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Customer Participation in Lead Service Line Replacement[1]

Heather Klemick*†, Ann Wolverton†, Bryan Parthum†, Kristin Epstein‡, Sandra Kutzing‡, Sarah Armstrong§

ABSTRACT:

Many water systems are developing programs to identify and replace the 6-10 million lead service lines (LSLs) estimated to supply drinking water to homes in the United States. This study investigates factors affecting customer participation in a voluntary LSL inspection and replacement program. Using individual account data from a large public water system, we examined the characteristics of properties and neighborhoods more likely to have LSLs and to participate in the program. We also used quasi-experimental and experimental methods to evaluate the causal impacts on LSL program registration, inspection, and replacement of two programs that offered subsidies to certain residents that covered the homeowner costs of replacement. LSLs were more prevalent in the urban area of the water system, which had a higher concentration of older housing stock, Black and Hispanic residents, renters, and poverty than the suburban portions of the service area where LSLs were less common. We found that renter-occupied and lower-valued properties were less likely to participate in the LSL replacement program, and properties receiving more outreach letters were more likely to participate. Results from the two program evaluations suggest that subsidies to cover homeowner LSL costs can significantly boost participation, but only when the programs are well publicized and easy to access. Even then, there was still significant non-participation among properties with confirmed LSLs.

Keywords: Lead Service Lines, Drinking Water, Randomized Controlled Trial, Quasi-experiment, Environmental Justice
JEL Codes: Q52 | Q53 | Q56

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1 Introduction

An estimated 6-10 million lead service lines (LSLs) supply drinking water to homes in the United States (EPA 2021), and about one third of U.S. water systems report at least some LSLs (Cornwell et al., 2016). These lines pose an increased risk of lead exposure through drinking water to residents (Brown et al., 2011; EPA 2021; Triantafyllidou and Edwards, 2012). Lead exposure increases the likelihood of adverse health outcomes for both adults and children (EPA 2013).[2] Adverse impacts on children's cognitive function and behavioral outcomes are particularly well established. No safe level of lead exposure has been identified. Pervasive LSLs coupled with ineffective corrosion control in Flint, Michigan, and Newark, New Jersey, illustrate the risks of elevated lead exposure and adverse health effects from LSL (Pieper et al. 2017; Dave and Yang 2022).

In response to legal requirements, public pressure, and new federal funding, water systems are developing programs to identify and replace LSLs. EPA's 2021 revisions to the Lead and Copper Rule require every water system to develop and release a service line material inventory by October 2024 and require systems exceeding EPA's action level for water lead concentrations to implement mandatory lead service line replacement (LSLR) programs. The Biden Administration announced a plan for eventual replacement of 100 percent of LSLs that leverages regulatory, non-regulatory, and funding mechanisms (White House 2021). The 2021 Bipartisan Infrastructure Law authorized $15 billion of direct funding for LSLR, and LSLR is eligible for additional federal funding.[3]

Utilities are developing or expanding LSLR programs using federal financing and other strategies. These strategies include rate increases, cost sharing programs, and replacement at no cost to residents. Potential benefits to residents from LSLR can include reduced probability of lead exposure and reduced household expenditures on bottled water and water filters purchased to mitigate exposure. The replacement may also be capitalized into property values (Theising 2019; Christensen et al. 2023). However, the cost of replacement is typically several thousand dollars and can be prohibitive to many residents (EPA 2021; AWWA 2022). A paucity of accurate historical records means that an inspection is often required to determine the service line material, and a resident is unlikely to independently know the lead status of their service line.

Even when full subsidies are offered, non-financial barriers could impede household participation in both inspections and replacements, including time and inconvenience costs, lack of trust in public institutions, and mismatched incentives between landlords and renters. LSLR programs that do not address both financial and non-financial barriers to participation could exacerbate pre-existing economic and racial disparities in lead exposure. Black children and children in poverty have persistently higher exposures to

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[2] Lead exposure has a causal relationship with reduced cognitive function and disorders related to attention, impulsivity, and hyperactivity in children, as well as hypertension and coronary heart disease, adverse hematological effects, and adverse reproductive and developmental effects in adults (EPA 2013).

[3] The Bipartisan Infrastructure Law authorized an additional $11.7 billion for which LSLRs are eligible, and the 2021 Build Back Better Act authorized a further $85 billion for which LSLRs are eligible.

lead from multiple sources than other children in the United States as indicated by higher blood lead levels (EPA 2022a).

This study investigates factors affecting customer participation in a voluntary LSL inspection and replacement program. Using customer-level data from a large water system in New Jersey, we examine the characteristics of properties and neighborhoods more likely to have LSLs and to participate in the inspection and replacement program. We also evaluate the causal impact on LSLR participation of two interventions offering full-cost subsidies to certain residents for replacement. The first intervention is a community-based program offering grants plus extensive outreach and education about LSLs to residents of a specific neighborhood in the urban area of the water system with a high percentage of Black and Hispanic residents and high poverty rates. We estimate the effect of the community grant program using a synthetic control approach comparing LSLR participation before and after the grant program was launched among treatment and control groups that were perfectly balanced in terms of observable characteristics affecting participation rates. In the second intervention, postcards were sent to customers informing them about a different program run by the city housing department offering grants to low-income homeowners for urgent home repairs, including LSLRs. Households in the treatment group of properties were randomly selected from a larger pool of potentially eligible residents.

Results show that LSLs were more prevalent in the urban area of the water system service area, which has a higher concentration of older housing stock, Black and Hispanic residents, renters, and poverty than the suburban portions of the service area where LSLs are less common. An observational regression analysis finds that renter-occupied and lower-valued properties were less likely to participate in LSL program registration, inspection, and replacement. Results also indicate that properties receiving more outreach letters were more likely to participate.

The evaluations of the two grant programs show that the community-based program was highly effective in boosting participation in all stages of the LSLR program, though replacements remained well below 100 percent among properties with confirmed LSLs. However, sending postcards with information about the housing department grant program did not have statistically significant effects on program participation. A comparison of the two interventions suggests that programs covering homeowners' LSL costs can substantially increase participation when they are well publicized and easy to access but are still insufficient to achieve replacement of 100% of LSLs. Understanding the characteristics of customers who participate in LSLR and the program characteristics that yield the highest participation rates can help inform equitable and effective program design.

2 Barriers to Customer Participation

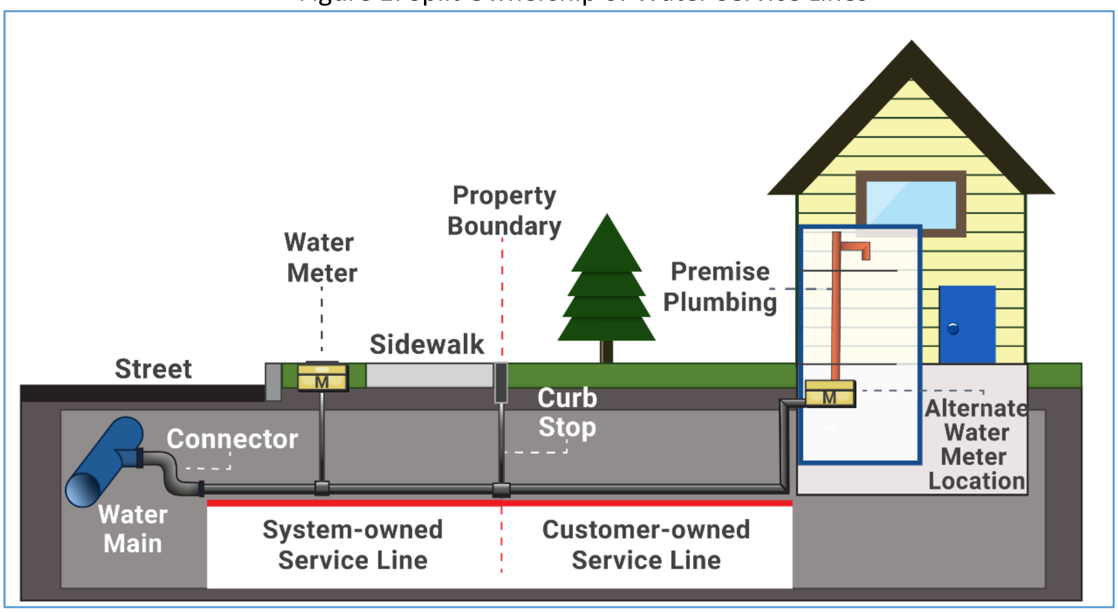
Inspection and replacement of LSLs is challenging due to numerous informational, transactional, and financial barriers. Informational barriers include potential lack of understanding about the risks of lead exposure, lack of trust in water systems, and language barriers. Transactional barriers include the time-cost and inconvenience of scheduling an inspection or replacement and any subsequent disruption to one's home or yard. Barriers to participation were likely exacerbated during our study period due to the

COVID-19 pandemic, which may have decreased households' willingness to allow in-person inspection and construction work.

2.1 Service Line Ownership and Transactional Barriers

The ownership structure for most service lines further complicates inspection and replacement (AWWA 2005) (Figure 1). Typically, the utility only owns the lines on the street-side of the curb stop valve or meter. The portion of the service line that extends from the curb stop or meter into the home is privately owned. Lead can be present in either or both sides of the line (EPA 2022b). In most cases, this implies that the utility must obtain homeowner permission to enter the property before it can inspect and then replace homeowner-side LSLs (Hull and Anderson 2022). Scheduling and participating in these efforts pose time and inconvenience costs to homeowners. Low-income households may face outsized transactional barriers due to tradeoffs between time spent ensuring basic needs versus preparing documents or attending appointments needed for LSLR program participation (Mullainathan and Shafir 2013). Needing to obtain permission from a landlord can pose further transactional barriers for rental properties. With lower-income households being more likely to rent, this additional hurdle can further exacerbate pre-existing economic and racial disparities in lead exposure.

Figure 1: Split Ownership of Water Service Lines



This typical service line configuration in a suburban area shows split ownership of the line between homeowner and utility. Public water systems may have records of where lead-containing utility-owned service lines are located. Inventory on the homeowner-side of the service line is typically less well documented and is a necessary step in replacing water service lines. Source: EPA 2022b.

2.2 Informational Barriers

The lead status of homeowner-side service lines is often unknown to residents and water systems alike due to limited availability of reliable records. Having an audit or inspection is a way to address imperfect or incomplete information prior to making a home improvement that may yield health or environmental benefits (Holladay, et al. 2016; Gillingham and Tsvetanov 2018). The inspection reveals or confirms the presence (or absence) of a qualifying condition (e.g., having an LSL) but also involves time and inconvenience costs. Participation in the inspection will therefore depend on how the costs of acquiring this information compare to household-level gains. Split incentives between renters and owners and language barriers both increase the cost of acquiring the information. Gains also likely correlate with housing and household characteristics (e.g., presence of children in the home; other sources of lead). Households might also decline to participate in an inspection to avoid potential bad news about their water quality, exhibiting an "ostrich effect" (Karlsson et al. 2009).

2.3 Financial Barriers

The decision to replace a lead service line once this information has been revealed also depends on how household costs compare to gains. Water utilities in some states and municipalities are not currently allowed to use rate revenue for homeowner-side service line improvements. In these cases, the homeowner is responsible for covering part or all of the homeowner-side replacement costs. EPA (2021) estimated average homeowner-side LSLR construction costs to be $4,000, and other estimates have found homeowner-side construction costs ranging up to $10,000 (AWWA 2022).[4] The gains from LSLR are more difficult to quantify since the probability of being exposed to lead and the likelihood of a subsequent health effect are uncertain.

2.4 Mitigating Barriers

Utilities seeking to encourage LSL inspection and replacement often focus on lowering coordination failures and reducing the cost of participation (e.g., AWWA 2005; U.S. EPA 2019). This includes the provision of subsidies or options to spread upfront costs over time, translating materials into languages other than English, and, in a few cases, not requiring homeowner approval to access a property for inspection and/or replacement. However, program design varies greatly across programs.[5]

Some utilities are constrained by local or state laws limiting the use of public funds to make investments in private property, while others offer partial or full subsidies to replace the homeowner portion of the service line (EPA 2019). Subsidies can take the form of discounted upfront prices or zero percent interest loans with payments spread over several years. Some systems, such as Washington, DC, and Providence, Rhode Island, target free or subsidized replacements to low-income homeowners or properties in disadvantaged neighborhoods (EPA 2019; Kuffner 2022). The state of Michigan requires most water systems to finance the full cost of LSLR for all properties, including the homeowner side (EPA 2019). Costs are recouped through a combination of grants, bond financing, and rate increases spread over all utility customers. While voluntary participation is typical, some cities are beginning to require mandatory replacements for confirmed LSLs while fully covering the costs. For example, Newark, New Jersey, adopted a free and mandatory approach including fines for non-compliance (City of Newark 2019).

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[4] Construction cost estimates provided in 2022 dollars.

[5] Participants in roundtable discussions held in ten Northeastern and Midwestern communities by the US Environmental Protection Agency (EPA 2021b–2021k) mentioned financial constraints, language barriers, landlord-renter split incentives, and lack of community trust in water utilities as barriers to LSLR. Participants in these sessions suggested subsidies, multiple types of outreach approaches (e.g., mailers, in person, online, door hangers), translation of materials into different languages, and partnerships with organizations viewed as "trusted messengers" in target communities as potential solutions to these barriers.

The existing literature on barriers to LSLR and ways to address them is minimal. One study investigating neighborhood characteristics associated with LSLR found that replacement rates in Washington, DC, were significantly higher in neighborhoods with higher incomes and a lower proportion of Black residents (Baehler et al. 2022). A discussion of the LSLR program in Flint, Michigan, by the Federal Reserve Bank of Chicago (2022) posits that the voluntary nature of the program contributes to homeowner non-responses and refusals to have their lines inspected or replaced.

Researchers have investigated the effectiveness of approaches to encourage testing and treatment of private wells for a wide range of contaminants. Renaud, et al. (2011) examined two programs to encourage testing for arsenic in Quebec via quasi-experimental empirical techniques. They found a significant increase in testing (but from a relatively low baseline) in response to targeted information supplied to households relative to a mass media campaign alone. However, even with the mass media campaign, they found evidence that having a neighbor who had previously tested their well had a strong influence on the uptake of testing. MacDonald and Tippett (2020) mailed letters to a random sample of New Jersey residents with private wells to examine if information on contamination at a nearby well (versus general information on contaminants of concern) encouraged testing. They found that nearby well contamination had a significant, positive influence on the likelihood to test regardless of the contaminant. However, testing (and treatment) remained low due to lack of concern regarding the health effects of contamination. A follow-up survey found that many households relied on bottled drinking water.

Respondents to a survey administered in Southern Ontario by Krewtzwiser, et al. (2011) indicated that even when testing is free, inconvenience is an important barrier. In rural areas, drop-off points were far away and only open during business hours. Hexemer, et al. (2008) distributed free sampling kits to private well owners in Southern Ontario and then collected samples the next day for testing. While removing cost and travel time barriers substantially increased participation, they still found that less than 50 percent of targeted households returned the test kits. A follow-up survey indicated that non-participants often were not home when kits were distributed and/or unable to sample their wells for next-day pickup. Household income and education did not affect participation.

Finally, Severtson, et al. (2006) administered a survey to a random sample of participants in a Wisconsin program to test for arsenic in private wells. They found that only one-third of those with elevated contaminant levels treated their water. A lack of observed health effects among long-term residents or obvious indicators of contamination (odor or taste) were listed as common reasons for failing to treat. In addition, female respondents to a post-program survey reported higher levels of worry about the potential health effects of arsenic exposure but also perceived greater financial and nonfinancial barriers to taking action to reduce exposure, while more educated respondents reported the opposite.

In the context of energy efficiency, several studies also have investigated interventions to increase household participation in inspections and subsequent adoption of energy saving technologies for the home. Fowlie, et al. (2015; 2018), Holladay, et al. (2016), and Allcott and Greenstone (2017) implemented randomized field experiments to offer a combination of subsidies and personalized assistance to encourage program take-up. Fowlie, et al. (2015) found that relatively few households participated in the federal Weatherization Assistance Program even when financial costs were fully subsidized. They posited that this may be due to non-monetary costs such as the time needed to fill out the application and for the audit itself. Likewise, Fowlie et al. (2018) found that extensive outreach and assistance in filling out applications to presumptively eligible households in Michigan – in combination with free audits and low interest rate loans to cover the cost of recommended energy-efficient investments – did not substantively increase program participation. Holladay, et al. (2016) found that individualized letters comparing households' electricity use with that of their neighbors increased the likelihood that a household scheduled an audit by two times the very low baseline rate. The offer of gift cards did not affect take-up of the audit, even when fully subsidized. Offers of substantial rebates for upgrades based on audit recommendations did not affect audit likelihood or subsequent purchases. Using a combination of letters and offers of subsidies to households in Wisconsin, Allcott and Greenstone (2017) found a small, marginally significant increase in the number of energy audits performed, but the content of the letter did not matter. Offering a gift card to encourage audits had no effect. Interestingly, households that were induced to be audited via the experiment were much less likely to make a subsequent investment than those that voluntarily signed up for the program.

Gillingham and Tsvetanov (2018) and Wallander, et al. (2017) implemented randomized field experiments that focused on relatively "low touch" forms of intervention to encourage pro-environmental behavior. Gillingham and Tsvetanov (2018) sent reminder postcards to households in Connecticut that had signed up for but not yet received an energy audit, noting a high attrition rate (60%) between initial sign up and the audit itself. Sending a reminder notecard resulted in a small (1.1 percentage points) but significant increase in the probability of following through with the audit for the average household. The method of communicating that message (e.g., basic reminder vs. use of social norms) did not matter. However, they found evidence of differential treatment effects: higher income and non-White households were more responsive. Wallander, et al. (2017) sent reminder letters to farmers with expiring Conservation Reserve Program contracts to encourage re-enrollment in the program. Like Gillingham and Tsvetanov (2018), they found a small increase in sign-ups (1.4 to 1.9 percentage points) in response to the letter but no evidence that the form of the message mattered.

3 Case Study: LSLR in a large New Jersey water system

3.1 Trenton-Area LSLR Program

Our case study involves a large public water system in New Jersey serving more than 60,000 properties in Trenton and four neighboring suburban municipalities. Water system records indicated that LSLs were commonly installed in homes built before 1960.[6] Roughly half of service lines connecting individual properties to water mains were originally estimated to contain lead. The water system launched an LSLR program in 2019 in response to exceedances of EPA's action level for drinking water lead concentrations in 2017 and 2018. By the end of our study period in July 2022, the system had conducted more than 17,000 service line inspections and replaced more than 9,000 lines found to contain lead, including 2,500 homeowner-side lines.

[6] Most service lines classified as "lead" by the water system are actually lead-lined galvanized steel lines that pose similar risks to water quality as solid lead service lines. The State of New Jersey also considers galvanized service lines as LSLs (https://www.nj.gov/dep/lead/notices.html, accessed Jan. 17, 2023). We follow this definition and refer to lead-lined galvanized steel service lines as LSLs.

The water system offered replacement of homeowner-side LSLs for a subsidized cost of $1,000 payable over five years without interest.[7] Customer participation in the LSLR program was voluntary and offered to all residents in Trenton and three suburban areas served by the water system with LSLs.[8] In addition to this partial subsidy offered directly by the water system, there were two additional grant programs during our study period that covered the remaining cost of homeowner-side LSLRs to certain, qualifying Trenton residents. These programs are described below.

The water system conducted various forms of outreach to encourage customers to register for the program, including mailings, community meetings, and door-to-door visits. The water system sent two targeted letters in 2018 and 2019 to the addresses of properties suspected of having LSLs to encourage program registration.[9] Program registration did not entail a formal commitment by the homeowner to pay the $1,000 cost and proceed with replacement (if the line was confirmed to be lead), nor was registration required for an inspection or eventual replacement – it served simply as a signal of interest. The water system prioritized properties that registered for the program prior to 2020 for inspection and replacement efforts. It also distributed contractor work throughout the service area to ensure that inspections and replacements occurred in all four municipalities with LSLs. LSLR construction work started in February 2020, paused during March 2020 due to the COVID-19 pandemic, then resumed in July 2020. As of July 2022, it had conducted some inspections and replacements in almost all neighborhoods in the service area.[10]

The homeowner-side service line material was often unknown when customers registered for the program. Consequently, customer cooperation was necessary for material identification or verification, typically with residents needing to allow a water system contractor or employee inside the home to inspect the pipe. Alternatives to an interior contractor inspection included a self-inspection photo sent by the homeowner to the utility (an option introduced by the utility in 2020 in response to the COVID-19 pandemic), or an external excavation that required no cooperation from the homeowner. If an LSL was confirmed by the inspection, the homeowner was asked to sign a contract and right-of-entry agreement to replace the line. A resident was required to be present during the replacement, which typically took about half a day to complete. Construction included patching of walls or floors and restoration of pavement or sod damaged during the replacement. For properties confirmed to have lead on the utility-side of the line and a non-lead material on the homeowner-side, the water system could conduct a replacement of the utility side without accessing the property, so further homeowner participation was not needed.

[7] Replacements of utility-side LSLs were completed at no cost to the homeowner.

[8] Water system records indicate that there are no lead service lines in one of the suburban municipalities of the water system. We exclude this municipality from the analysis.

[9] Because mailings were sent to property addresses, renters rather than landlords received them at non-owner-occupied properties.

[10] An interior inspection and/or replacement occurred in at least one home in 95% of Census block groups in the study area by the end of the study period. These block groups included over 99% of accounts in our final analysis sample.

3.2 Community-Based Grant Program

In March 2021, a trusted community organization active in the East Trenton neighborhood for over a decade launched a grant program to cover 100% of the $1,000 LSLR cost for owner-occupied homes and 50% of the cost for renter-occupied homes (with landlords covering the remainder) in that neighborhood. The grants involved minimal paperwork and no eligibility requirements besides location of the property in the community organization's target neighborhood. This neighborhood, which is comprised of four U.S. Census block groups, was home to a higher share of Black and Hispanic residents and those living below the poverty level than the remainder of the city. The community organization conducted extensive outreach through in-person and virtual events, door-to-door and neighborhood canvassing, and social media to notify residents about the program. We subsequently refer to this subsidy program as the "community-based grant program."

3.3 Housing Department Grant Program

In addition, Trenton's Department of Housing and Economic Development offered an existing program funded by a U.S. Department of Housing and Urban Development Community Development Block Grant to subsidize urgent home repairs for low- and moderate-income homeowners. LSLR was added as a qualifying home repair in 2021, meaning that the entire $1,000 cost to customers would be covered for successful applicants. Applicants were required to provide extensive documentation, such as W-2s and tax returns, to prove their eligibility. Only owner-occupied properties in Trenton were eligible. Information about the urgent repair grant program was publicly available on the city government website but was not otherwise advertised, and the program had not been widely utilized.[11] We subsequently refer to this subsidy program as the "housing department grant program."

3.4 Study Objectives

Based on observations from the existing literature, we test the following hypotheses within the context of the Trenton LSLR program:

> *Hypothesis 1:* Renters, properties with lower assessed value, and customers living in neighborhoods with higher poverty, lower educational attainment, and other indicators of economic disadvantage are less likely to participate in the LSLR program, absent additional interventions, due to greater financial, informational, and transactional barriers.
>
> *Hypothesis 2:* Households receiving outreach letters to register for the LSLR program participate at greater rates due to reduced informational barriers.
>
> *Hypothesis 3:* Subsidies to cover the $1,000 cost-share will mitigate financial barriers for low-income customers, leading to higher program participation among customers offered a subsidy through either the community-based grant program or the housing department grant program.
>
> *Hypothesis 4:* Low-income households are less likely to participate in the LSLR program unless both financial and non-financial barriers are addressed. Thus, we expect a larger response to the

[11] A housing department representative indicated that there are fewer than 50 applicants for urgent rehabilitation grants in a typical year (personal communication, Farrah Gee, City of Trenton Department of Housing and Economic Development).

community-based grant program than to postcards providing a single notification about the housing department grant program, which had greater transactional barriers.

4 Data

We assembled the dataset by linking individual water system account records with property tax assessment data and Census neighborhood characteristics. We obtained data from the water system on 62,529 customer accounts reflecting LSLR program status as of July 2020, May 2021, and July 2022.[12] The data included property address, property type (residential or non-residential), account status (active or inactive), utility-side and homeowner-side service line material prior to any replacement work (if known), LSLR program registration and date of response, and date of utility-side and/or homeowner-side replacement (if applicable). We also obtained data from the water system on which properties were sent letters and postcards about the LSLR program and which street segments in the service area were under a moratorium for non-emergency water line construction due to recent street paving.

Using street address, city, and zip code, we linked 91% of water system accounts to county property tax assessment records for tax year 2020.[13] Tax assessment records included data on property type, number of dwellings, year constructed, assessed value, location address, and property owner address. We compared location address and owner address to identify owner-occupied properties.[14] We excluded duplicate accounts, as well as accounts that either tax assessment or water system records identified as non-residential properties, or apartment buildings with more than four dwellings (7% of accounts).[15] As noted above, we also excluded all properties located in one suburban municipality where the water system determined that LSLs were never installed based on the dates of water main and service connection installations (3% of accounts).

We incorporated data on neighborhood sociodemographic characteristics at the block group level from the 2015-2019 Census American Community Survey (ACS) 5-year estimates. We geocoded property addresses and identified Census block groups using the Census Geocoder batch address processing tool.[16] We excluded accounts in one block group that ACS data indicated had no occupied housing units (less than 1% of accounts). The organization implementing the community-based grant program provided neighborhood boundaries, which corresponded to four Census block groups. Our final analysis dataset

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[12] The research team also obtained weekly water system data pulls from September 2021-April 2022 that were not used in this analysis.

[13] Observations across the two datasets were linked based on an exact string match of street address and city name, and when, available in the assessor data, zip code. We did extensive data cleaning to fix typos and to increase consistency in street type abbreviations across datasets to attain a high merge rate. Water accounts that were unable to be linked may have remaining differences in spellings, abbreviations, or other characteristics that we were unable to identify.

[14] We categorized properties as owner-occupied if the first seven characters of the property address exactly matched the first seven characters of the owner address. This indicator is extremely similar to a variable denoting a match of the entire character string of the property and owner addresses (rho = 0.99) but allows for flexibility due to spelling mistakes or differences in the way apartment numbers are recorded across the datasets.

[15] We excluded residential buildings with more than four dwellings from the analysis because LSLs typically serve single-family or small multi-family residences due to their relatively small diameter; larger buildings require larger diameter service lines that were rarely made of lead (EPA 2022b).

[16] https://geocoding.geo.census.gov/geocoder/geographies/addressbatch?form [Accessed Jan. 22, 2022]

consisted of 55,917 water system accounts; 91% of these were residential properties of four families or less as indicated by property assessment records, while 9% were not able to be linked to the assessment data.

5 Methods

We estimated the parameters of a series of regression models, first to examine the characteristics of households willing to participate in the LSLR program, and then to evaluate the impact of two specific programs intended to subsidize the cost of LSLR for certain eligible properties.

5.1 Observational Analysis

Our first analysis used the full-sample dataset to examine the factors associated with three outcome variables reflecting different aspects of program participation: registration for the LSLR program, participation in an interior home inspection conducted by a water system contractor or employee, and completion of an LSLR conditional on having an LSL. We regressed each participation variable on a set of property and neighborhood characteristics in a linear probability model[17] as follows:

$$y_{ij} = \beta_0 + \boldsymbol{\beta_1 X_i} + \boldsymbol{\beta_2 Z_j} + \varepsilon_{ij} \qquad (1)$$

In equation (1), y_{ij} is one of the three participation outcomes observed for property i in neighborhood j as of July 2022, the end of our study period. The vector $\boldsymbol{X_i}$ represents individual characteristics of the property. These characteristics include whether the account was inactive at any point during the study period (denoting a vacant property),[18] the number of letters the property was sent to encourage registration in 2018 or 2019 (prior to the start of the LSLR program), and whether the property was located on a street segment where non-emergency service line repairs were under moratorium during 2020 and 2021 due to recent street paving.[19] We also included a variable denoting whether the utility-side of the service line contained lead; contractors had incentivizes to seek out these properties because they would be able to conduct a replacement even if the homeowner-side of the line was found to be lead free. Furthermore, if the homeowner side was found to be an LSL, they would be paid more for the work because both sides of the line required replacement. For properties linked to tax assessment data, we included the year built (pre-1951 and 1951-1960, after which LSLs were uncommon in the study area), the natural logarithm of assessed value, and indicators for owner-occupied and multi-unit (2-4 family) properties. We included a dummy variable denoting missing assessment data. We imputed missing assessment data values using the average value for linked residential properties in the same municipality.[20] The vector $\boldsymbol{Z_j}$ represents neighborhood characteristics at the Census block group level.

[17] While other estimators could be used in the case of a binary outcome variable, such as probit or logistic, the linear probability model is attractive in our observational setting that includes a mix of continuous and categorical variables while also offering easily interpretable marginal effects (Angrist and Pischke 2008).
[18] Accounts are considered inactive by the water system when a property is abandoned or when a property owner requests that the water be shut off due to vacancy. Failure to pay water bills did not trigger inactive status or water shutoff in the study area during the study period.
[19] We considered a property to be affected by a street paving moratorium if it was located within 50 meters of a street segment under moratorium.
[20] The results of the analysis are not substantively different if we instead exclude observations unable to be linked to the assessment data.

These characteristics include percent of residents that are Black, percent of residents of Hispanic ethnicity, percent living below the poverty level, percent that are below age 5, percent above age 64, percent of residents age 25 and over with a college degree, and percent of the occupied housing stock occupied by renters. The β terms are coefficients to be estimated, and ε_{ij} is heteroskedasticity-robust error term. We estimated equation (1) separately for the urban and suburban properties in our analysis to allow for heterogeneity in the association of property and neighborhood characteristics with LSLR program participation.

For two of the three outcomes in our analysis—registrations and inspections—we included the full samples of urban and suburban properties regardless of service line material in the regression models, since material was typically unknown prior to inspection. The third outcome, replacement, is only relevant for properties found to have a homeowner-side LSL, which customers can then decide to leave as-is or replace. Therefore, we estimated the LSLR outcome equation restricting the sample to properties whose homeowner-side service line was confirmed to contain lead, excluding those whose line was of unknown material or was confirmed to not contain lead. Focusing on this smaller sample allows us to isolate factors affecting the decision of whether to proceed with LSLR conditional on having an LSL. Conditioning the sample in this way provides the most relevant interpretation for water systems and policymakers interested in understanding the willingness to participate in LSLR among the most relevant customer population. We included the same property and neighborhood characteristics as explanatory variables, except for housing age because 98% of properties with a confirmed LSL were built before 1961.

5.2 Program Evaluations

Next, we evaluated the impacts on willingness to participate in the LSLR program of two programs offered to certain residents in the urban core of the service area during the study period: a community-based grant program for residents of a specific neighborhood and a housing department grant program for low- and moderate-income homeowners.

5.2.1 Synthetic control to evaluate impact of community-based grant program

We conducted a quasi-experimental evaluation of the community-based grant program on LSLR program participation in the water system's urban municipality.[21] We estimated a difference-in-difference (DiD) linear probability model:

$$y_{ijt} = \gamma_0 + \gamma_1 Treat_j + \gamma_2 After_t + \delta Treat_j * After_t + \varepsilon_{ij} \qquad (2)$$

In equation (2), y_{ijt} represents each of the same three participation outcomes already discussed but includes subscript t to denote time. The model includes $Treat$ to denote location in one of the four Census

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[21] The sample used for the quasi-experimental community-based grant program evaluation consisted of all urban properties in our final analysis sample except for 1,338 properties that received postcards about the housing department grant program as part of the field experiment, 201 properties receiving other special outreach mailings from the water system after the launch of the community-based grant program, 80 properties whose program registration and LSLR dates could not be determined from the water utility account data, and 22 properties in neighborhoods that were not visited by water system contractors during both the pre- and post-grant periods. The 22 properties in neighborhoods never visited by a contractor were not in the target neighborhood; however, 13 of these properties did receive at least one outreach letter encouraging program registration in 2018 or 2019.

block groups that comprise the neighborhood eligible for the grant program and $After$ to represent the period after the grant program's launch. The coefficients γ_0, γ_1, and γ_2 represent city-wide LSLR participation pre-launch, the difference in LSLR participation in the target neighborhood from the rest of the city pre-launch, and the city-wide increase in LSLR participation post-launch, respectively. The key coefficient is δ, which represents the impact of the grant program on participation in the target neighborhood. ε is a cluster-robust error term that is clustered at the level of the block group to match the spatial scale of the grant intervention (Abadie et al. 2022).

Because location in the treatment neighborhood is not random and may be correlated with factors affecting LSLR program participation, we used a synthetic control approach to estimate the causal effect of the community-based grant program. A synthetic control is a weighted average of observations in the untreated sample that serves as a counterfactual for the treatment group (Abadie 2021). In settings with many treated units (as is the case in this study), the weights balance the mean values (or other moments) of a set of observed characteristics across the treated and synthetic control groups (Hainmueller 2012; Robbins, Saunders, and Kilmer 2017). To implement the synthetic control approach, we estimated the DiD model as a weighted regression.[22]

We used entropy balancing to derive the weights for our synthetic control group. Entropy balancing is a matching method that identifies a set of non-negative weights that satisfy a set of balance constraints (in our case, equality of means of several variables), that sum to the number of observations in the treatment group and are as close as possible to uniform (Hainmueller 2012). We constrained the treatment and synthetic control groups to have equal mean values across all three pre-intervention outcomes, all property-level characteristics, and the neighborhood characteristics found to have a statistically significant association with LSLR program participation in the urban core.[23] Because the weights exactly balance the characteristics of all variables associated with LSLR program participation across the treatment and synthetic control groups, it is not necessary to include control variables in equation (2) to obtain an unbiased estimate of δ.[24]

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[22] In the appendix, we also present results of a standard unweighted DiD model that controls for property characteristics and block group fixed effects, as well as results using an alternative set of weights derived using coarsened exact matching (Iacus et al. 2012).

[23] Note that we examined the LSLR completion outcome using a restricted sample of properties confirmed to have a homeowner-side LSL and the other outcomes using the broader sample of properties regardless of having a confirmed LSL. Consequently, we derived two sets of weights using entropy balancing corresponding to these two samples. The weights used with the broader sample to examine the likelihood of registration and inspection were derived using all three pre-treatment outcomes, all individual property characteristics, and all neighborhood characteristics except for share of the population under age 5 because this variable was not a significant predictor of any of the outcomes in the urban area (Table 2, columns 1 and 2). The weights used when examining LSLR conditional on having an LSL were derived using all three pre-treatment outcomes, all property characteristics, and the share of occupied housing that is renter occupied because this is the only neighborhood characteristic that is significantly associated with LSLR uptake in this sample (Table 2, column 3). The two sets of weights are highly correlated (rho = 0.82).

[24] In the appendix, we also present results of a model that included property characteristics and block group fixed effects.

5.2.2 Experimental design to evaluate impact of housing department grant program

The second evaluation is a field experiment to assess the impact of postcards informing residents about a program run by the city's housing department to cover homeowner-side LSLR costs (and other urgent home repairs) for low- and moderate-income homeowners. The research team worked with the water system to identify a sample of 3,100 properties located in the urban core that were potentially eligible for the housing department grant program but outside of the neighborhood targeted by the community grant program.[25] The sample of 3,100 properties was stratified by block group and then split into equally sized treatment and control groups. Rerandomization (Morgan and Rubin 2012) was used to ensure balance on pre-intervention LSLR program registration, participation in an inspection, and, for properties linked to assessor data, the inflation-adjusted home sales price and an indicator for pre-1951 construction.

The water system sent English-language postcards to the treatment group providing information on the availability of the grant program to cover the costs of LSLR, eligibility criteria, information on how to apply, and a brief reminder about the health benefits of LSLR (Appendix Figure A3). Properties in the control group did not receive an LSLR mailing at that time. For 15% of the treatment group, either the mailing address was deemed invalid by the firm contracted to print and mail the postcards, or the postcard was returned to the water system by the postal service, so this portion of the treatment group did not receive the mailing.

To evaluate the impact of notifying customers about the availability of the housing department grant program on participation in the LSLR program, we estimated the following equation:

$$y_{ijt} = \beta_0 + \gamma_1 Treat_i + \gamma_2 After_t + \delta Treat_i * After_t + \varepsilon_{ij} \qquad (3)$$

Equation (3) is similar to equation (2), except that the treatment, $Treat$—being sent a postcard with information about the housing department grant program to cover the cost of LSLR—was assigned at the individual rather than neighborhood level. It is again unnecessary to include control variables or block group fixed effects in this equation to estimate δ, the impact of notification about the urgent repair grant program, because the intervention was randomized within block groups and balanced on key observable characteristics related to LSLR program participation.[26] The heteroskedasticity-robust error term, ε, is not clustered at the neighborhood level, consistent with random assignment of individual properties to the treatment after stratifying by block group.

Because 15% of the treatment group did not receive the postcard, equation (3) is more appropriately characterized as an "intent to treat" model. To address the treatment contamination resulting from non-

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[25] To obtain the sample for the randomized controlled trial, we excluded properties that met at least one of the following criteria prior to the intervention: location outside of the urban municipality; location inside the target neighborhood for the community-based grant program; the homeowner-side service line was confirmed to not contain lead; a LSLR already occurred; the water system account was inactive, vacant, or a non-valid address according to water system records; the property was not owner-occupied according to assessor data or the municipality's registry of rental properties; occupants had previously refused water system staff or contractors access to the property; the property was located in a Census block in which no properties had previously registered for the LSLR program.

[26] In the appendix, we also present results of a model that included property characteristics and block group fixed effects.

delivered postcards, we estimated (3) using an instrumental variables (IV) model with receipt of the postcard as the treatment variable and assignment to the treatment group as the instrument (Sussman and Hayward 2010).

6 Results

6.1 Characteristics of LSL Incidence and LSLR Participation

Table 1 summarizes the characteristics of all properties in our final analysis sample. It disaggregates by homeowner-side service line material (prior to the completion of an LSLR, if applicable) to shed light on whether properties with a confirmed LSL systematically differed from those with a confirmed lead-free service line or a service line of unknown material.

Forty percent of properties with confirmed homeowner-side lead lines registered for the LSLR program, in contrast to 27% of properties with confirmed non-lead lines (who presumably registered before learning their line did not contain lead), and 2% of properties with unknown material. About two-thirds of properties had their homeowner-side material confirmed as either lead or non-lead through an interior contractor inspection (as opposed to an external excavation or a self-inspection photo sent by the homeowner to the utility).[27] Forty-three percent of confirmed homeowner-side LSLs were replaced by the end of the study period. Most, but not all, customers who had a homeowner-side LSLR had registered for the program; while registration was encouraged, it was not a required step.

Most properties with confirmed homeowner-side LSLs were sent at least one letter encouraging registration prior to the launch of the LSLR program (out of a maximum of two letters). Properties with non-lead and unknown material were less likely to receive these outreach letters. This is unsurprising given that the utility targeted letters to properties with suspected homeowner-side LSL based on age of the home and the utility-side service line material. Properties with confirmed homeowner-side LSLs were also somewhat less likely to have inactive accounts during the study period.

Fifty-nine percent of properties with a homeowner-side LSL also had lead on the utility-side of the line (prior to any replacement work). The percentage was similar for properties with a non-lead homeowner-side line. This similarity is surprising, though it could be due to the fact that the water system targeted properties with utility-side LSLs for inspections and outreach because they suspected these properties were also more likely to have lead on the homeowner side. Utility-side LSLs were much less common for properties with unknown homeowner-side material. The data on utility-side service line material are mostly comprised of historic utility records, with only 20% verified by a contractor inspection, so it could contain inaccuracies.

[27] We consider homeowner-side service line material to be "confirmed" if it was inspected by a utility employee or contractor (interior visual inspection or exterior excavation) or a homeowner visual inspection documented in a photo submitted to the utility. We do not consider historic utility records to be sufficient for service line material confirmation.

While most homes in the study area were built before 1951, properties with confirmed homeowner-side LSLs were especially likely to fall into this category. Most of the remaining homes with homeowner-side LSLs were constructed by 1960.[28]

Table 1. Full-sample summary statistics disaggregated by pre-construction homeowner-side service line material

	Confirmed lead		Confirmed non-lead		Material unknown	
Observations	5,769		15,761		34,387	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
LSLR participation outcomes						
Registered for LSLR program	40%	0.49	27%***	0.44	2%***	0.13
Interior contractor inspection	66%	0.48	67%	0.47	0%***	0.02
Homeowner-side LSLR completed	43%	0.50	0%***	0.00	0%***	0.00
Property characteristics						
Lead on utility side of line	59%	0.49	58%	0.49	28%***	0.45
Number of LSLR letters◊	1.15	0.80	1.09***	0.82	0.60***	0.74
Account inactive	8%	0.27	7%	0.26	6%***	0.25
Street paving moratorium	10%	0.30	8%***	0.27	12%***	0.33
Suburban location	46%	0.50	59%***	0.49	68%***	0.47
Assessor data unlinked	4%	0.20	6%***	0.24	11%***	0.31
Property built before 1951†	87%	0.33	59%***	0.49	55%***	0.50
Property built 1951-1960†	10%	0.30	23%***	0.42	16%***	0.37
Owner-occupied property†	66%	0.47	71%***	0.46	71%***	0.45
Multi-family property†	5%	0.21	4%***	0.19	5%	0.21
Assessed value ($100,000)†	1.11	0.68	1.39***	0.78	1.58***	0.93
Block group characteristics						
Share Black	36%	0.27	31%***	0.27	29%***	0.27
Share Hispanic	31%	0.24	23%***	0.23	22%***	0.22
Share under 5	7%	0.05	6%***	0.04	6%***	0.04
Share over 64	11%	0.06	13%***	0.07	13%***	0.08
Share rental	45%	0.23	41%***	0.23	39%***	0.24
Share college graduate	19%	0.13	25%***	0.16	25%***	0.17
Share below poverty	18%	0.14	15%***	0.14	15%***	0.13

†Data presented only for properties linked to assessor data. ◊LSLR letters refers to mailings sent by the utility in 2018 and 2019 to properties suspected of having an LSL to encourage program registration rather than outreach conducted through the community-based grant program or the housing department grant program. *** p<0.01, ** p<0.05, * p<0.1 denotes a statistically significant difference compared to properties with confirmed homeowner-side lead lines.

More than half of properties with confirmed homeowner-side LSLs were located in the urban core, while the majority of properties with non-lead or unknown material were located in the suburbs. Properties

[28] While not presented in the table, we note that, among properties confirmed *not* to have lead on the homeowner side, those with a LSL on the utility side were more likely to have been built pre-1951 than those without lead on the utility side.

with confirmed LSLs had lower rates of owner occupancy, lower assessed values, and were in neighborhoods with a higher share of Black and Hispanic residents, rental housing, young children, and poverty and a lower share of college graduates and elderly residents. These results suggest that LSLs were more prevalent in economically disadvantaged neighborhoods and could pose an environmental justice concern in the water system service area. The results are similar to an analysis of block group characteristics in four cities that found that likelihood of having an LSL was associated with a higher share of older homes, multi-unit buildings, and poverty in all four cities and a higher share of minority residents, renters, and adults without a college degree in three out of the four cities (GAO 2020).

When we further disaggregate the summary statistics by urban/suburban location as well as service line material (Tables A1a and A1b in the Appendix), we find that properties in the urban core were somewhat more likely to register for the program and have a contractor inspection than those in the suburbs, while the two locations had similar rates of replacement of confirmed lead lines. Irrespective of service line material, urban properties were more likely to be renter-occupied, multi-family buildings constructed before 1951 with lower assessed values and to be located in neighborhoods with higher rates of Black and Hispanic residents, people living below the poverty level, and lower rates of college graduation compared to properties in the suburbs.

Table 2 presents the estimated coefficients from the regression models exploring the characteristics associated with LSLR program participation, estimated separately for properties in urban (i.e., Trenton) and suburban municipalities. We present results from an alternative model in the Appendix (Table A1c) that includes urban and suburban properties in the same regression and interacts all predictor variables with an indicator for suburban to test for heterogeneity in characteristics affecting LSLR program participation by location. The results are not sensitive to this alternate specification but show that the magnitudes of the coefficients for several property and neighborhood characteristics are statistically different across the urban and suburban samples, even though the coefficients for the property characteristics often have the same sign across the two areas.

Table 2 reveals several commonalities in the characteristics of properties that participated in the LSLR program across urban and suburban areas.[29] Properties in both locations that registered and had interior inspections of their service lines were significantly more likely to be built pre-1951 or 1951-61 and to have lead on the utility side of the service line. Neither result is surprising; pre-1961 homes are more likely to have homeowner-side LSLs, and contractors had incentives to encourage registration and conduct inspections at homes with utility-side LSLs, where they would be guaranteed some construction work and would receive a higher payment if a full line replacement was needed. In addition, properties that received outreach letters from the water system about the LSLR program were much more likely to register and have an inspection than properties not sent letters, even after controlling for home age and utility-side service line material (characteristics used by the water system to target properties for LSLR outreach).

[29] Figure A1 in the Appendix provides an illustration and comparison for a subset of these coefficients.

Table 2: Regression analysis of determinants of LSLR program participation

	Urban municipality			Suburban municipalities		
	(1) Registration	(2) Inspection	(3) Replacement of confirmed LSL	(4) Registration	(5) Inspection	(6) Replacement of confirmed LSL
Number of LSLR letters	0.027***	0.052***	0.068***	0.099***	0.148***	0.114***
	(0.005)	(0.006)	(0.014)	(0.004)	(0.004)	(0.017)
Account inactive	-0.024***	0.002	-0.027	-0.005	-0.017**	-0.010
	(0.008)	(0.010)	(0.028)	(0.007)	(0.008)	(0.033)
Lead on utility side	0.179***	0.359***	0.350***	0.037***	0.171***	0.353***
	(0.007)	(0.008)	(0.021)	(0.006)	(0.007)	(0.029)
Street paving moratorium	-0.001	-0.063***	-0.009	-0.015***	-0.126***	-0.128***
	(0.008)	(0.009)	(0.023)	(0.005)	(0.005)	(0.029)
Owner-occupied property	0.072***	0.037***	0.212***	0.023***	0.043***	0.076***
	(0.006)	(0.007)	(0.017)	(0.004)	(0.006)	(0.023)
Multi-unit property	-0.064***	-0.137***	0.005	0.002	-0.095***	-0.101
	(0.010)	(0.011)	(0.033)	(0.018)	(0.020)	(0.086)
Log assessed value	0.065***	0.046***	0.046**	0.014***	0.032***	-0.049*
	(0.008)	(0.009)	(0.022)	(0.005)	(0.006)	(0.030)
Property built before 1951	0.100***	0.139***		0.043***	0.068***	
	(0.009)	(0.011)		(0.004)	(0.005)	
Property built 1951-1960	0.092***	0.209***		0.016***	0.075***	
	(0.020)	(0.022)		(0.004)	(0.005)	
Assessor data unlinked	-0.088***	-0.136***	-0.073	-0.008	-0.044***	-0.032
	(0.011)	(0.013)	(0.053)	(0.005)	(0.007)	(0.037)
Share Black	0.159***	0.069**	-0.101	-0.006	-0.113***	-0.290***
	(0.024)	(0.027)	(0.070)	(0.010)	(0.012)	(0.053)
Share Hispanic	0.068**	0.046	-0.058	0.065***	0.032*	-0.115*
	(0.028)	(0.032)	(0.084)	(0.016)	(0.019)	(0.069)
Share under 5	-0.088	0.075	-0.120	0.007	-0.333***	0.376*
	(0.064)	(0.072)	(0.195)	(0.042)	(0.052)	(0.205)
Share over 64	0.012	0.289***	0.072	-0.016	-0.060**	0.240*
	(0.049)	(0.056)	(0.165)	(0.022)	(0.028)	(0.135)
Share rental housing	-0.105***	-0.089***	-0.109**	-0.001	0.054***	0.165***
	(0.017)	(0.020)	(0.050)	(0.010)	(0.012)	(0.051)
Share college graduate	0.186***	0.241***	-0.059	0.053***	0.022	-0.031
	(0.044)	(0.049)	(0.128)	(0.013)	(0.016)	(0.077)
Share below poverty	0.164***	0.079***	0.092	-0.036	-0.069**	-0.150
	(0.025)	(0.029)	(0.074)	(0.023)	(0.028)	(0.132)
Constant	-0.111***	-0.043	0.182**	-0.043***	-0.006	0.081
	(0.028)	(0.032)	(0.083)	(0.011)	(0.014)	(0.053)
Observations	20,529	20,529	3,098	35,388	35,388	2,671
R-squared	0.103	0.211	0.237	0.116	0.270	0.313

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Single-unit, owner-occupied properties with higher assessed values were also more likely to register and have an inspection compared to non-participating properties in both urban and suburban areas. These properties were also less likely to be on a block with a street construction moratorium, where water system contractors were not supposed to conduct LSLRs. Urban properties with an inactive water system account were significantly less likely to register, and suburban properties with an inactive account (where there might have been no one in residence to let in a contractor) were significantly less likely to have an inspection. Participation among properties that we were unable to link with property assessor records was lower than those we successfully merged. We note that unlinked data could include some non-residential properties because the assessor data was our primary data source for determining property type; the water system included some data on property type, but it was sparse.

Urban properties in neighborhoods with higher shares of Black residents, college graduates, and residents below the poverty line and lower shares of rental properties were more likely to register and have an inspection. Registration rates were also higher in urban neighborhoods with higher shares of Hispanic residents. Urban properties that had inspections also tended to be in neighborhoods with higher shares of elderly residents, which could indicate that retirees had fewer constraints when scheduling an inspection. A higher share of young children in the neighborhood was not significantly associated with LSLR program participation in the urban core.

In suburban municipalities, location in a neighborhood with a higher share of Hispanic residents and college graduates was associated with higher registration rates, similar to results from the urban core. However, unlike the urban results, being located in a neighborhood with a higher share of Black residents, young children, elderly residents, and people below the poverty level and a lower share of rental properties was associated with lower inspection rates in the suburbs.

Columns 3 and 6 show the factors associated with participation in the LSLR program—the most important outcome in our study—in urban and suburban areas, respectively. The coefficient estimates show that properties receiving more outreach letters and those with lead on the utility side of the line were more likely to have a homeowner-side LSLR. Contractors may have targeted these homes since they were paid a higher rate by the utility for replacements involving both sides of the service line. Owner-occupied properties had significantly higher replacement rates. These findings are all consistent across urban and suburban properties.

In the urban core, LSLR was more common among properties with higher assessed values and in neighborhoods with a lower share of rental housing, but other neighborhood characteristics were not significantly associated with LSLR in the urban area. Suburban properties with confirmed higher assessed valued were slightly less likely to have an LSLR than those with lower assessed value, which is surprising, but this result is only marginally significant. Properties in suburban neighborhoods with higher shares of Black or Hispanic residents were less likely to participate in a replacement, and those with a higher share of young children and elderly residents were more likely to have a replacement, though the results for percent Hispanic, young children, and elderly residents are only marginally significant. Suburban properties with confirmed homeowner-side LSLs located in neighborhoods with a higher share of rental properties were also more likely to have a LSLR. The positive association between replacements and neighborhood-level rental housing is counterintuitive, but recall that our regression controls for whether the property itself is owner-occupied. The Census rental variable therefore captures any additional effect associated with living in a neighborhood with a high concentration of rental properties, regardless of an individual property's tenancy status.[30]

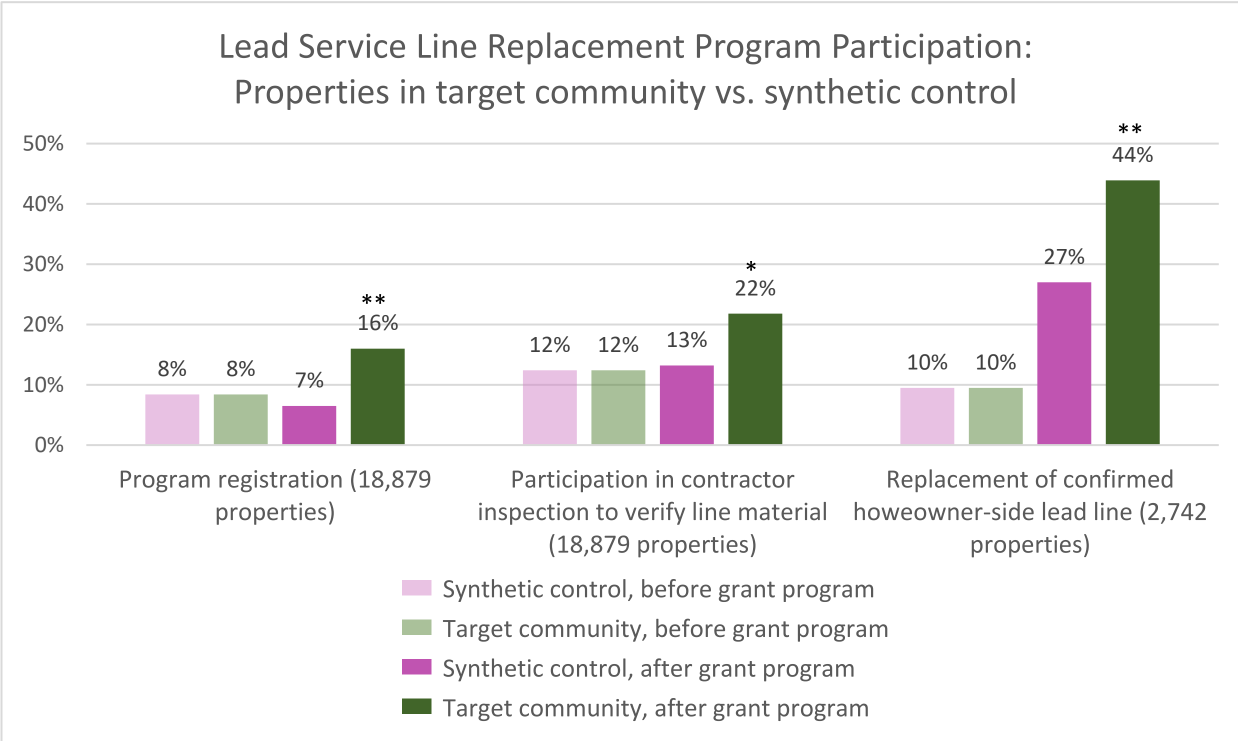
These results characterize participation in the program for the entire service area, where the cost to replace a confirmed LSL was $1,000 for all suburban and most urban customers. The higher rates of program registration and inspection (and, in the urban core, replacement of confirmed LSL) among properties with higher assessed values suggest that households living in lower valued properties (who likely also had lower incomes) faced greater barriers to participation. This analysis did not assess whether programs that subsidize the cost of LSLR can reduce these barriers and whether these barriers were solely financial or were also non-financial. We address these questions next in our evaluations of two programs offered to certain urban residents during the study period.

6.2 Effect of subsidies on LSLR participation

Figure 2 presents the results of the quasi-experimental analysis evaluating the impact of the community-based grant program on LSLR participation in the urban core. Recall that the community-based grant program offered to cover the entirety of the $1,000 LSLR cost for homeowners and half of the cost for landlords in a specific low-income neighborhood in Trenton with almost no paperwork or additional eligibility requirements. The organization also conducted outreach in the target community using a variety of methods, including social media, virtual community meetings, and in-person canvassing. After the introduction of the grant program, LSLR participation was substantially higher in the target community than in a synthetic control group of urban properties with similar characteristics. After the launch of the grant program, registration rates were twice as high, and inspection and replacement rates were more than 50 percent higher in the treatment group than in the synthetic control group. The increases in participation among the treatment group relative to the synthetic control for all three outcomes are all statistically significant (though the increase in inspection rates in the treated group is only significant at the 10 percent level using a two-tailed test). Most notably, replacement rates among properties with confirmed homeowner-side LSLs increased by 17 percentage points more in the target community than in the synthetic control group. Note that completion of homeowner-side LSLRs also increased in the synthetic control group in the period after the grant launch, consistent with the uptick in overall LSLR program activity in the study area throughout 2021 and 2022.

[30] We also note that in suburban properties with confirmed homeowner-side LSLs, percent rentals in the census block group is highly correlated with percent Black population (rho = 0.48) and percent of the population below the poverty level (rho = 0.49). When these two variables are excluded from the regression, the coefficient on percent rental is much smaller and is no longer statistically significant. Thus, the positive and significant association with percent rental is driven in part by multicollinearity with other neighborhood characteristics.

Figure 2. Impact of community-based grant program on LSLR registrations, inspections, and completions



Asterisks denote statistical significance of the treatment effect (*** p<0.01, ** p<0.05, * p<0.1).

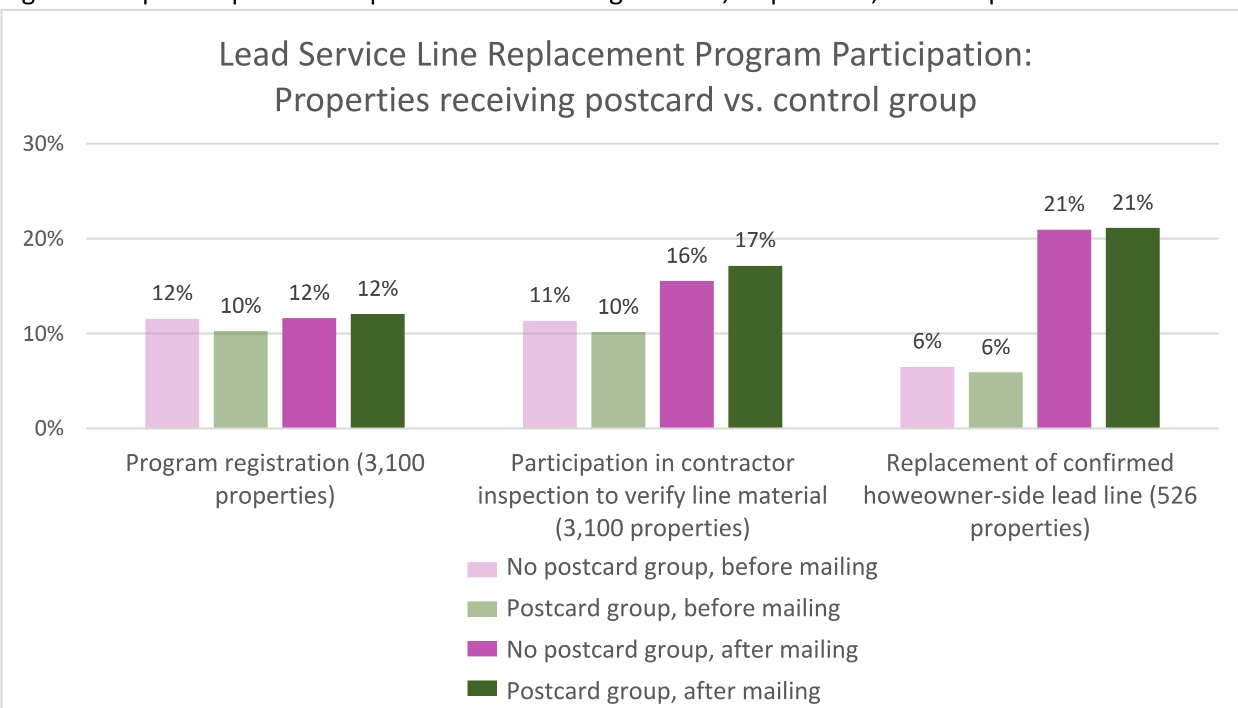
The synthetic control approach ensures that pre-treatment participation rates are equal across the treatment and synthetic control groups. The estimated difference-in-difference coefficients representing the impact of the community grant program are identical regardless of whether property characteristics and block group fixed effects are included in the regressions using the synthetic control approach (Tables A2b and A2c in the Appendix). The estimated impacts are also similar when using an unweighted difference-in-difference model including property characteristics and block group fixed effects in lieu of a synthetic control approach, indicating that the results are robust to alternative ways of constructing the control group (Table A2d in the Appendix). However, pre-treatment inspection and replacement rates were notably higher without the synthetic control approach (Figure A2 in the Appendix), suggesting that the synthetic control provides a more appropriate counterfactual for the target community.[31]

Next, we present the results of the field experiment providing a sample of urban residents with information about the housing department grant-program offered to low-income homeowners. Recall that while the program would cover the entire $1,000 cost of LSLR, applicants were required to provide extensive documentation to prove their eligibility. Prior to randomly assigning addresses to the treatment and control groups, power calculations were estimated using a sample size of 1,500 treatment and 1,500 control with an assumed baseline take-up rate of 10%, resulting in a minimum detectable effect of 3.2%.

[31] Results were also qualitatively similar using coarsened exact matching (CEM) as an alternative matching approach (Appendix Table A2e). As with the unweighted data, pre-treatment participation outcomes were significantly different across the treatment and control groups when using CEM, confirming that the synthetic control approach provides a more appropriate control group.

Figure 3 shows participation rates before and after the postcard mailing in the treatment and control groups. Program registration, inspection, and replacement rates were similar across the control and treatment groups before the intervention.[32] After the postcards were sent, registration rates stayed roughly constant, while inspection and replacement rates increased significantly among both groups, consistent with the uptick in LSLR program activity throughout the service area in the latter half of the study period. There were slightly larger increases in registration and inspection rates in the treatment group than the control group. The treatment effects for registration and inspections are 1.7% and 2.8%, respectively. Given post-intervention participation rates among the control group of 12% for registration and 16% for inspection (which were higher than the 10% originally assumed), these effects are below the minimum detectable effect size and are not statistically significant.

Figure 3. Impact of postcard experiment on LSLR registration, inspections, and completions



There were no statistically significant treatment effects in this analysis.

The increase in replacement rates among properties with confirmed homeowner-side LSLs was nearly identical across the two groups. The effect size of 0.8% is near zero in a qualitative sense as well as not being statistically distinguishable from zero. These results show that the informational treatment about a grant opportunity was largely ineffective in boosting LSLR program participation.[33] Housing department staff also confirmed that they received no applications for LSLR under the grant program after the

[32] Baseline registration and inspection were included as features in the rerandomization strategy implemented at assignment of households to treatment and control groups.

[33] Because the postcards only included English-language information, they could have been less effective in areas with a higher concentration of non-English speakers. We tested this hypothesis by interacting the treatment variable with the share of Hispanic residents in the block group (Table A3d). The impact of receiving a postcard interacted with the share of Hispanic residents is not statistically significant in any of the three LSLR program participation outcomes.

postcards were sent (personal communication, Farrah Gee, City of Trenton Department of Housing and Economic Development).

Even if these effects were shown to be statistically significant in a more highly powered study, the magnitudes of the effects may not be substantial enough to make this type of intervention attractive to water systems, particularly given the negligible effect on the ultimate outcome of interest—replacement of confirmed homeowner-side LSLs. While the cost of the postcard intervention is low, it still entails administrative and time costs to water systems to coordinate with the organization providing the grants and to design the outreach.

The results in Figure 3 were derived using the coefficient estimates from the instrumental variables difference-in-difference regression (Table A3b in the Appendix). Table A3c presents the coefficient estimates for the intent-to-treat difference-in-difference model that does not account for the fact that 15% of observations in the assigned treatment group did not receive the postcards. The intent-to-treat and instrumental variables approaches yield similar results.[34]

Results from the two program evaluations are not entirely consistent with the hypothesis that households offered subsidies are more likely to participate in the LSLR program, since the postcards about the housing department grant program had no effect on LSLR participation. The differing results across the two grant programs is, however, consistent with the hypothesis that subsidies are more effective when combined with outreach and trusted community messengers that can address non-financial barriers to program participation.

7 Discussion and Conclusions

To our knowledge, this study is the first to examine individual property and neighborhood characteristics associated with occurrence of LSL and participation in a voluntary LSLR program. LSLs were more prevalent in the urban portion of the water system service area, which has a higher concentration of pre-1950 housing stock, Black and Hispanic residents, renters, and poverty than the suburban portions of the service area. Properties in the urban area were somewhat more likely to register for the program and participate in a service line inspection than those in the suburbs. Replacement of confirmed LSLs occurred at similar rates across the two location types.

Notable results from the observational regression analyses of the full urban and suburban samples include the importance of tenancy, property values, and outreach. Replacement rates among urban properties with confirmed LSLs were 21 percentage points higher in owner-occupied than in renter-occupied properties. In suburban areas, this association was less pronounced but still statistically significant, with owner-occupied properties 7 percentage points more likely to have a replacement than renter-occupied properties. Registration and inspection rates were also significantly higher in owner-occupied than renter-occupied properties in both urban and suburban areas. These results support the hypothesis that split incentives between landlords and renters pose a substantial barrier to LSLR.

Properties with higher assessed value were also significantly more likely to register and to have an inspection in both urban and suburban municipalities, and significantly more likely to replace a confirmed

[34] Table A3e presents the coefficients for the intent-to-treat difference-in-difference model adding property-level control variables and block group fixed effects. The estimated treatment effects are identical to those in the intent-to-treat model that does not include the control variables and fixed effects.

LSL in the urban municipality. This result suggests that barriers to participation are greatest among lower income households, though we cannot identify the relative importance of financial and non-financial barriers contributing to this outcome since low-income households may face both types of barriers disproportionately.

Another consistent finding across urban and suburban areas is the importance of water system outreach. The number of letters sent to encourage registration before program implementation was significantly associated with all three participation outcomes in both urban and suburban areas. In the urban municipality, replacement conditional on having a confirmed LSL was 7 percentage points higher per letter sent, while in suburban areas, the effect was even larger at 11 percentage points per letter. Since letters were sent to the properties rather than owners, the higher rental rate in the city could be a reason for the smaller magnitude of the coefficient on outreach letters. The water system intentionally targeted the letters to properties suspected to have homeowner-side LSLs, so we cannot make a strong causal claim about the impact of the letters *per se* because they are likely to be correlated with additional forms of outreach that were not tracked in our data, such as contractor and water system staff door-to-door visits. In addition, homeowners who suspected they had an LSL might have been more likely to register and sign up for an inspection even in the absence of outreach letters, though our analysis controlled for housing age, the primary determinant of LSL occurrence. Despite these limitations, the results suggest that individualized property-level outreach is a useful strategy, and that multiple outreach attempts are more effective than single attempts in eliciting a customer response.

At the neighborhood level, registration rates were generally higher in areas with more Black and Hispanic residents, suggesting that lack of information, mistrust, and language barriers were not particular barriers for minority residents. However, participation in replacement of confirmed LSL—the ultimate outcome of interest—was lower in these neighborhoods, which could reflect additional financial constraints not reflected in tenancy and property values. The inconsistent findings about other neighborhood characteristics associated with LSLR program participation across urban and suburban areas, such as poverty and presence of young children and elderly residents, make it difficult to generalize about additional barriers to participation.

One limitation of our study is that we were not able to examine the impact of the COVID-19 pandemic on customer participation. In-person outreach, inspection, and construction work paused from March through July 2020, but customers after that time could still have been reluctant to allow contractors inside of their homes due to concerns about disease transmission, dampening program participation.

Using quasi-experimental and experimental approaches, we evaluated two interventions designed to address the financial barriers to participation by providing full-cost subsidies for certain urban residents. The results yield insights about approaches that do and do not motivate participation among residents facing financial barriers. We found that the community-based grant program was highly effective in encouraging participation in the LSLR program. In contrast, the postcard informing residents about the housing department grant program was not. The two programs differed substantially in terms of both mode of outreach and transactional barriers, so we cannot parse the relative contribution of these factors to the divergent outcomes. The community organization conducted extensive in-person and virtual outreach and education about LSLR, while the field experiment involved a single postcard mailing about the housing department grant program, which was not otherwise well publicized. In addition, the housing department grant program required an application and review process including formal documentation of income to prove eligibility, while the community program had no income requirements. The results suggest that programs to cover homeowner-side LSL costs can greatly boost customer participation when the programs are well publicized and easy to access.

It is worth noting that participation rates in the neighborhood targeted by the community grant program, while significantly higher than the control group, topped out at 54% of properties with confirmed LSLs during study period. Despite the promising results from this program, participation was well under 100% even when the financial barrier to participation was removed for homeowners and substantially reduced for landlords. A representative from the community organization confirmed that the program could have funded more LSLRs had they received more applications, indicating that the shortfall in full participation was due to lack of customer demand rather than insufficient funding (personal communication, Caitlin Fair, East Trenton Collaborative). Our results confirm that water systems designing programs to identify and replace LSLs will need to address both financial and non-financial barriers to achieve the goal of full and equitable replacement of LSLs.

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Appendix: Additional Tables and Figures

A1. Urban and suburban full-sample analyses

Table A1a. Summary statistics disaggregated by location and service line material: Urban municipality

	Confirmed lead		Confirmed non-lead		Material unknown	
Observations	3,098		6,429		11,002	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
LSLR participation outcomes						
Registered for LSLR program	41%	0.49	36%***	0.48	2%***	0.12
Interior contractor inspection	70%	0.46	80%***	0.40	0%***	0.03
Homeowner-side LSLR completed	44%	0.50	0%***	0.00	0%***	0.00
Property characteristics						
Lead on utility side of line	60%	0.49	65%***	0.48	32%***	0.47
Number of LSLR letters sent	1.32	0.72	1.30	0.72	0.97***	0.69
Account inactive	9%	0.29	10%	0.30	10%	0.30
Street paving moratorium	12%	0.33	11%	0.32	13%	0.34
Suburban location	0%	0.00	0%	0.00	0%	0.00
Assessor data missing	3%	0.17	6%***	0.23	10%***	0.30
Property built before 1951†	99%	0.12	92%***	0.27	90%***	0.30
Property built 1951-1960†	1%	0.09	5%***	0.21	2%***	0.14
Owner-occupied property†	51%	0.50	49%**	0.50	43%***	0.50
Multi-family property†	8%	0.27	8%	0.28	12%***	0.33
Assessed value ($100,000) †	0.64	0.35	0.64	0.37	0.61***	0.31
Block group characteristics						
Share Black	47%	0.28	49%***	0.29	49%***	0.29
Share Hispanic	40%	0.27	37%***	0.27	38%***	0.26
Share under 5	7%	0.05	7%	0.05	7%***	0.05
Share over 64	9%	0.06	9%***	0.06	9%	0.06
Share rental	57%	0.20	58%***	0.20	60%***	0.19
Share college graduate	12%	0.09	13%***	0.10	12%***	0.08
Share below poverty	25%	0.13	27%***	0.13	28%***	0.14

†Data presented only for properties linked to assessor data. *** p<0.01, ** p<0.05, * p<0.1 denotes a statistically significant difference compared to properties with confirmed homeowner-side lead lines.

Table A1b. Summary statistics disaggregated by location and service line material: Suburban municipalities

	Confirmed lead		Confirmed non-lead		Material unknown	
Observations	2,671		9,332		23,385	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
LSLR participation outcomes						
Registered for LSLR program	39%	0.49	20%***	0.40	2%***	0.14
Interior contractor inspection	61%	0.49	57%***	0.49	0%***	0.02
Homeowner-side LSLR completed	42%	0.49	0%***	0.00	0%***	0.00
Property characteristics						
Lead on utility side of line	57%	0.50	53%***	0.50	26%***	0.44
Number of LSLR letters sent	0.96	0.85	0.95	0.85	0.43***	0.69
Account inactive	6%	0.24	5%*	0.22	5%**	0.22
Street paving moratorium	8%	0.27	6%***	0.23	12%***	0.33
Suburban location	100%	0.00	100%	0.00	100%	0.00
Assessor data missing	6%	0.24	6%	0.24	11%***	0.31
Property built before 1951†	74%	0.44	37%*	0.48	38%*	0.49
Property built 1951-1960†	22%	0.41	35%*	0.48	23%	0.42
Owner-occupied property†	84%	0.37	86%*	0.35	85%	0.36
Multi-family property†	1%	0.10	1%	0.08	1%	0.11
Assessed value ($100,000) †	1.68	0.54	1.91*	0.53	2.04*	0.75
Block group characteristics						
Share Black	24%	0.19	18%***	0.17	20%***	0.20
Share Hispanic	20%	0.16	13%***	0.12	14%***	0.14
Share under 5	7%	0.05	6%***	0.04	6%***	0.04
Share over 64	13%	0.06	16%***	0.06	15%***	0.08
Share rental	31%	0.19	29%***	0.17	29%***	0.18
Share college graduate	26%	0.14	33%***	0.14	32%***	0.16
Share below poverty	9%	0.08	8%***	0.07	9%*	0.08

†Data presented only for properties linked to assessor data. *** $p<0.01$, ** $p<0.05$, * $p<0.1$ denotes a statistically significant difference compared to properties with confirmed homeowner-side lead lines.

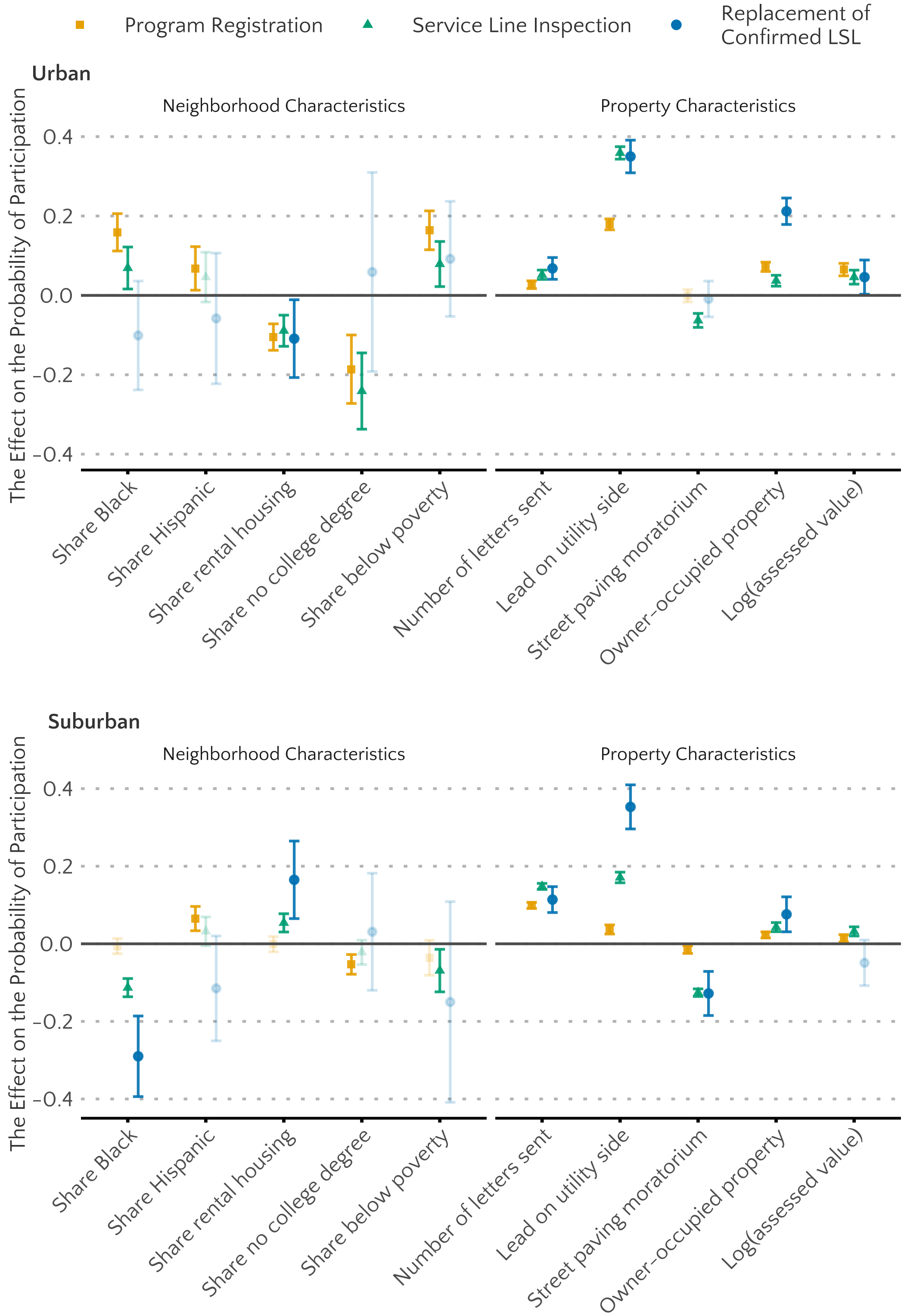
Table A1c: Full-sample regression analysis of determinants of LSLR program participation

	(1) Registration	(2) Inspection	(3) Replacement of confirmed LSL
Number of letters sent	0.027***	0.052***	0.068***
	(0.005)	(0.006)	(0.014)
Account inactive	-0.024***	0.001	-0.027
	(0.008)	(0.010)	(0.028)
Lead on utility side	0.179***	0.359***	0.350***
	(0.007)	(0.008)	(0.021)
Street paving moratorium	-0.001	-0.063***	-0.009
	(0.008)	(0.009)	(0.023)
Owner-occupied property	0.072***	0.037***	0.212***
	(0.006)	(0.007)	(0.017)
Multi-unit property	-0.065***	-0.137***	0.005
	(0.010)	(0.011)	(0.033)
Ln assessed value	0.065***	0.047***	0.046**
	(0.008)	(0.009)	(0.022)
Property built before 1951	0.100***	0.139***	
	(0.009)	(0.011)	
Property built 1951-1960	0.092***	0.209***	
	(0.020)	(0.022)	
Assessor data unlinked	-0.088***	-0.136***	-0.073
	(0.011)	(0.013)	(0.053)
Share Black	0.159***	0.069**	-0.101
	(0.024)	(0.027)	(0.070)
Share Hispanic	0.068**	0.046	-0.058
	(0.028)	(0.032)	(0.084)
Share under 5	-0.088	0.075	-0.120
	(0.064)	(0.072)	(0.195)
Share over 64	0.011	0.288***	0.072
	(0.049)	(0.056)	(0.165)
Share rental housing	-0.105***	-0.089***	-0.109**
	(0.017)	(0.020)	(0.050)
Share college graduate	0.186***	0.241***	-0.059
	(0.044)	(0.049)	(0.128)
Share below poverty	0.164***	0.079***	0.092
	(0.025)	(0.029)	(0.074)
Suburb	0.068**	0.037	-0.101
	(0.030)	(0.035)	(0.099)
Number of letters sent	0.071***	0.096***	0.046**
*suburb	(0.006)	(0.007)	(0.022)
Account inactive	0.019*	-0.019	0.018
*suburb	(0.011)	(0.013)	(0.043)
Lead on utility side	-0.142***	-0.189***	0.003
*suburb	(0.009)	(0.010)	(0.036)

Street paving moratorium	-0.014	-0.063***	-0.119***
*suburb	(0.009)	(0.010)	(0.038)
Owner-occupied property	-0.049***	0.007	-0.136***
*suburb	(0.007)	(0.009)	(0.028)
Multi-unit property	0.067***	0.041*	-0.106
*suburb	(0.021)	(0.023)	(0.092)
Ln assessed value	-0.051***	-0.015	-0.096***
*suburb	(0.009)	(0.011)	(0.037)
Property built before 1951	-0.057***	-0.072***	
*suburb	(0.010)	(0.012)	
Property built 1951-1960	-0.076***	-0.134***	
*suburb	(0.021)	(0.023)	
Assessor data unlinked	0.079***	0.092***	0.041
*suburb	(0.012)	(0.015)	(0.065)
Share Black	-0.165***	-0.182***	-0.189**
*suburb	(0.025)	(0.030)	(0.088)
Share Hispanic	-0.003	-0.014	-0.057
*suburb	(0.032)	(0.037)	(0.109)
Share under 5	0.096	-0.407***	0.497*
*suburb	(0.076)	(0.089)	(0.283)
Share over 64	-0.027	-0.349***	0.169
*suburb	(0.054)	(0.062)	(0.214)
Share rental housing	0.104***	0.143***	0.274***
*suburb	(0.020)	(0.023)	(0.072)
Share college graduate	-0.132***	-0.218***	0.027
*suburb	(0.046)	(0.051)	(0.150)
Share below poverty	-0.199***	-0.148***	-0.243
*suburb	(0.034)	(0.040)	(0.152)
Constant	-0.111***	-0.043	0.182**
	(0.028)	(0.032)	(0.083)
Observations	55,917	55,917	5,769
R-squared	0.124	0.267	0.272

Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Figure A1. Regression analysis of select determinants of LSLR program participation



Note: The point estimates of the coefficients are plotted along with 95% confidence intervals. When the 95% confidence interval includes 0, the estimate is a lighter shade.

A2. Quasi-experimental evaluation of community grant program

Table A2a. Summary statistics for treated, untreated, and synthetic control groups

	Target community		Untreated urban properties		Synthetic control‡	
Observations	1,010		17,869		17,869	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
LSLR participation outcomes						
Registered for LSLR program	24%	0.43	17%***	0.38	14%***	0.35
Interior contractor inspection	34%	0.47	36%	0.48	26%***	0.44
Homeowner-side LSLR completed	6%	0.24	7%	0.25	4%***	0.20
Property characteristics						
Lead on utility side of line	44%	0.50	46%	0.50	44%	0.50
Number of LSLR letters sent	1.07	0.73	1.12**	0.72	1.07	0.74
Account inactive	13%	0.34	10%***	0.30	13%	0.34
Street paving moratorium	25%	0.43	12%***	0.32	25%	0.43
Suburban location	0%	0.00	0%	0.00	0%	0.00
Assessor data missing	11%	0.32	7%***	0.26	11%	0.32
Property built before 1951†	91%	0.28	92%	0.28	91%	0.28
Property built 1951-1960†	0%	0.00	3%***	0.16	0%	0.02
Owner-occupied property†	41%	0.49	45%**	0.50	41%	0.49
Multi-family property†	4%	0.19	11%***	0.31	4%	0.19
Assessed value ($100,000)†	0.32	0.13	0.64***	0.33	0.32	0.11
Block group characteristics						
Share Black	50%	0.13	48%	0.29	50%	0.31
Share Hispanic	43%	0.14	38%***	0.27	43%	0.27
Share under 5	6%	0.02	7%***	0.05	8%***	0.06
Share over 64	5%	0.04	9%***	0.06	5%	0.03
Share rental	64%	0.10	59%***	0.20	64%	0.16
Share college graduate	6%	0.03	12%***	0.09	6%	0.05
Share below poverty	34%	0.15	27%***	0.13	34%	0.16

†Data presented only for properties linked to assessor data. *** p<0.01, ** p<0.05, * p<0.1 denotes a statistically significant difference compared to properties with confirmed homeowner-side lead lines. ‡Synthetic control summary statistics are calculated using entropy balancing weights.

Figure A2. Impact of community-based grant program on LSLR registrations, inspections, and completions using an unweighted average of all untreated properties instead of a synthetic control

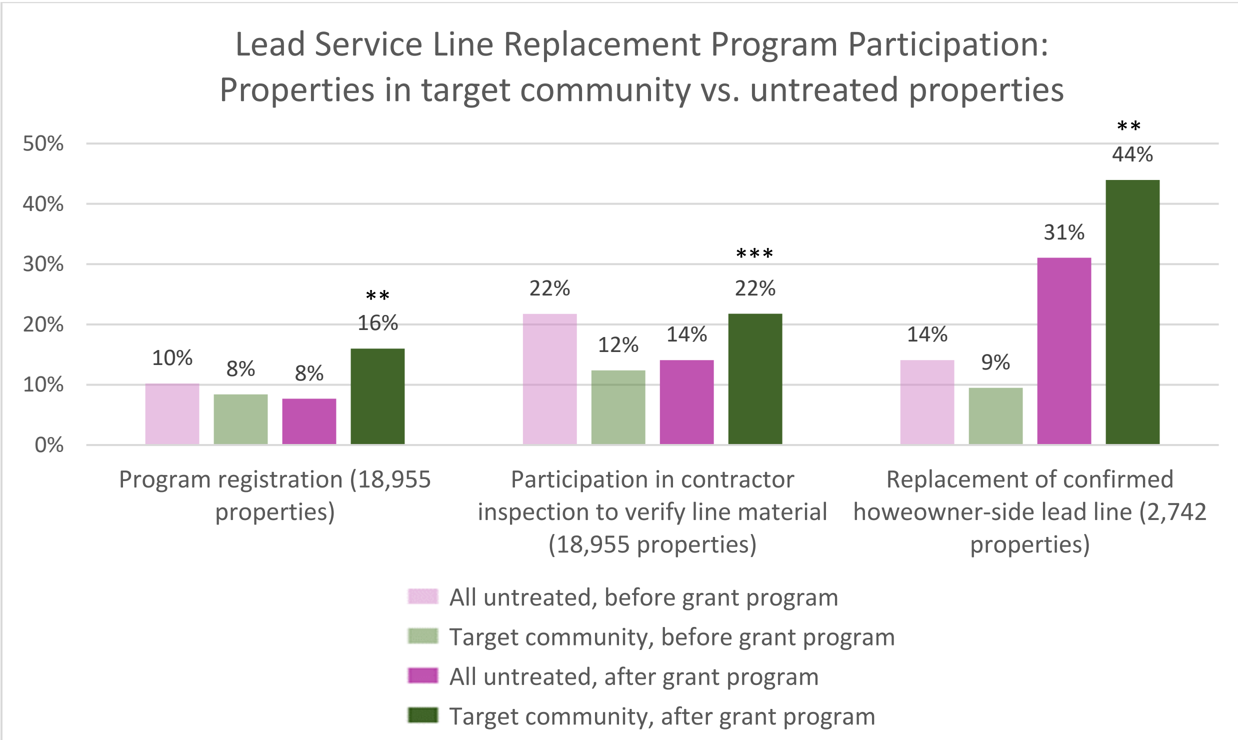


Table A2b. Synthetic control difference-in-difference regression estimates of impact of community-based grant program on LSLR program participation

	(1) Registration	(2) Inspection	(3) Replacement (conditional on confirmed lead)
Target community	0.000	-0.000	-0.000
	(0.012)	(0.018)	(0.053)
After	-0.019	0.008	0.169***
	(0.014)	(0.025)	(0.047)
Target community*	0.095**	0.086*	0.175**
After	(0.041)	(0.048)	(0.078)
Constant	0.084***	0.124***	0.095***
	(0.007)	(0.014)	(0.031)
Property characteristics	No	No	No
BG fixed effects	No	No	No
Observations	37,758	37,758	5,484
R-squared	0.015	0.012	0.117

Regressions are weighted using entropy balancing weights. Standard errors clustered by Census block group are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1

Table A2c. Synthetic control difference-in-difference regression estimates of impact of community-based grant program on LSLR program participation including block group fixed effects and property control variables

	(1) Registration	(2) Inspection	(3) Replacement (conditional on confirmed lead)
Target community	—	—	—
After	-0.019	0.008	0.169***
	(0.014)	(0.025)	(0.048)
Target community* After	0.095** (0.041)	0.086* (0.048)	0.175** (0.078)
Constant	0.001	-0.038*	-0.076
	(0.016)	(0.020)	(0.074)
Property characteristics	Yes	Yes	Yes
BG fixed effects	Yes	Yes	Yes
Observations	37,758	37,758	5,484
R-squared	0.084	0.103	0.269

Regressions are weighted using entropy balancing weights. Standard errors clustered by Census block group are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1

Table A2d. Unweighted difference-in-difference regression estimates of impact of community-based grant program on LSLR program participation including block group fixed effects and property control variables

	(1) Registration	(2) Inspection	(3) Replacement (conditional on confirmed lead)
Target community	—	—	—
After	-0.025**	-0.077***	0.170***
	(0.011)	(0.025)	(0.048)
Target community* After	0.101** (0.040)	0.171*** (0.048)	0.175** (0.078)
Constant	-0.001	0.043**	-0.053*
	(0.010)	(0.017)	(0.027)
Property characteristics	Yes	Yes	Yes
BG fixed effects	Yes	Yes	Yes
Observations	37,758	37,758	5,484
R-squared	0.056	0.102	0.149

Standard errors clustered by Census block group are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1

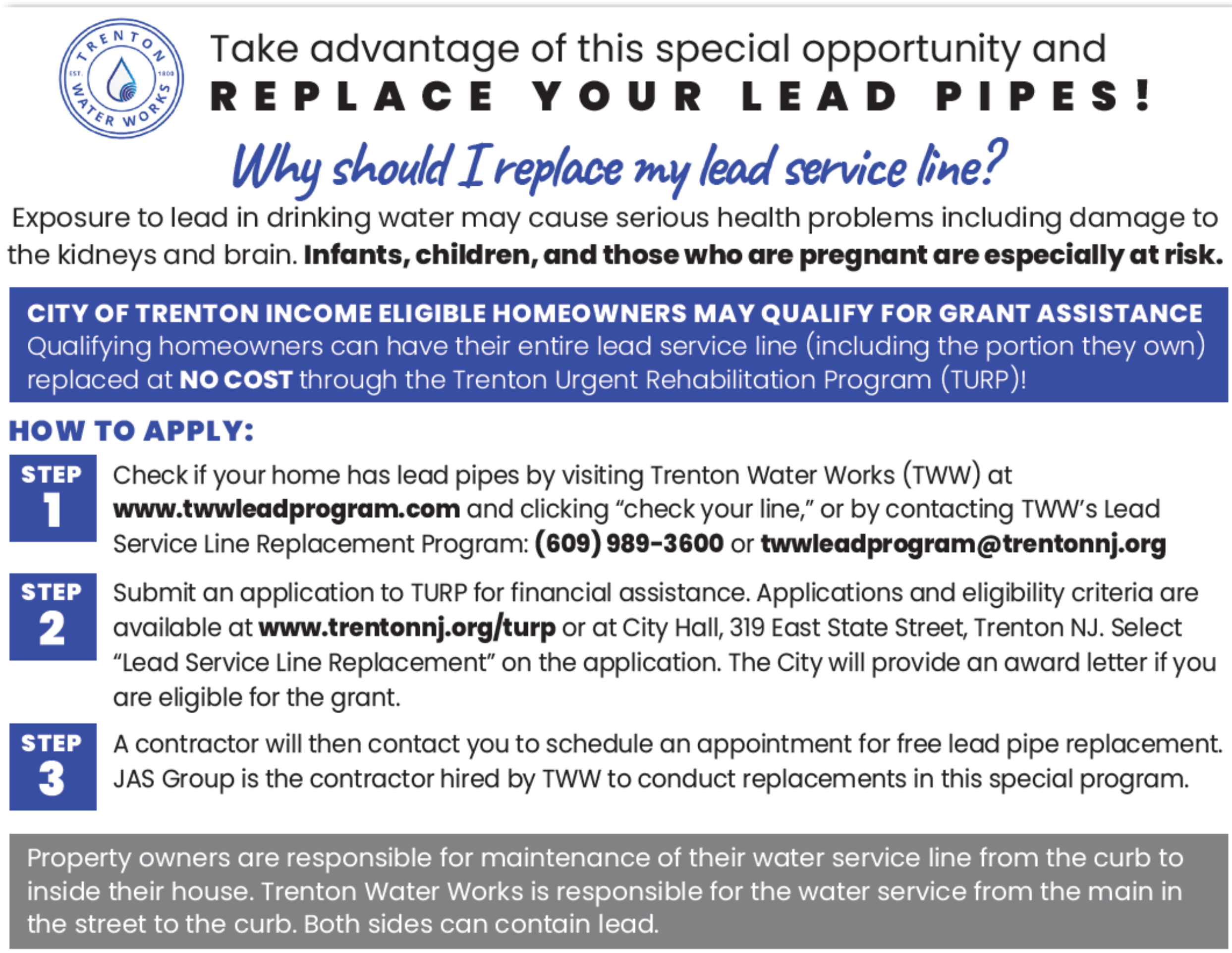
Table A2e. CEM (coarsened exact matching) weighted difference-in-difference regression estimates of impact of community-based grant program on LSLR program participation including block group fixed effects

	(1) Registration	(2) Inspection	(3) Replacement (conditional on confirmed lead)
Target community	—	—	—
After	-0.007	-0.049**	0.203***
	(0.011)	(0.023)	(0.055)
Target community* After	0.084**	0.144***	0.148*
	(0.040)	(0.046)	(0.086)
Constant	0.084***	0.183***	0.129***
	(0.005)	(0.011)	(0.026)
Property characteristics	No	No	No
BG fixed effects	Yes	Yes	Yes
Observations	32,612	32,612	4,060
R-squared	0.014	0.022	0.102

Regressions are weighted using CEM weights (Iacus et al. 2012). CEM weights were derived by matching the treatment and comparison groups on all nine property-level covariates: lead on the utility-side of the line, number of LSLR letters sent, account inactive, street paving moratorium, assessor data missing, property built before 1951, property built 1951-1960, owner-occupied property, and assessed value. An exact match was used for all variables except assessed value, which was coarsened into five categories denoting $1-$25,000, $25,000-$50,000, $50,000-$75,000, $75,000-$100,000, and $100,000-$125,000. Census block group characteristics were not used as match variables; instead, the regressions include block group fixed effects. Standard errors clustered by Census block group are in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1

A3. Experimental evaluation of postcards with information about city grant program

Figure A3. Postcard sent to experimental sample



Take advantage of this special opportunity and

REPLACE YOUR LEAD PIPES!

Why should I replace my lead service line?

Exposure to lead in drinking water may cause serious health problems including damage to the kidneys and brain. **Infants, children, and those who are pregnant are especially at risk.**

CITY OF TRENTON INCOME ELIGIBLE HOMEOWNERS MAY QUALIFY FOR GRANT ASSISTANCE
Qualifying homeowners can have their entire lead service line (including the portion they own) replaced at **NO COST** through the Trenton Urgent Rehabilitation Program (TURP)!

HOW TO APPLY:

STEP 1 Check if your home has lead pipes by visiting Trenton Water Works (TWW) at **www.twwleadprogram.com** and clicking "check your line," or by contacting TWW's Lead Service Line Replacement Program: **(609) 989-3600** or **twwleadprogram@trentonnj.org**

STEP 2 Submit an application to TURP for financial assistance. Applications and eligibility criteria are available at **www.trentonnj.org/turp** or at City Hall, 319 East State Street, Trenton NJ. Select "Lead Service Line Replacement" on the application. The City will provide an award letter if you are eligible for the grant.

STEP 3 A contractor will then contact you to schedule an appointment for free lead pipe replacement. JAS Group is the contractor hired by TWW to conduct replacements in this special program.

Property owners are responsible for maintenance of their water service line from the curb to inside their house. Trenton Water Works is responsible for the water service from the main in the street to the curb. Both sides can contain lead.

Table A3a. Summary statistics for postcard treatment and control groups

	Assigned treatment group		Assigned control group	
Observations	3,100		3,100	
	Mean	Std. Dev.	Mean	Std. Dev.
LSLR participation outcomes				
Registered for LSLR program	22%	0.41	22%	0.41
Interior contractor inspection	27%	0.44	27%	0.44
Homeowner-side LSLR completed	4%	0.2	5%	0.21
Property characteristics				
Postcard received	85%	0.35	0%***	0.06
Lead on homeowner side of the line	47%	0.5	51%	0.50
Lead on utility side of line	51%	0.5	53%	0.50
Number of LSLR letters sent	1.09	0.73	1.13	0.73
Account inactive	4%	0.2	5%	0.23
Street paving moratorium	13%	0.33	14%	0.34
Assessor data missing	8%	0.28	9%	0.29
Property built before 1951†	94%	0.25	94%	0.23
Property built 1951-1960†	4%	0.19	4%	0.19
Owner-occupied property†	67%	0.47	65%	0.48
Multi-family property†	7%	0.25	8%	0.26
Assessed value ($100,000) †	0.85	4.02	0.80	1.52
Block group characteristics				
Share Black	52%	0.3	52%	0.30
Share Hispanic	36%	0.28	36%	0.28
Share under 5	7%	0.05	7%	0.05
Share over 64	9%	0.06	9%	0.06
Share rental	61%	0.19	61%	0.19
Share college graduate	12%	0.09	13%	0.09
Share below poverty	27%	0.13	27%	0.13

†Data presented only for properties linked to assessor data. *** p<0.01, ** p<0.05, * p<0.1 denotes a statistically significant difference compared to properties with confirmed homeowner-side lead lines.

Table A3b. Instrumental variables difference-in-difference regression estimates of impact of postcard on LSLR program participation

	(1) Registration	(2) Inspection	(3) Replacement (conditional on confirmed lead)
Received postcard	-0.013	-0.012	-0.006
	(0.013)	(0.013)	(0.024)
After	0.001	0.042***	0.144***
	(0.012)	(0.012)	(0.029)
Received postcard × After	0.017	0.028	0.008
	(0.019)	(0.020)	(0.047)
Constant	0.116***	0.114***	0.065***
	(0.008)	(0.008)	(0.015)
Observations	6,200	6,200	1,056
R-squared	0.000	0.006	0.046

Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1

Table A3c. Intent-to-treat difference-in-difference regression estimates of impact of postcard on LSLR program participation

	(1) Registration	(2) Inspection	(3) Replacement (conditional on confirmed lead)
Received postcard	-0.011	-0.010	-0.005
	(0.011)	(0.011)	(0.021)
After	0.001	0.042***	0.144***
	(0.011)	(0.012)	(0.029)
Received postcard* After	0.015	0.024	0.007
	(0.016)	(0.017)	(0.041)
Constant	0.115***	0.114***	0.065***
	(0.008)	(0.008)	(0.015)
Observations	6,200	6,200	1,056
R-squared	0.000	0.007	0.046

Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1

Table A3d. Intent-to-treat difference-in-difference regression estimates of impact of postcard interacted with percent Hispanic on LSLR program participation

	(1) Registration	(2) Inspection	(3) Replacement (conditional on confirmed lead)
Received postcard	-0.030	-0.022	-0.036
	(0.020)	(0.019)	(0.032)
After	-0.012	0.063***	0.110**
	(0.021)	(0.021)	(0.045)
Received postcard* After	0.022	0.037	0.079
	(0.029)	(0.030)	(0.065)
Share Hispanic	-0.158***	-0.059**	-0.069
	(0.027)	(0.030)	(0.043)
Share Hispanic*After	0.037	-0.060	0.105
	(0.040)	(0.044)	(0.099)
Share Hispanic* Received postcard	0.054	0.032	0.090
	(0.038)	(0.040)	(0.064)
Share Hispanic*After* Received postcard	-0.019	-0.036	-0.209
	(0.056)	(0.062)	(0.140)
Constant	0.171***	0.135***	0.088***
	(0.015)	(0.014)	(0.024)
Observations	6,200	6,200	1,056
R-squared	0.011	0.012	0.049

Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1

Table A3d. Intent-to-treat difference-in-difference regression estimates of impact of postcard on LSLR program participation including block group fixed effects and property control variables

	(1) Registration	(2) Inspection	(3) Replacement (conditional on confirmed lead)
Received postcard	-0.009	-0.009	-0.008
	(0.011)	(0.011)	(0.024)
After	0.001	0.042***	0.144***
	(0.011)	(0.012)	(0.027)
Received postcard* After	0.015	0.024	0.007
	(0.016)	(0.017)	(0.039)
Constant	0.055	0.040	-0.350***
	(0.043)	(0.044)	(0.125)
Observations	6,196	6,196	1,056
R-squared	0.080	0.098	0.194

Robust standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1