. Pérez (2021). Intergenerational mobility of immigrants in the united states over two centuries. *American Economic Review 111*(2), 580–608.

Adams, H. (1852). *On the action of water on lead pipes, and the diseases proceeding from it*. Transactions of the American Medical Association.

Aizer, A. and J. Currie (2019). Lead and juvenile delinquency: new evidence from linked birth, school, and juvenile detention records. *Review of Economics and Statistics 101*(4), 575–587.

Aizer, A., J. Currie, P. Simon, and P. Vivier (2018). Do low levels of blood lead reduce children's future test scores? *American Economic Journal: Applied Economics 10*(1), 307–41.

Baker, M. N. (1897). *The Manual of American Water-Works*, Volume 4. Engineering News.

Beach, B. (2022). Water infrastructure and health in us cities. *Regional Science and Urban Economics 94*, 103674.

Beach, B., J. Ferrie, M. Saavedra, and W. Troesken (2016). Typhoid fever, water quality, and human capital formation. *The Journal of Economic History 76*(1), 41–75.

Bellinger, D. C. (2004). Lead. *Pediatrics 113*(3), 1016–1022.

Bellinger, D. C. (2008). Very low lead exposures and children's neurodevelopment. *Current opinion in pediatrics 20*(2), 172–177.

Bellinger, D. C., K. M. Stiles, and H. L. Needleman (1992). Low-level lead exposure, intelligence and academic achievement: a long-term follow-up study. *Pediatrics 90*(6), 855–861.

Berkes, E., E. Karger, and P. Nencka (2023). The census place project: A method for geolocating unstructured place names. *Explorations in Economic History 87*, 101477.

Borja-Aburto, V. H., I. Hertz-Picciotto, M. R. Lopez, P. Farias, C. Rios, and J. Blanco (1999). Blood lead levels measured prospectively and risk of spontaneous abortion. *American Journal of Epidemiology 150*(6), 590–597.

Bradbury, M. and R. Deane (1993). Permeability of the blood-brain barrier to lead. *Neurotoxicology 14*(2-3), 131–136.

Canfield, R. L., C. R. Henderson Jr, D. A. Cory-Slechta, C. Cox, T. A. Jusko, and B. P. Lanphear (2003). Intellectual impairment in children with blood lead concentrations below 10 μg per deciliter. *New England Journal of Medicine 348*(16), 1517–1526.

Cecil, K. M., C. J. Brubaker, C. M. Adler, K. N. Dietrich, M. Altaye, J. C. Egelhoff, S. Wessel, I. Elangovan, R. Hornung, K. Jarvis, and B. P. Lanphear (2008, May). Decreased Brain Volume in Adults with Childhood Lead Exposure. *PLOS Medicine 5*(5), e112.

Chetty, R. and N. Hendren (2018). The impacts of neighborhoods on intergenerational mobility ii: County-level estimates. *The Quarterly Journal of Economics 133*(3), 1163–1228.

Chetty, R., N. Hendren, P. Kline, and E. Saez (2014). Where is the land of opportunity? the geography of intergenerational mobility in the united states. *The Quarterly Journal of Economics 129*(4), 1553–1623.

Christensen, P., D. A. Keiser, and G. E. Lade (2023). Economic effects of environmental crises: Evidence from flint, michigan. *American Economic Journal: Economic Policy 15*(1), 196–232.

Clay, K., J. Lingwall, and M. Stephens Jr (2021). Laws, educational outcomes, and returns to schooling evidence from the first wave of us state compulsory attendance laws. *Labour Economics 68*, 101935.

Clay, K., W. Troesken, and M. Haines (2014). Lead and mortality. *Review of Economics and Statistics 96*(3), 458–470.

Collins, W. J. and M. H. Wanamaker (2022). African american intergenerational economic mobility since 1880. *American Economic Journal: Applied Economics 14*(3), 84–117.

Committee on Service Pipes (1917). Report of the committee on service pipes. *Journal American Water Works Association 31*, 323–389.

Coury, M., T. Kitagawa, A. Shertzer, and M. Turner (2022). The value of piped water and sewers: Evidence from 19th century chicago. Technical report, National Bureau of Economic Research.

Dave, D. M. and M. Yang (2022). Lead in drinking water and birth outcomes: A tale of two water treatment plants. *Journal of Health Economics 84*, 102644.

Dorsey, C. D., B.-K. Lee, K. I. Bolla, V. M. Weaver, S.-S. Lee, G.-S. Lee, A. C. Todd, W. Shi, and B. S. Schwartz (2006, May). Comparison of Patella Lead With Blood Lead and Tibia Lead and Their Associations With Neurobehavioral Test Scores. *Journal of Occupational and Environmental Medicine 48*(5), 489–496.

Environmental Protection Agency (2021). https://www.epa.gov/ground-water-and-drinking-water/lslr-financing-case-studies.

Feigenbaum, J. J. and C. Muller (2016). Lead exposure and violent crime in the early twentieth century. *Explorations in Economic History 62*, 51–86.

Feigenbaum, J. J. and H. R. Tan (2020). The return to education in the mid-twentieth century: Evidence from twins. *The Journal of Economic History 80*(4), 1101–1142.

Ferrie, J. P., K. Rolf, and W. Troesken (2012). Cognitive disparities, lead plumbing, and water chemistry: Prior exposure to water-borne lead and intelligence test scores among world war two us army enlistees. *Economics & Human Biology 10*(1), 98–111.

Ferrie, J. P., K. Rolf, and W. Troesken (2015). Lead exposure and the perpetuation of low socioeconomic status. *Working Paper*.

Goldin, C. (1998). America's graduation from high school: The evolution and spread of secondary schooling in the twentieth century. *The Journal of Economic History 58*(2), 345–374.

Goldin, C. and L. F. Katz (1995). The decline of non-competing groups: Changes in the premium to education, 1890 to 1940.

Goldin, C. and L. F. Katz (1999). The returns to skill in the united states across the twentieth century.

Goodlad, J. K., D. K. Marcus, and J. J. Fulton (2013, April). Lead and Attention-Deficit/Hyperactivity Disorder (ADHD) symptoms: A meta-analysis. *Clinical Psychology Review 33*(3), 417–425.

Grönqvist, H., J. P. Nilsson, and P.-O. Robling (2020). Understanding how low levels of early lead exposure affect children's life trajectories. *Journal of Political Economy 128*(9), 3376–3433.

Gulson, B., K. Mahaffey, C. W. Jameson, K. Mizon, M. Korsch, M. Cameron, and J. Eisman (1998). Mobilization of lead from the skeleton during the postnatal period is larger than during pregnancy. *Journal of Laboratory and Clinical Medicine 131*(4), 324–329.

Hammond, P. B. (1982). Metabolism of lead. *Lead Absorption in Children: Management, Clinical, and Environmental Aspects, Urban and Schwarzenberg, Baltimore, Munich*.

Hoehn-Velasco, L. (2021). The long-term impact of preventative public health programs. *The Economic Journal 131*(634), 797–826.

Hollingsworth, A., J. M. Huang, I. Rudik, and N. J. Sanders (2022). A thousand cuts: Cumulative lead exposure reduces academic achievement. *Journal of Human Resources*, 0222–12169R2.

Hollingsworth, A. and I. Rudik (2021). The effect of leaded gasoline on elderly mortality: Evidence from regulatory exemptions. *American Economic Journal: Economic Policy 13*(3), 345–73.

Hu, H., M. M. Téllez-Rojo, D. Bellinger, D. Smith, A. S. Ettinger, H. Lamadrid-Figueroa, J. Schwartz, L. Schnaas, A. Mercado-García, and M. Hernández-Avila (2006). Fetal lead exposure at each stage of pregnancy as a predictor of infant mental development. *Environmental Health Perspectives 114*(11), 1730.

Journal of the American Medical Association (1942). Queries and minor notes: lead pipe for connection between water main and residence. *Journal of the American Medical Association 120*, 995.

Lee, H., M. W. Lee, J. R. Warren, and J. Ferrie (2022). Childhood lead exposure is associated with lower cognitive functioning at older ages. *Science Advances 8*(45), eabn5164.

Lindsay, L. (1859). On the action of hard waters upon lead. *Edinburgh New Philosophical Journal 9*, 245–58.

Lohr, E. and S. Love (1954). Industrial utility of public water supplies in the united states 1952: Parts 1 and 2. *Geological Survey Water-Supply Papers 1299*.

Long, J. and J. Ferrie (2013). Intergenerational occupational mobility in great britain and the united states since 1850. *American Economic Review 103*(4), 1109–1137.

Manton, W., C. Angle, K. Stanek, D. Kuntzelman, Y. Reese, and T. Kuehnemann (2003). Release of lead from bone in pregnancy and lactation. *Environmental Research 92*(2), 139–151.

Marcus, D. K., J. J. Fulton, and E. J. Clarke (2010, March). Lead and Conduct Problems: A Meta-Analysis. *Journal of Clinical Child & Adolescent Psychology 39*(2), 234–241.

Needleman, H. (2004). Lead poisoning. *Annual Review Medicine 55*, 209–222.

Needleman, H. L. and C. A. Gatsonis (1990, February). Low-Level Lead Exposure and the IQ of Children: A Meta-analysis of Modern Studies. *Journal American Medican Association 263*(5), 673–678.

Needleman, H. L., C. McFarland, R. B. Ness, S. E. Fienberg, and M. J. Tobin (2002). Bone lead levels in adjudicated delinquents: a case control study. *Neurotoxicology and teratology 24*(6), 711–717.

Olivetti, C. and M. D. Paserman (2015). In the name of the son (and the daughter): Intergenerational mobility in the united states, 1850–1940. *American Economic Review 105*(8), 2695–2724.

Parman, J. (2011). American mobility and the expansion of public education. *The Journal of Economic History 71*(1), 105–132.

Price, J., K. Buckles, J. Van Leeuwen, and I. Riley (2021). Combining family history and machine learning to link historical records: The census tree data set. *Explorations in Economic History 80*, 101391.

Reyes, J. W. (2007). Environmental policy as social policy? the impact of childhood lead exposure on crime. *The BE Journal of Economic Analysis & Policy 7*(1).

Reyes, J. W. (2015, February). Lead Exposure and Behavior: Effects of Antisocial and Risky Behavior Among Children and Adolescents. *Economic Inquiry 53*(3), 1580–1605.

Ruggles, S., C. A. Fitch, R. Goeken, J. D. Hacker, M. A. Nelson, E. Roberts, M. Schouweiler, and M. Sobek (2021). Ipums ancestry full count data: Version 3.0 [dataset]. *Minneapolis, MN: IPUMS*.

Schock, M. R. (1990). Causes of temporal variability of lead in domestic plumbing systems. *Environmental monitoring and assessment 15*(1), 59–82.

Stewart, W. F. and B. S. Schwartz (2007). Effects of lead on the adult brain: A 15-year exploration. *American Journal of Industrial Medicine 50*(10), 729–739.

Swann, A. (1892). A national danger: Lead poisoning from service pipes. *The Lancet 140*(3595), 194–195.

Tan, H. R. (2023). A different land of opportunity: The geography of intergenerational mobility in the early twentieth-century united states. *Journal of Labor Economics 41*(1), 77–102.

The White House (2022). Fact sheet: The biden-harris lead pipe and paint action plan. https://www.whitehouse.gov/briefing-room/statements-releases/2021/12/16/fact-sheet-the-biden-harris-lead-pipe-and-paint-action-plan/.

Troesken, W. (2006). *The great lead water pipe disaster*. MIT Press.

Troesken, W. (2008). Lead water pipes and infant mortality at the turn of the twentieth century. *Journal of Human Resources 43*(3), 553–575.

Ward, Z. (2021). Intergenerational mobility in american history: Accounting for race and measurement error. Technical report, National Bureau of Economic Research.

Ward, Z. (2022). Internal migration, education, and intergenerational mobility evidence from american history. *Journal of Human Resources 57*(6), 1981–2011.

Zheng, J. (2021). Lead exposure, human capital formation, and inequality: the impacts of drinking water lead on short-run and long-run educational outcomes.

Appendix

to

“Economic Consequences of Childhood Exposure to Urban Environmental Toxins”