Journal of Public Economics 153 (2017) 69–81

Contents lists available at ScienceDirect

Journal of Public Economics

journal homepage: www.elsevier.com/locate/jpube

The value of a healthy home: Lead paint remediation and housing values

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ARTICLE INFO

Article history:
Received 9 June 2016
Received in revised form 27 June 2017
Accepted 19 July 2017
Available online 25 July 2017

JEL classification codes:
Q51
Q52
Q58
R21
R23
R31
I18

Keywords:
Lead paint exposure
Lead hazard remediation
Value of environmental health risk
Urban environmental health

ABSTRACT

The presence of lead paint significantly impairs cognitive and behavioral development, yet little is known about the value to households of avoiding this residence-specific environmental health risk. In this paper, we estimate the benefits of lead-paint remediation on housing prices. Using data on all homes that applied to a HUD-funded program in Charlotte, North Carolina, we adopt a difference-in-differences estimator that compares values among remediated properties with those for which an inspection does not identify a lead paint hazard. Results indicate large returns for public and private investment in remediation with each $1 spent on lead remediation generating $2.60 in benefits as well as a reduction in residential turnover.

1. Introduction

Residents of disadvantaged neighborhoods typically face an elevated risk of exposure to harmful environmental toxins due to an increased prevalence of key sources of pollution such as dilapidated homes, industrial activity and busy roads. One of the most pervasive sources of these toxins is lead paint in older residential structures.[1] Recent work by Aizer et al. (2016), Zhang et al. (2013), and Miranda et al. (2007), find detrimental effects of childhood exposure to lead paint hazards on a number of education outcomes.[2] Beyond the effects of lead pollution on child health and development, the presence of lead may impact neighborhoods through its capitalization in housing values and the sorting of residents to/away from homes with lead paint. As a result, the presence of lead is likely an important mechanism contributing to the profound relationship between neighborhood of birth and later economic well-being(Chetty et al., 2016; Chetty and Hendren, 2016; Chetty et al., 2014).

A growing set of papers in environmental economics use hedonic methods to estimate the capitalization of environmental disamenities into housing prices. Exposure to toxins through poor air quality (Chay and Greenstone, 2005), EPA Superfund sites (Gamper-Rabindran and Timmins, 2013; Greenstone and Gallagher, 2008), Toxic Release Inventory (TRI) facilities (Currie et al., 2015; Mastromonaco, 2015; Sanders, 2012), and other polluted areas (Davis, 2004; Leggett and Bockstael, 2000) are associated with lower housing values. Due to the endogenous sorting of lower income families toward affordable neighborhoods with higher health risks (Banzhaf and Walsh, 2008; Kahn, 2000), research that estimates the housing-price capitalization of environmental disamenities typically adopts quasi-experimental research designs based on information shocks or discontinuities in selection criteria for environmental cleanup.

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[1] The National Survey of Lead and Allergens in Housing estimated that 38 million housing units in the United States (40% of all housing units) contained lead paint and approximately 24 million had significant lead paint hazards (Jacobs et al., 2002).

[2] See EPA (2013) for a comprehensive review of the vast literature documenting the effects of lead exposure on cognitive and behavioral outcomes.

http://dx.doi.org/10.1016/j.jpubeco.2017.07.006
0047-2727/

This paper contributes to this literature by providing estimates of the value of residential lead exposure risk and the benefits of lead remediation programs. Since the primary source of this health risk is limited to specific structures, we are able to compare the estimated capitalized benefits directly with the actual costs of remediation. The remediation program we evaluate is one of the most common ways in which the federal government addresses lead hazards in homes across the United States. Since 1998, the U.S. Department of Housing and Urban Development (HUD) has provided more than $1.2 billion in grants through its Lead Hazard Control Program to target high exposure risk homes occupied by lower income residents.[3] We focus on one of these HUD-funded programs, LeadSafe Charlotte, which remediated over 2000 parcels between 1998 and 2014 in Charlotte, North Carolina.

We combine administrative data from LeadSafe Charlotte with county assessor parcel records and use a difference-in-difference research design to evaluate the effect of lead paint hazard remediation on property values. In order to construct a relevant control group of properties, we exploit the fact that approximately 30% of applicants to LeadSafe Charlotte believed they were at risk for lead paint but were found to be safe from lead after the LeadSafe inspection.[4] Among the LeadSafe applicants, we are able to incorporate 959 parcels with lead remediation and 400 parcels with no remediation into our difference-in-difference estimates. Remediated and non-remediated parcels have similar housing price trends and structural attributes prior to the lead inspection date and tend to locate in similar or even the same neighborhoods.

We exploit a sharp change in expected exposure risk at the parcel-level, a similar approach as taken by recent studies focusing on information and exposure shocks through the Environmental Protection Agency's Toxic Release Inventory program (Currie et al., 2015; Mastromonaco, 2015; Sanders, 2012). Our setting is somewhat different from previous studies in that the perceived lead exposure risk changes for both treatment and control parcels in our primary empirical strategy. However, the change in perceived exposure risk should be much larger for treatment parcels due to pre-inspection differences. Remediated properties are likely to have other unobserved attributes (e.g. prior lead exposure cases and deteriorating paint) related to lead exposure risk that will be capitalized into pre-inspection home prices. Due to these unobserved differences, remediated properties will experience a larger drop in the perceived risk of exposure associated with the property. We also expect larger benefits associated with remediation from its role as an information shock to future homebuyers. While all prior lead paint inspection results are required to be disclosed at the time a home is under contract, we expect remediation to be revealed prior to this stage.[5] Remediation is easily observable to potential buyers since LeadSafe Charlotte reports a list of remediated homes but does not disclose any information about other applicant parcels.[6] Moreover, the remediation process is conspicuous since it requires signage around the outside of the home about the presence of lead, plastic sealing of the house, and workers with protective suits and respirators.

Comparing changes in property values between LeadSafe applicant properties which receive remediation and those which do not, we find a large and statistically significant effect of lead remediation on housing values. In our preferred model, the capitalized benefits of lead remediation are $26,270, or 32%, of the average sales price in our LeadSafe applicant sample. Accounting for the capitalization of home improvements ($7350) that coincide with remediation and the average cost of lead remediation in our dataset ($7291), we estimate a net benefit of about $11,629 per home or a return on investment of 160%.[7] The large net benefits of lead remediation are consistent with prior environmental risk research which documents a larger decline in sales price than the capitalized value of insurance premiums for properties located within a flood zone after major storms (Bin and Landry, 2013; MacDonald et al., 1987). In our case, the presence of lead paint generates uncertainty in both the risk of exposure as well as the costs of remediation. Robustness checks that include repeat sales models, alternative control groups and controls for neighborhood trends and schools confirm our main results. Additionally, falsification tests using dates prior to lead inspection or using nearest-parcel neighbors as our treatment and control properties generate no effects from lead-paint remediation. Decomposing our effects suggests that about 30% of our capitalized benefits from lead remediation are likely due to property improvements that may be part of the lead remediation process and no evidence that lead inspections themselves impact home values. Finally, we find that homeowners are less likely to sell their homes after lead remediation, consistent with a story of decreased neighborhood turnover after the removal of lead.

Overall, our estimates imply that the presence of lead pollution significantly depresses housing prices in neighborhoods with older housing stock. The contribution of this pollutant to housing value is larger than recent estimates of the effects of an opening of a large toxic industrial plant within one mile of a residential property—Currie et al. (2015) and Mastromonaco (2015) find a decrease of 11% (approximately $15,000 to $40,000). Beyond property improvements as part of lead remediation, our larger estimates of an increase over 20% may be explained by differences in the information about residential toxins available to homebuyers: the impact of lead exposure on childhood development is widely recognized and the risks are quite salient during property transactions due to disclosure laws, while the detrimental effects of polluting plants are less understood and it is difficult to determine residential exposure risk.

Recent studies find large cognitive and behavioral benefits associated with interventions following elevated blood lead levels that trigger lead paint hazard remediation (Billings and Schnepel, 2017), and from policies requiring landlords to obtain "lead-safe" certificates (Aizer et al., 2016). Our findings suggest that lead paint hazard remediation is also associated with large capitalized wealth benefits for lower-income homeowners who qualify for federally-funded programs which reduce residential lead exposure. The large estimated net benefits of the LeadSafe Charlotte program are likely generalizable to other cities given that the federal government provides regulations and funding for the identification of lead exposure risk through lead testing as well as reducing lead risk through lead remediation.

The remainder of the paper is structured as follows: Section 2 describes the LeadSafe Charlotte program and our data. Section 3 outlines our empirical strategy to identify causal effects of remediation. Section 4 presents and discusses estimated effects on

3 Totals allocated to the Lead Hazard Control Program were drawn from annual funding announcements available from https://www.federalregister.gov [accessed 6 November 2015].

4 Home owners may have applied due to previous elevated blood lead tests at their home or due to the belief that existing paint contained lead. In both cases, control group parcels were found to have paint that did not contain lead or had lead based paint that was not at risk to transfer lead to residents and thus labelled "safe from lead".

5 Lead paint disclosure laws dictate the disclosure of prior lead paint inspections at the time a home is under contract for purchase and allow potential homebuyers to conduct further inspections or request lead remediation as a condition of sale.

6 The homepage for the LeadSafe Charlotte program (http://charmeck.org/city/charlotte/nbs/housing/pages/leadbasedpaint.aspx) [accessed 8 June 2016] advertises a link to a document listing remediated properties.

7 Our costs of remediation do not include the costs of inspection, which average about $650 for the LeadSafe program.

property values and other outcomes. Finally, Section 5 provides some concluding remarks and a further discussion of our results.

2. LeadSafe program and data

Lead was commonly used as an additive in residential paint starting in the late 19th century. Several lead paint manufacturers began to voluntarily reduce the lead content in the 1950s due to increasing public attention regarding health risks, but lead paint was not effectively banned in the United States until 1978 when the Consumer Product Safety Commission lowered the amount of allowable lead in paint to 0.06% (ATSDR, 1988). The presence of lead in paint contributes to human exposure primarily through lead dust, which is ingested by small children through hand-to-mouth activity or directly inhaled as particulates.[8]

In the early 1990s, a series of medical studies and a report by the U.S. Department of Housing and Urban Development (HUD) documented the pervasive and serious health threats of lead paint to children. HUD estimated that two-thirds of homes built before 1980 contained lead paint (Lueck, 1991).[9] In response to this evidence, HUD began awarding grants to assist state and local governments with the control of lead paint hazards in lower-income, privately-owned homes.[10] In 1996, Section 1018 of the Residential Lead-Based Paint Hazard Reduction Act (Title X) mandated that sellers of homes must disclose the presence of lead hazards as well as provide any prior tests for lead in the home. Disclosure of lead hazards occurs at the time a home is under contract for purchase and may not be known during the initial home search. Recent research does not find an impact of the Title X disclosure law on housing prices (Bae, 2016; Zhao, 2016), but Gazze (2017) does find a decrease in housing prices associated with state-level laws mandating mitigation in old homes with children present. Bae (2012) finds an increase in the probability that a homebuyer has a property tested for lead and Zhao (2016) finds that Title X lead disclosure laws are associated with families relocating to new homes, greater lead mitigation and reductions in blood lead levels among children in rental properties.

Starting in 1998, LeadSafe Charlotte began providing lead remediation under the HUD Lead-Based Paint Hazard Control (LHC) grant program. Consistent with guidelines of grant funding, remediation from LeadSafe is available to owners of a property built before 1978 who meet certain income eligibility requirements and have children under six years of age.[11] Eligible property owners may apply to the LeadSafe program if they suspect that lead is present inside or outside the home. Almost all applicants are eligible since program administrators discourage individuals from applying if they do not meet eligibility criteria. After receiving an eligible applicant, LeadSafe contracts for a lead inspection of the home. In years where a home is not inspected due to limited grant funds, inspection of the parcel is delayed to the following year.

A residential lead inspection first involves determining whether lead is present and then whether lead exposure is possible. In this context, the lead inspection labels a home as “safe from lead” or “in need of lead mitigation”. Lead inspections involve systematically testing all window sills, door frames and other areas in the home with deteriorating paint or potential for lead dust. Any lead interior surface test concentration of greater than the HUD-recommended limit of 250 micrograms per square foot (μg/ft^2) or soil area in excess of 400 micrograms per gram (μg/g) represents a lead hazard and generates a recommendation of remediation.[12] Lead dust is always removed through remediation but existing lead paint may be sealed if the area does not involve moving parts (e.g. wall, ceiling). In many cases, areas with old and deteriorating paint have to be removed. The replacement of windows and doors is the most common type of remediation. For our purposes, we simplify our main analysis to two distinct groups: Our treatment group consists of all homes in which the inspection triggered the need to remove lead paint hazards; our control group includes parcels determined “safe from lead” by the LeadSafe-contracted inspector.

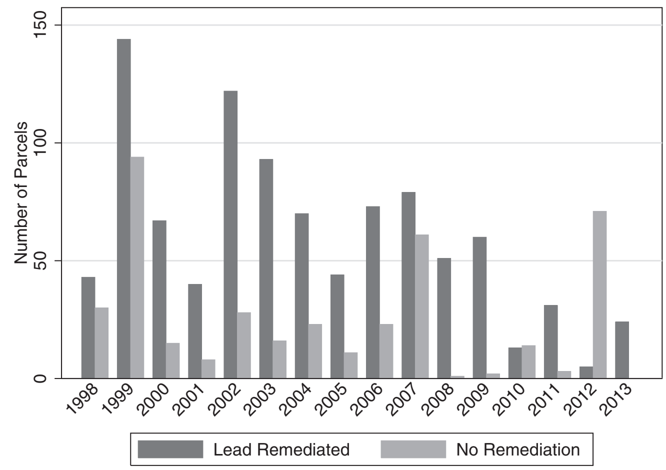

Fig. 1. LeadSafe inspections by year. This figure provides the distribution of LeadSafe applicants by inspection year.

Approximately 70% of applicants are assigned to our treatment group and we are able to incorporate 959 treatment parcels and 400 control parcels.[13] This non-trivial portion of applicants that are determined to be “safe from lead” stems from the fact that the presence of lead paint does not always translate to lead exposure risk as well as the fact that about two-thirds of homes built before 1980 contain lead paint (Lueck, 1991). The 30% of applicants without lead remediation represent a reasonable control group since, by completing applications, both our treatment and control groups believed their homes may contain lead paint hazards.

Since 1998, LeadSafe Charlotte has received over \$17 million dollars from HUD to reduce lead paint hazards in more than 2000 homes within Charlotte-Mecklenburg County. Information about the LeadSafe Charlotte program was obtained through grant reporting records from program administrators, which includes records on all parcels inspected and remediated from 1998 to 2014. The average total cost of remediation among our treated parcels was \$7291. Based on conversations with LeadSafe Charlotte, remediation in our sample typically involved removing and replacing windows and doors; painting or installing siding on the exterior of homes; and repairing doors to avoid chipping within the door frame when opening and closing.

To estimate the effects of remediation on property values, we combine the LeadSafe Charlotte data using residential addresses with

[8] Jacobs et al. (2002), Brown et al. (2006), and Lanphear et al. (1999) provide evidence that lead dust is the primary means of lead paint exposure. Lead is also found in soil outside residences from exterior paint sources and settled particulates from air pollution prior to the phase-out of leaded gasoline.

[9] While lead paint is a widespread problem, the mere presence of lead paint in a home is not always a hazard and most children live safely in these homes and apartments.

[10] Public housing was addressed separately in 1971 through the Lead-Based Poisoning Prevention Act.

[11] The income eligibility requirement states that the property owner must have a household income no greater than 80% of the median income for the household size.

[12] Ideally, we could use inspection information on lead concentration to implement a regression discontinuity design but unfortunately individual lead inspection reports are not available.

[13] The treatment and control parcels span the time frame of data and Fig. 1 provides counts for treatment and control groups by LeadSafe inspection year.

Table 1
Descriptive statistics.

	All parcels	Applicant remediated	Applicant not remediated
		Treatment	Control
Outcomes			
Sales price ($000)	195,426	78,735	86,332
	(148,819)	(90,149)	(91,176)
Property sold	0.72	0.55	0.47
	(0.45)	(0.50)	(0.50)
Parcel attributes			
Lot size (acres)	0.57	0.23	0.26
	(3.45)	(0.10)	(0.19)
Bathrooms	2.08	1.13	1.23
	(0.79)	(0.38)	(0.50)
Living area (sqft - 00s)	20.13	11.21	11.82
	(11.03)	(3.29)	(3.40)
Fireplace	0.80	0.43	0.34
	(0.40)	(0.50)	(0.48)
Age of building	26.65	62.74	57.56
	(23.24)	(15.02)	(16.33)
Built pre 1978	0.41	1.00	1.00
	(0.49)	(0.00)	(0.00)
Average BLL tests	3.52	5.33	4.51
	(2.60)	(4.53)	(2.65)
Total renovation costs ($000)	1842	1365	1,512
	(42,253)	(8222)	(5692)
Distance to CBD (miles)	8.22	2.37	2.76
	(3.91)	(0.87)	(1.31)
Distance to highway (miles)	1.98	0.81	0.86
	(1.32)	(0.59)	(0.78)
Neighborhood attributes			
Median HH income ($000)	61.80	26.61	28.74
	(26.30)	(6.30)	(8.97)
Percent black residents	0.23	0.81	0.78
	(0.25)	(0.18)	(0.21)
Pop density (per sq mile)	2014.15	3574.69	3367.23
	(1427.92)	(1521.84)	(1520.26)
Percent homes with elevated lead tests	0.03	0.09	0.08
	(0.03)	(0.03)	(0.03)
Percent homes pre 1978	0.35	0.85	0.80
	(0.33)	(0.16)	(0.20)
Observations	204,254	960	400

Summary statistics are based on all single-family residences and broken down for LeadSafe program parcels. Applicant remediated are parcels that applied and received lead remediation under the LeadSafe Charlotte program. Not remediated indicates parcels that applied to the LeadSafe program, but upon inspection were found to be safe from lead. Average BLL tests based on the average (Blood Lead Level) BLL test values for a given address prior to the sale of a home and we limit this value to parcel addresses with at least one BLL and one property sale. Average BLL tests based on NC BLL surveillance program and limited to 1993–2008 for this study. Total renovation costs ($) is limited to renovations done 5 years prior to a parcel being sold and does not include any costs related to lead remediation.

the complete assessor's records for Mecklenburg County, NC which encompasses all of Charlotte. This dataset provides information on detailed structural attributes and complete sales records from 1995 through 2014 for the full population of residential parcels in the county. We limit our analysis to single-family parcels and sales that involve arm's-length transactions.[14] We augment this parcel data with county building permits for all home renovations.[15] This database allows us to incorporate information on housing stock and neighborhoods, directly accounting for some degree of home maintenance that may be correlated with lead exposure. This parcel database allows us to generate variables for prior home renovations, age, and housing structural attributes.

We also incorporate blood lead screening data from the state of North Carolina to provide another measure of lead exposure risk. North Carolina requires all children participating in Medicaid or the Special Nutrition Program for Women, Infants and Children (WIC) to be screened for lead at one or two years of age. Other children are screened if a parent responds "yes" or "don't know" to any of the questions on a Centers for Disease Control (CDC) Lead Risk Assessment Questionnaire. Lead screening is commonplace with approximately 25% of children living in Mecklenburg County receiving a blood lead test by age 6.[16] The blood lead surveillance data

14 We focus on single-residence parcels due to the limited number of multi-family parcels sold during this time period as well as the fact that lead remediation often occurred for a subset of units within an apartment complex. As is typical with most county parcel records, we cannot always identify the specific type of transaction, so we exclude transactions with excessively low prices (<$10,000) and missing property attributes to address this concern.

15 Our database of building permits is useful for identifying larger scale renovations (anything that costs more than $5000 or involves structural, mechanical, electrical or plumbing work), but does not include most lead remediations, which are regulated and permitted through other local government agencies

16 This statistic is based on 2002 lead surveillance data from the NC Environmental Health division of the Department of Public Health and available online at http://ehs.ncpublichealth.com/hhccehb/cehu/lead/resources.htm.

contains the following information: a child's name, birth date, test date, blood lead level (BLL), type of test, and home address.[17] We use the blood lead screening data to incorporate information on the level of lead in the home prior to lead remediation, but are limited by the fact that lead test results occurred for children living in only 526 out of our 1359 LeadSafe applicant properties.[18]

Table 1 provides summary statistics for all parcels in the county as well as our main estimation sample of LeadSafe applicants by those remediated and those labeled "safe from lead" following an inspection. The average parcel in Charlotte-Mecklenburg has a considerably higher sales price; more bathrooms, living area, and lot size; shorter distance to the CBD; and lower BLL tests. The fact that homes with high lead risk are located in poorer, older neighborhoods is consistent with both the presence of lead in homes built before 1978 as well as the sorting of homebuyers to more affordable homes in neighborhoods with higher environmental risk. Since outcomes in this table reflect both pre and post remediation, these summary statistics simply provide a sense of the scale of home prices, renovations, the likelihood of property sale and lead exposure risk for our sample of LeadSafe applicants. Our treatment and control groups are similar in terms of parcel and neighborhood attributes, but sales price for treatment properties are lower. We later show that lower sales prices for remediated properties are due to pre-inspection price differences across Leadsafe properties that likely reflect differences in expected lead exposure risk.

Since one may be concerned that treatment parcels are concentrated in certain neighborhoods while control parcels are in different neighborhoods, and this may be symptomatic of different neighborhood unobservables, we examine the spatial distribution of treatment and control parcels. Appendix Fig. A1 provides the distribution of distances between parcels for three groups: 1) lead-remediated parcels to other lead-remediated parcels; 2) lead-remediated to non-lead-remediated parcels and 3) all parcels to all other parcels. From this figure, we see that lead-remediated and non-remediated parcels are substantially more spatially concentrated than the general distribution of all parcels. Furthermore, the joint spatial distribution of lead-remediated and non-remediated parcels is almost identical to that of the spatial distribution of lead-remediated parcels, indicating that our treatment and control parcels are spatially concentrated in the same neighborhoods. One additional matter is that applicant parcels that sold after inspection may be different than those that sold prior to inspection or did not sell at all. Appendix Table A1 provides parcel and neighborhood attributes for three groups: all applicants with property sales (our estimation sample); all applicants with sales post inspection; and applicant homes never sold (and thus not in our estimation sample). These three groups appear similar in both property attributes as well as neighborhood characteristics.

3. Empirical framework

Linking LeadSafe administrative data with county parcel records, we empirically estimate the impact of lead exposure risk on neighborhoods through its capitalization in housing prices. Given the well-known detrimental effects of lead on childhood development, homebuyers will pay substantial premiums for remediated properties or newer neighborhoods to avoid a high (or uncertain) risk of exposure within older properties. To estimate the impact of lead exposure risk on property values, we need a measure of exposure that entails salient information to a homebuyer such as a lead-paint remediation event or the disclosure of information about blood test results indicating high levels of exposure.

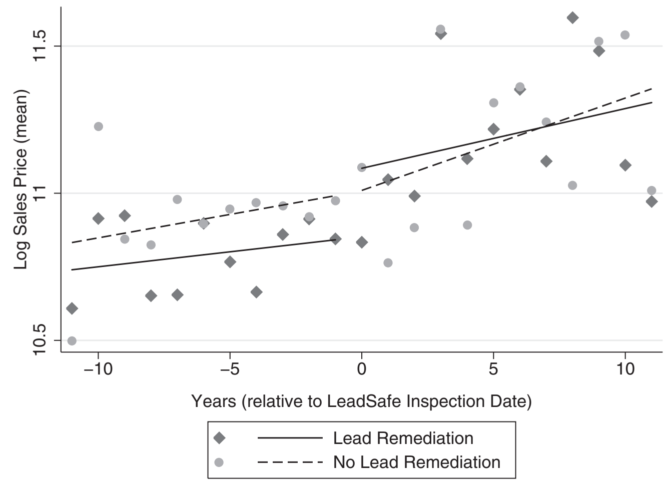

Fig. 2. Difference-in-difference figure. This figure plots the relationship between our dependent variable, ln(Sales Price), and years relative to LeadSafe inspection for our estimation sample of LeadSafe applicants. We split results by whether or not lead paint inspection required follow-up remediation. We include 1410 property sales and average logged sales price based on year relative to LeadSafe inspection separately for applicants that required lead remediation and those that did not. All fitted lines are weighted by the number of sales.

Our analysis focuses on substantial changes in lead exposure risk for families in older homes following remediation from LeadSafe Charlotte. In a supplementary analysis, we incorporate blood lead level (BLL) test values at a home prior to its sale as a measure of residential lead exposure risk in a hedonic housing price model and report these estimates in the Appendix.[19] We do not focus on these estimates since measuring the presence of residential exposure using blood test results is problematic for several reasons. First, childhood blood lead levels can reflect exposure through a number of different environments and is, at best, a noisy measure of own-household exposure. Second, as discussed by Aizer et al. (2016) and Billings and Schnepel (2017), there is a great deal of measurement error in testing exposure with blood tests. Both of these factors will attenuate the relationship between this proxy for exposure risk and property values toward zero. Furthermore, bias can arise through selection on who is tested for lead exposure since the testing decision likely relates to the structural or neighborhood attributes of a home, both observed and unobserved. Finally, lead disclosure laws only require disclosure of known lead inspections or sources of lead in the home and do not require the disclosure of historical blood lead test results.

Our estimates of the value of lead exposure risk are based on the relationship between LeadSafe remediation and property values. Two factors generate differences in lead exposure risk for remediated and non-remediated homes within our pool of applicants. First,

[17] The limit of detection for lead in blood as analyzed by the North Carolina State Laboratory is 1 microgram per deciliter (μg/dL), and all children whose blood lead levels are below this level of detection are assigned this minimum value. Blood lead levels are stored in the NC database as integer values only.

[18] When we include BLL values as control variables in later regressions, we set missing values to zero for parcels without BLL tests and include a dummy for missing BLL test.

[19] We provide standard hedonic housing price estimates of the relationship between average BLL test values and home prices in Appendix Table A2. Results show a negative relationship between BLL and home prices that becomes smaller and less precise once we control for neighborhood attributes and prior home renovations.

applicant homes that eventually receive lead remediation likely differ from non-remediated homes in terms of the probability that they contain lead paint hazards prior to inspection. Second, homes that receive lead remediation experience a different information shock than those homes that have a lead paint inspection that reveals no lead paint hazards. Both factors generate a larger and more salient reduction in lead exposure risk to homebuyers of lead-remediated properties.

We expect that applicants to the Leadsafe program have a non-zero probability of lead paint hazards or they would not apply to the program. Conditional on being an applicant, there likely exists variation in lead exposure risk due to information about the use of lead paint, the presence of lead paint at neighboring properties as well as how often a home is repainted. Those properties with high lead exposure risk will most likely be assigned to our remediated group after lead inspection while low lead exposure risk homes will be assigned to the non-remediated groups. This variation generates initial differences in lead exposure risk between our remediated and non-remediated homes. Since both remediated and non-remediated homes are safe from lead after completing the LeadSafe program, they both drop to almost no risk of lead-paint hazards. We exploit the fact that our treatment group experienced a substantially larger drop in lead exposure risk. Therefore, simply finding a high lead risk home to be lead safe would generate greater benefits than finding a low lead risk home to be lead safe.

We also expect some benefits due to the information component of lead remediation. As mentioned, the nature of lead requires a visible remediation process that likely imparts more information about future lead risk than under standard lead-paint disclosure requirements. The fact that a home was remediated may also provide a type of certification that homebuyers do not need to worry about future lead risk. This information about decreased lead exposure risk due to the lead remediation process may impart benefits on homebuyers beyond simply the reduction in lead exposure risk. Furthermore, the lead remediation process may include benefits to structural attributes of the home such as new windows and doors or fresh paint. Since these benefits due to property improvements cannot be directly disentangled with our data, we later provide additional analysis that highlights the potential contribution of property improvements to our main estimates of the value of reducing lead exposure risk.

In order to test the impacts of removing lead exposure risk through lead-based paint remediation, we adopt a difference-in-difference estimator that highlights both initial differences between our remediated and non-remediated homes as well as how these homes differ after one group received lead remediation. Our main estimation equation is given by:

$$\begin{aligned}\ln(\mathrm{P_{ijt}}) = {} & \alpha + \beta_1 \mathrm{LeadRemediated_i} * \mathrm{Post_{it}} + \beta_2 \mathrm{LeadRemediated_i} \\ & + \beta_3 \mathrm{Post_{it}} + \beta_4 \mathrm{LeadSafeYear_t} + \beta_5 X_{it} + \delta_t + \gamma_j + \varepsilon_{ijt} \quad (1)\end{aligned}$$

where $\mathrm{P_{ijt}}$ is the transacted sales price for a single-family home i in neighborhood j at time t; $\mathrm{X_{it}}$ includes a wide range of parcel and neighborhood attributes given in Table 1. We also include an indicator variable for the year in which the property was inspected by LeadSafe ($\mathrm{LeadSafeYear_i}$); year-by-quarter-of-sale fixed effects (δ_t); and, in most models, Census Block Group (CBG) fixed effects (γ_j). $\mathrm{LeadRemediated_i}$ indicates whether parcel i is ever remediated by LeadSafe Charlotte between 1998 and 2014; $\mathrm{Post_{it}}$ indicates whether the transacted sale follows the date of lead inspection for the applicant parcel. The interaction of $\mathrm{LeadRemediated_i} * \mathrm{Post_{it}}$ represents our difference-in-difference estimator and β_1 is the marginal increase in housing prices following lead remediation. Since lead paint hazards and applicant properties are heavily concentrated in older residential neighborhoods, standard errors are two-way clustered by CBG and by year-quarter of sale.[20]

For a difference-in-difference estimator to be valid it must satisfy the parallel trend assumption, which we present graphically in Fig. 2. Each point in Fig. 2 represents the average logged home price by years relative to the lead inspection date with its shape indicating whether the observation is part of the treatment or control group. The linear trends are estimated separately for positive and negative years relative to inspection date and demonstrate that both types of parcels had similar upward trends prior to inspection. Even though this figure simply provides unconditional home values relative to the timing of LeadSafe inspections, it is consistent with our later regression results which include control variables for housing attributes, neighborhood characteristics as well as fixed effects for CBG and year-quarter of sale. Our identification assumption is also supported by models which estimate treatment effects for various pre- and post-period time frames which we will discuss in Section 4.1.

The parallel trend assumption in the prior period appears valid, and Fig. 2 depicts an upward shift in home prices after lead remediation and no upward shift for the control properties. One may expect that our control group would also see price increases following an inspection finding the property "safe from lead". Fig. 2 does not depict significant benefits from such inspection-revealed exposure information for our control group. These smaller effects may be due to several factors. First, LeadSafe control homes may have lower lead exposure risk initially and thus less potential benefit from being labeled safe from lead. Second, information from prior inspections revealing no immediate risk becomes salient only after a home is under contract. Even with an inspection report, buyers interested in these control properties may expect future remediation costs in the case that areas where lead paint has been sealed deteriorate over time.

One additional issue arises in that remediation may decrease the value of other homes through a general equilibrium mechanism (e.g., Anenberg and Kung, 2014) which could potentially inflate our difference-in-difference estimate. For example, remediation could increase the value of treated homes, but decrease the value of the control homes as buyers shift away from the non-remediated properties. In our context, we are less concerned with any general equilibrium effects due to our use of a small sample of older homes inspected by LeadSafe Charlotte. During our sample period, only 1.1% of pre-1978 homes are remediated under LeadSafe (3.9% when we focus on the subset of neighborhoods that had any LeadSafe remediated homes). Moreover, we find similar effects when comparing remediated homes to alternative control groups suggesting that our estimates are not substantially inflated by decreases in value among the non-remediated parcels.

Given the similarities in property attributes in Table 1, we formally test if our remediated and non-remediated groups are similar on observable attributes in Table 2. Column one indicates that in models without CBG fixed effects, we find a few property attributes that are significant, but jointly covariates do not explain lead remediation. This conclusion becomes stronger after including neighborhood (CBG) fixed effects in Column 2, with our F-test p-value of 0.61 indicating that we must accept the null hypothesis that these property attributes cannot jointly explain remediation among the applicant properties. The only individual coefficient that is statistically significant in predicting remediation is the age of the property, but the magnitude of the estimated effect is small—a 10-year increase in the age of a home is associated with an increase of 3 percentage points in the probability of remediation. Within narrowly defined neighborhoods, our treatment and control groups

[20] Our sample incorporates 101 CBGs that contain at least one LeadSafe applicant.

Table 2
Balancing test.

	(1) Remediated	(2) Remediated
Lot size (acres)	−0.160	−0.110
	(0.173)	(0.181)
Bathrooms	0.012	−0.013
	(0.048)	(0.067)
Living area (sqft)	−0.009	−0.006
	(0.006)	(0.008)
Fireplace	0.056*	0.006
	(0.034)	(0.042)
Age of building	0.003**	0.003*
	(0.001)	(0.002)
Average BLL in home (prior to sale)	0.002	0.001
	(0.005)	(0.006)
Renovation costs ($) last 5 years	0.001	−0.000
	(0.003)	(0.003)
Distance to CBD (miles)	0.011	0.060
	(0.028)	(0.119)
Distance to highway (miles)	0.034	0.118
	(0.033)	(0.152)
Median HH income ($000)	−0.000	
	(0.000)	
Percent black residents	−0.000	
	(0.001)	
Pop density (per sq mile)	0.000	
	(0.000)	
F-Stat (p-value)	0.102	0.613
CBG fixed effects		Yes
Observations	1359	1359

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are two-way clustered by CBG and by year-quarter of sale. Dependent variable is a dummy for LeadSafe Remediated. We include, but do not report, coefficients for a series of dummies for applicant year.

Table 3
Main effects of LeadSafe remediation on housing prices.

	(1)	(2)	(3)
Leadsafe remediation*post	0.256**	0.281**	0.278**
	(0.107)	(0.116)	(0.121)
Leadsafe remediation	−0.109	−0.135	−0.133
	(0.076)	(0.086)	(0.087)
Post	0.006	−0.098	−0.093
	(0.145)	(0.141)	(0.143)
Fixed effects		CBG	CBG & school
Observations	1410	1410	1410

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are two-way clustered by CBG and by year-quarter of sale. There are 101 CBGs that contain our applicant parcels. Dependent variable in all models is ln(sales price). All models include standard hedonic controls (given in Table 2) including polynomials in age and square feet and year by quarter of sales fixed effects. We limit our sample to single family homes and also include applicant year fixed effects. We define the date to indicate the pre/post period based on the lead inspection date for either the remediated or non-remediated parcels. In some cases, the specific date was not given, so we base lead inspection date on annual grant cycle reporting dates as part of the LeadSafe grant program reporting to Housing and Urban Development (HUD).

are observationally very similar. The fact that property attributes (including a measure of prior property renovations) are similar between our remediated and non-remediated homes, but initial home prices are lower for remediated homes provides support that differences in lead exposure risk and not other property attributes are contributing to initial differences in home prices for our two groups.

4. Results

Our primary estimates of the effect of lead paint hazard remediation on property values are given in Table 3. We find that remediation is associated with an increase in property values of 32% from the difference-in-difference specification (Eq. (1)) including CBG fixed effects (Column 2 of Table 3).[21] Results are similar without neighborhood fixed effects in Column 1 and when adding school fixed effects in Column 3. Additionally, these results show that homes sold prior to remediation are about 13% lower in value, suggesting that our estimated increase of 32% is due to both higher perceived lead exposure risk initially as well as the impact of lead remediation. Given the average transaction price in our applicant sample is $80,969, our estimated effect from remediation in Column 2 translates to a nominal increase of $26,270, which represents a substantial return, considering the average cost of remediation is $ 7291. We also explore if our results are concentrated in certain types of neighborhoods in Table 4 and find impacts to be similar in magnitude for neighborhoods with a larger share of homes that have lead (based on child lead testing), older homes as well as a larger number of LeadSafe remediated homes.

Some of the strongest support for our estimated effects is provided through a repeat sales regression model in Table 5. While our interpretation of our repeat sales model is limited by the small number of LeadSafe applicant parcels that are sold multiple times within our study period of analysis, estimates from these repeat sales specifications are consistent (albeit less precise) with our primary results reported in Table 3. We also present estimates from a specification that uses remediation completion date (rather than inspection date) to define the $Post_{it}$ indicator in Eq. (2) and a model which includes neighborhood-specific time trends. Estimates from these specifications presented in Columns 3 and 4 of Table 5 are also very similar to our primary estimates in Table 3. Since we have information on the cost of lead remediation for each LeadSafe home, Column 5 presents estimates from a model which interacts the cost of lead remediation with $LeadRemediated_i * Post_{it}$. We find that the actual cost of remediation is not driving our estimated benefits from remediation. This weak relationship between the cost of remediation and property values suggests that our estimated benefits are mostly a function of changes in exposure risk from remediation and not property improvements that may occur as part of lead remediation. We further discuss the role of property improvements in Section 4.1.

We test the validity of our identification assumptions using three types of falsification tests presented in Table 6. To alleviate concerns that differential trends between treatment and control properties affect our results, the first column in Table 6 implements a model where we change the inspection date to be three years earlier and drop sales after actual lead remediation. Results are small in magnitude and insignificant. To alleviate any concerns that our estimated effects are driven by differential characteristics across our treatment and control groups, the second column in Table 6 uses lead-remediated parcels to estimate a first stage model that predicts the likelihood that an applicant parcel is remediated and applies these coefficients to the universe of parcels excluding LeadSafe applicants to create a pool of 1410 pseudo-applicant sales transactions. We use the top 70% (the same fraction as the original treatment group) of pseudo applicants to create a pseudo treatment group and estimate our difference-in-difference estimator. Again, we find small and insignificant results. Finally, to alleviate any concerns that differential neighborhood characteristics or differential trends across areas with more treatment properties (such as localized gentrification) influence our estimates, our final falsification test in Column 3 of Table 6 estimates pseudo-treatment effects for a sample constructed of only the nearest neighbor parcels of our main estimation sample. These pseudo-treatment and pseudo-control applicants

[21] Based on the Halvorsen et al. (1980) correction for interpreting dummy variable coefficients in a semilogarithmic equation. All estimated percentage impacts on property values are calculated as follows: $e^{\hat{\beta}_1} - 1$.

Table 4
Effects of LeadSafe remediation on housing prices by types of neighborhoods.

	(1)	(2)	(3)
	Only neighs high # homes with lead	Only neighs older homes	Only neighs high # remediations
Leadsafe remediation*post	0.200*	0.269**	0.274
	(0.113)	(0.122)	(0.190)
Leadsafe remediation	−0.078	−0.031	−0.117
	(0.102)	(0.128)	(0.135)
Post	−0.080	−0.181	−0.066
	(0.116)	(0.130)	(0.228)
Fixed effects	CBG	CBG	CBG
Observations	709	725	740

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are two-way clustered by CBG and by year-quarter of sale. There are 101 CBGs that contain our applicant parcels. Dependent variable in all models is ln(sales price). All models include standard hedonic controls (given in Table 2) including polynomials in age and square feet and year by quarter of sales fixed effects. We limit our sample to single family homes and also include applicant year fixed effects. We define the date to indicate the pre/post period based on the lead inspection date for either the remediated or non-remediated parcels. In some cases, the specific date was not given, so we base lead inspection date on annual grant cycle reporting dates as part of the LeadSafe grant program reporting to Housing and Urban Development (HUD).
We report results for separate models by neighborhood attributes for presence of lead based on BLL >1 as well as older housing stock (pre 1978). We bisect into high/low lead and older/newer neighborhoods based on average values of these attributes. Our final column provides results using above or below median values for the cumulative number of lead remediations in a neighborhood at the time of sale.

should experience identical neighborhood attributes and neighborhood trends as our main sample and, once again, we find small and insignificant effects on property values. These results also indicate that there are limited spillover effects from remediation to neighboring properties.

4.1. Decomposing effects

To verify that LeadSafe remediation has no impact prior to inspection dates as well as estimate how differences evolve following inspection, we estimate a model including indicators for time periods pre- and post-lead inspection. We use indicators to illustrate immediate (0–2 years), medium term (3–5 years) and longer term (6+ years) effects. Fig. 3 plots the six coefficients from this model.[22]

The three pre-inspection coefficients indicate some initial differences 6 or more years prior to application, but, most importantly, we do not find significant differences in the five years prior to remediation. These coefficients are largely consistent with small differences in trends between our treated and control applicants prior to inspection and, along with Fig. 2, support the parallel trends identification assumption of our difference-in-difference empirical strategy. The results are quite different following lead inspection, where short-term effects are positive and significant. These effects remain positive but decrease in magnitude for the medium and long-term effects. This pattern of diminishing effects is consistent with the nature of lead remediation. First, the information component of remediation deteriorates over time as once visible remediations become less salient to buyers. Second, any benefits of lead remediation from property improvements will depreciate in value over time. Finally, the standard protocol of remediation through the LeadSafe program includes actions which do not permanently remove lead from the household. Exposure risk could increase in remediated homes over time as sealed paint surfaces deteriorate.

In order to address concerns that information given at the time of lead inspection may be contaminating our control group of non-remediation applicant homes, Table 7 provides results for three different control groups. Column 1 repeats our main estimates given in Table 3 for comparison. Column 2 limits our sample to only lead remediated homes and estimates the change in prices from before to after lead remediation. Estimates from this simple pre/post comparison of prices for our treated group are similar to our main difference-in-difference estimates. Column 3 confirms prior results by comparing the change in home values for lead remediated homes and applicants with no remediation to overall trends in housing prices for all single-family homes over our period of analysis (1995–2014). Relative to this third control group, we obtain similar estimates of the impact from remediation. This model also estimates the effect of the lead information disclosure relative to other non-applicant households. The direction of the information effect estimate is negative but is not statistically significant. We consistently do not find evidence of any gain in value following an initial inspection which does not prompt a remediation.

We extend this analysis by estimating effects relative to a few other comparison groups in Columns 4 through 6 of Table 7. First, we further investigate the extent to which property improvements, which coincide with lead remediation, contribute to our main estimates by estimating the remediation impact relative to homes that had similarly priced renovations during our sample period.[23] In order to make this comparison, we estimate difference-in-difference

[22] Specifically, we estimate the following equation:

$$\begin{aligned}\ln(P_{ijt}) = {} & \alpha + \beta_1 \mathrm{LeadRemediated}_i * 6^{+}\mathrm{YrsPrior}_{it} + \beta_2 \mathrm{LeadRemediated}_i * 3-5\mathrm{YrsPrior}_{it} \\ & + \beta_3 \mathrm{LeadRemediated}_i * 0-2\mathrm{YrsPrior}_{it} + \beta_4 \mathrm{LeadRemediated}_i * 0-2\mathrm{YrsPost}_{it} \\ & + \beta_5 \mathrm{LeadRemediated}_i * 3-5\mathrm{YrsPost}_{it} + \beta_6 \mathrm{LeadRemediated}_i * 6^{+} + \mathrm{YrsPost}_{it} \\ & + \beta_7 \mathrm{LeadSafeYear}_t + \beta_8 X_{it} + \delta_t + \gamma_j + \varepsilon_{ijt} \qquad (2)\end{aligned}$$

and plot β_1 through β_6.

[23] We limit our comparison group of renovated homes to only those homes that have renovations valued within the interquartile range of LeadSafe remediation costs ($3283 to $9630.)

Table 5
Repeat sales and other specifications.

	(1)	(2)	(3)	(4)	(5)
	Repeat sales *all*	Repeat sales *Just parcels pre & post inspection*	Alternative remediation date	Neigh time trends	Interact remediation amount
LeadSafe remediation*post	0.180	0.217**	0.264**	0.280**	0.249
	(0.130)	(0.096)	(0.111)	(0.116)	(0.152)
LeadSafe remediation	n/a	n/a	−0.123	−0.134	−0.134
			(0.078)	(0.086)	(0.087)
Post	−0.203	n/a	−0.071	−0.098	−0.096
	(0.123)		(0.143)	(0.142)	(0.144)
Leadsafe remediation*post*amount($)					0.004
					(0.008)
Observations	283	63	1410	1410	1410

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are two-way clustered by CBG and by year-quarter of sale. For repeat sales observations, we remove properties which had a high probability of major renovations by excluding repeat sales with more than 100% appreciation between sales or sales that occurred less than 2 years apart. Dependent variables in columns 1 and 2 are $ln(P_{i,t}) - ln(P_{i,t-1})$ and we include year by quarter dummies for both initial purchase in time $t - 1$ and later sale in time t. Column two varies from column one due to the removal of parcels that did not have a transacted sale both before and after lead inspection.
Dependent variables in columns 3–5 are $ln(P_{i,t})$. Non-repeat sales models include standard hedonic controls including polynomials in age and square feet, lot size, baths, fireplace. All models include quarter-year for each sale as well as applicant year fixed effects. Column 3 provides an alternate estimate of remediation date based on LeadSafe grant reporting. Column 4 estimates our main model with CBG time trends and Column 5 tests if the amount of LeadSafe reported spending on a lead remediation (interaction with remediation costs ($000*s*)) provides additional impacts.

Table 6
Falsification (placebo) checks effects of LeadSafe remediation on housing prices.

	(1)	(2)	(3)
	False Leadsafe date 3 years prior CBG FEs	False predicted LeadSafe CBG FEs	False neighbor of Leadsafe CBG FEs
Leadsafe remediation*post	−0.011	−0.004	0.039
	(0.090)	(0.065)	(0.079)
Leadsafe remediation	−0.084	0.043	−0.021
	(0.068)	(0.052)	(0.075)
Post	−0.027	0.041	0.099
	(0.114)	(0.051)	(0.088)
Observations	955	1410	2087

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are two-way clustered by CBG and by year-quarter of sale. Dependent variable in all models is ln(sales price) and all models include CBG fixed effects. All models include standard hedonic controls (given in Table 2) including polynomials in age and square feet and year by quarter of sales fixed effects. and we limit our sample to single family homes.
We provide three types of falsifications. The first falsification test is based on assuming LeadSafe inspections occur three years prior and we drop post LeadSafe observations. The second falsification is based on predicting LeadSafe remediation based on property attributes, dropping LeadSafe applicants and using predicated values to determine pool of pseudo applicants. We use the top 30% (same number as original treatment group) of applicants to create a pseudo treatment group and estimate our difference-in-difference estimator. The third falsification takes the neighboring parcels of LeadSafe applicants and generates psuedo remediation parcels for neighbors of actual LeadSafe remediated homes as well as psuedo non-remediated parcels based on neighbors of applicants without remediation. We drop any neighbor that is a LeadSafe applicant. Our sample size increases in Column 3 since we include two parcels for a number of LeadSafe parcels with neighbors on both sides of the home.

models that compare changes in housing prices for LeadSafe applicants relative to homes with renovations using the date and construction cost estimate from the renovation permit database. Compared to similar renovations, we estimate a remediation benefit of 17.5% in Column 4 of Table 7.[24] Relative to using a comparison group of all single family homes, this result suggests that a portion of the remediation benefit is likely due to the value of property improvements. However, among older homes, many of the non-LeadSafe renovations we observe in the permit database may be private remediation efforts or other renovations which reduce exposure risk. If part of the non-LeadSafe renovation benefits were due to reductions in exposure risk, we would expect the effect of remediation to be larger when compared to a group of homes for which renovations do not affect exposure risk. We test this in Column 5 of Table 7, by presenting estimated effects relative to a sample of post-1978 homes which have similarly priced renovations. These homes should not contain lead-paint since lead-paint was banned in 1978. Our estimated effects increase to 23% in this model suggesting a more limited effect of property improvements once we account for the potential benefit of private market lead remediation. Overall, these result suggests that between one-sixth and one-third of our main remediation effects are due to property improvements.

4.2. Other outcomes

To explore the dynamics of sorting to and away from lead-remediated homes, we evaluate whether remediation affects residential mobility and other outcomes in Table 8. Because we no longer rely on having a property sales transaction, the models in Table 8 are based on a balanced panel of our sample parcels from 1995 to 2013. We implement two sets of models with the top panel providing pooled results and the bottom panel including parcel-level fixed effects (which is feasible now that we have multiple observations for each parcel). Results are consistent across both models and we refer to the bottom model for interpretation.

[24] Recall, all estimated percentage impacts on property values are calculated as follows: $e^{\hat{\beta}_1} - 1$.

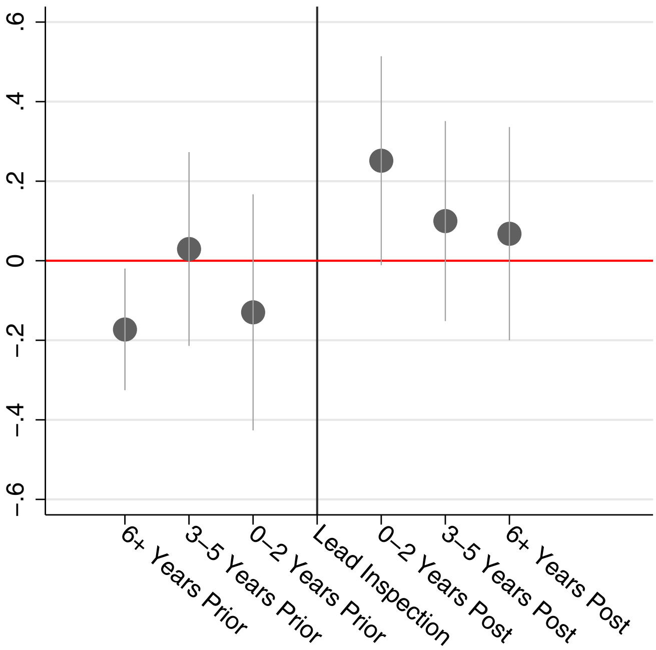

Fig. 3. Temporal distribution of lead remediation effects. This figure plots the coefficients and confidence intervals for a version of our main model that includes separate indicators for time intervals of effects spanning prior and post the inspection/remediation date. All other estimation notes from Table 3 apply.

The first outcome we examine in Column 1 of Table 8 is whether a property was more or less likely to be sold following remediation compared with the control group. Since we do not observe residential relocations for families located at LeadSafe applicant parcels, we have to rely on the sale of a home as an indicator of moving. Of course, home sale is not a perfect measure for residential relocation, but in most cases, an arm's-length transaction of a home indicates new residents. We interpret the decrease in the probability of a home sale in a remediated property of 3.5 percentage points (Column 1 of Table 8) as evidence that remediation substantially reduces residential turnover. The magnitude of the effect of remediation on residential turnover is very large and represents nearly a 70% decrease from the 5% average annual probability of a sale. In essence, lead remediation appears to increase the tenure of a homebuyer at a residence. This result indicates that either existing residents are more willing to stay in a neighborhood or families buying lead-remediated properties are the type of households that stay longer in a home. Both scenarios are consistent with a story of less neighborhood turnover and greater housing stability among residents of remediated properties, an important outcome given high rates of housing insecurity and residential mobility in these neighborhoods.[25] Since our measure of residential movement is not ideal, we also estimate the effects of remediation on residential mobility using a completely different measure of residence based on BLL test addresses at ages one or two and the home addresses at the start of public school for all public school children during our study period. Upon linking these datasets to our applicant properties, Appendix Table B3 confirms that remediation decreases residential mobility by a similar magnitude as Table 8.[26]

We estimate the effect of remediation on the annual dollars spent on renovations (not including lead remediation based renovations) in Columns 2 and 3 of Table 8. Results indicate a small and statistically insignificant effect of lead remediation on renovations of about \$208 . Given that we average 9.8 years of renovation costs after remediation, this coefficient translates to about \$2038 or 8% of our total effect on housing prices. Column 3 estimates this effect only for homes which are sold post renovation to mitigate concerns that those homes selected into sales are not the ones that are renovated and finds nearly identical results in the model with parcel fixed effects. This result is consistent with a story of higher property maintenance following remediation, but the effect is small and imprecise enough that is does not influence our main conclusions regarding the net benefits of lead remediation.

Using the same panel design described for the residential turnover outcome, we also test whether children are more or less likely to be tested for lead exposure after lead remediation. For the specification reported in Column 3 in Table 8, we create a dependent variable that is an indicator as to whether we observe a child at the parcel address in the blood lead surveillance data in each year. We do not find any significant effects of remediation on the probability of testing.[27] Column 4 measures the effect of remediation on the result of the blood lead test for those parcel-year observations in which we observe a blood lead test level. We find a small negative but insignificant effect of remediation on blood lead levels conditional on testing in Column 4 of Table 8.

The lack of a relationship between lead testing and lead remediation may simply reflect the fact that individuals may respond in two opposing ways to knowing that lead was removed from a home. If parents know a home was remediated, they may be more aware of the potential health risk and may be more likely to have their children tested. On the other hand, remediation reduces the risk of exposure and therefore decreases the need for lead testing. The fact that remediated homes sell less often further limits the number of new households who may have concern about lead exposure and thus minimizes the number of potential children tested for lead. The noisy and small detected relationship between blood lead levels and remediation is influenced by these factors as well as inaccuracies inherent in the testing process. As discussed by Aizer et al. (2016), the measurement error in BLL testing attenuates estimates toward zero so we are likely underestimating the effects of lead remediation on BLL values.

5. Conclusions

The large net benefits of remediation are interesting since an informed homebuyer should only increase an initial offer for a remediated property by the estimated cost of remediation. We believe that several factors contribute to the high return on remediation investment. First, families may be willing to pay a premium to know for certain that an old home has been remediated. Even if prior inspection reports indicate that a property is "safe from lead", a degree of uncertainty as to future exposure risk within the residence may remain a concern. The risk of exposure (and the damaging effects of lead) may become more salient to both buyers and sellers following treatment given the high profile of remediation by LeadSafe Charlotte. Previous research documents a larger decline in sales price than the capitalized value of insurance premiums for

[25] Table 8 also reports a significant difference in the post-inspection probability of sale relative to the pre-inspection period for non-remediated properties. This coefficient is consistent with an intention to sell a home triggering some applications to the *LeadSafe Charlotte* program.

[26] These results are described in more detail in Appendix A.2.

[27] We do find a marginally significant increase in the probability a child is screened for lead in the post inspection period (relative to the pre inspection period) for all applicant parcels. We believe that the higher rate in the post period could be due to an increased awareness of household lead hazards in both the remediated and non-remediated following the initial application triggering an inspection.

Table 7
Lead remediation and housing prices: Different control groups.

	(1) LeadSafe applicants	(2) Only remediated homes	(3) Applicants & all homes	(4) Applicants & renovated homes	(5) Applicants & renovated homes built post 1978
Leadsafe remediation*post	0.281**	0.235***	0.242***	0.162**	0.210***
	(0.116)	(0.074)	(0.075)	(0.066)	(0.072)
Leadsafe remediation	−0.135	n/a	−0.110***	−0.140	0.002
	(0.086)		(0.040)	(0.111)	(0.153)
Applicant no remediation*post	n/a	n/a	−0.103	−0.140	−0.097
			(0.112)	(0.113)	(0.115)
Applicant no remediation	n/a	n/a	0.073	−0.069	0.150
			(0.080)	(0.080)	(0.167)
Post	−0.098		−0.002	0.009	0.016
	(0.141)		(0.007)	(0.010)	(0.012)
Observations	1410	1062	258,767	21,561	14,089

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are two-way clustered by CBG and by year-quarter of sale. Dependent variable in all models is ln(sales price). All models include standard hedonic controls (given in Table 2) including polynomials in age and square feet and year by quarter of sales fixed effects. We also include applicant year fixed effects. Column 1 incorporates our main control group of applicant parcels that were not remediated by LeadSafe. Column 2 provides a simple post-pre change in housing prices for lead remediated homes. Column 3 compares both remediated and non-remediated LeadSafe applicants to a control group using all homes sold over our sample period 1995–2014; Column 4 limits the control group to only renovated homes and Column 5 limits the sample to renovated homes built after 1978.

properties located within a flood zone and risk premiums differing substantially before and after major storms (Bin and Landry, 2013; MacDonald et al., 1987). Therefore, some of the benefits from remediation may result from the removal of uncertainty in both the cost of remediation as well as the risk of lead exposure. Second, arbitraging these large net benefits of remediation is difficult given the lack of financing available for lead remediation (especially to low-income households) and the transactions costs incurred for outside buyers to purchase, remediate and then sell a home.

The negative effects of lead exposure on a number of educational and behavioral outcomes is well established in the literature, but less is known about how lead contributes to neighborhoods or housing values. We show that lead remediation increases property values and represents a large net benefit for public investment in lead remediation programs—every dollar invested in lead remediation returns more than two and a half dollars in benefits to home owners. Our results suggest that lead remediation programs, such as HUD's *Healthy Homes and Lead Hazard Control Program*, which provides grants to LeadSafe Charlotte and other similar organizations, can help address the lasting negative effects of growing up in disadvantaged neighborhoods with high concentrations of environmental toxins. Future assessments of these programs should include the potential benefits to low-income housing values in addition to improvements in childhood health and development from reductions in exposure.

Acknowledgments

We thank Anna Aizer, Prashant Bharadwaj, Paul Gaggl, Ludovica Gazze, Scott Holladay, Heather Royer, Reed Walker as well as two anonymous referees and editor, Francisco Ferreira, for their helpful comments and edits. We are grateful to the participants at the Urban Economics Association Meetings 2016 and the ASSA/AREUEA 2017 meetings for their comments/discussions. We would also like to thank Tena Ward and Ed Norman from the North Carolina Childhood Lead Poisoning Prevention Program; David Jacobs of the National Center for Healthy Housing and Diana Adams of LeadSafe Charlotte.

Table 8
Other outcomes: Residential mobility, housing renovations, and blood lead tests.

	(1) Any sale	(2) Renovation cost	(3) Renovation cost *sold post inspection only*	(4) Any lead test	(5) Lead value
CBG and year FEs					
Leadsafe remediation*post	−0.030***	157.859	219.162	0.002	−0.515
	(0.008)	(129.552)	(185.720)	(0.007)	(0.462)
Leadsafe remediation	0.023***	−116.372**	−149.592*	0.008	0.335
	(0.007)	(49.452)	(77.899)	(0.006)	(0.364)
Post	0.015**	245.444***	179.739	0.009*	0.426
	(0.007)	(92.289)	(176.862)	(0.005)	(0.366)
Parcel and year FEs					
Leadsafe remediation*post	−0.035***	207.567	207.948	0.004	−0.491
	(0.008)	(138.890)	(221.642)	(0.008)	(1.003)
Observations	25,802	25,802	7,296	25,802	938
Dep. var. (mean)	0.05	330.85	330.85	0.04	4.02

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are two-way clustered by CBG and by year. We provide a number of new outcomes given by column headings. This data represents a panel of 1358 parcels that applied to the LeadSafe program over 19 years (1995–2013). The results for lead value contain substantially fewer observations because we only include a parcel-year observation if we had a recorded BLL. In the case of multiple kids with BLL values in a given parcel-year, we simply average BLL values.

Appendix A

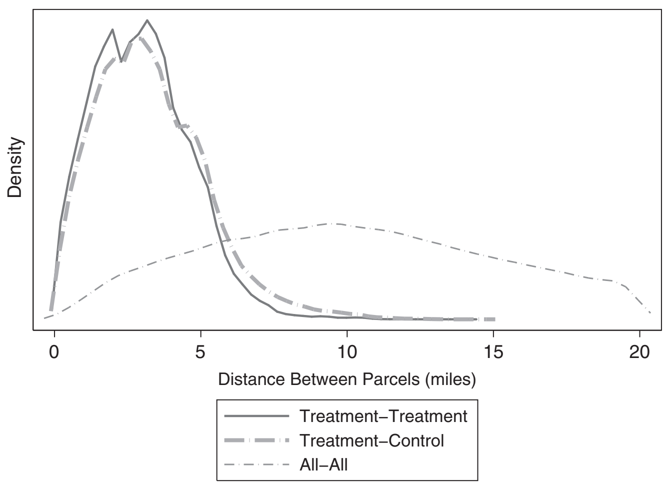

Fig. A1. Spatial distribution of LeadSafe parcels. These three distributions above are based on kernel density estimators for all pairwise combinations of treatment parcels to treatment parcels; treatment parcels to control parcels; and a random sample (N=500) of all parcels to all parcels.

Table A1
Descriptive statistics - Applicant parcels.

	Applicant sales	Applicant sales post inspection	Applicant never sold parcels
Lot size (acres)	0.22	0.21	0.25
	(0.09)	(0.08)	(0.17)
Bathrooms	1.11	1.14	1.21
	(0.34)	(0.36)	(0.48)
Living area (sqft - 00s)	11.22	11.34	11.53
	(3.47)	(3.73)	(3.33)
Fireplace	0.42	0.42	0.37
	(0.49)	(0.49)	(0.48)
Age of building	60.11	65.31	65.89
	(15.97)	(16.19)	(14.30)
Average BLL tests	5.05	5.82	4.11
	(3.81)	(4.62)	(2.43)
Total renovation costs ($000s)	1.056	0.942	0.740
	(5.280)	(4.835)	(4.100)
Distance to CBD (miles)	2.37	2.22	2.52
	(0.89)	(0.84)	(1.12)
Distance to highway (miles)	0.83	0.82	0.80
	(0.65)	(0.61)	(0.60)
Median HH income ($000)	26.98	27.20	27.24
	(6.88)	(7.05)	(7.60)
Percent black residents	0.79	0.79	0.82
	(0.19)	(0.20)	(0.18)
Pop density (000 per sq mile)	3.616	3.927	3.471
	(1.531)	(1.497)	(1.533)
Observations	1410	648	647

Summary statistics are based on all single-family residences and broken down based on column headings. Average BLL tests based on the average (Blood Lead Level) BLL test values for a given address prior to the inspection of a home by LeadSafe and we limit this value to parcel addresses with at least one BLL. Average BLL tests based on NC BLL surveillance program and limited to 1993–2008 for this study. Total renovation costs is limited to renovations done 5 years prior to a parcel being inspected and does not include any costs related to lead remediation.

A.1. Hedonic estimates of lead exposure on housing values using blood lead surveillance data to proxy for parcel-level exposure

As a supplementary exercise to our primary analysis, we estimated a series of hedonic housing price regressions in order to test the relationship between the presence of lead in a home and property values. The standard hedonic model is given by:

$$\ln(P_{ijt}) = \alpha + \beta_1 BLL_{ijt\text{-}T} + \beta_2 X_{it} + \delta_t + \gamma_j + \varepsilon_{ijt} \quad (A1)$$

Table A2
Relationship between blood lead test results and property values.

	(1)	(2)	(3)	(4)
	Main	Control for neigh covars	Control for neigh covars & renovations	Add CBG fixed effects
Average BLL in home (prior to sale)	−0.0131***	−0.0020	−0.0019	−0.0002
	(0.0024)	(0.0015)	(0.0015)	(0.0012)
$2 \le BLL \le 4$	−0.0684***	−0.0237***	−0.0226***	−0.0127*
	(0.0111)	(0.0076)	(0.0076)	(0.0067)
$5 \le BLL \le 9$	−0.1210***	−0.0267**	−0.0256**	−0.0081
	(0.0168)	(0.0115)	(0.0115)	(0.0087)
$BLL \ge 10$	−0.1190***	−0.0339	−0.0322	−0.0208
	(0.0391)	(0.0283)	(0.0282)	(0.0260)
Observations	27,768	27,768	27,768	27,768

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors are two-way clustered by CBG and by year-quarter of sale.
All models include standard hedonic controls including polynomials in age and square feet, lot size, baths, fireplace, year and quarter of sales fixed effects and we limit our sample to single family homes. Dependent variable in all models is log(sales price). Measures of lead based on average BLL tests prior to any property sale. The lowest possible BLL is 1 and we exclude a few BLL tests of greater than 44.

where our dependent variable and control variables are as described in Eq. (1). In this specification, our main variable of interest is $BLL_{ijt\text{-}T}$ which indicates the average blood lead level for individuals tested prior to the sale of a parcel.[28] Since poor home maintenance coincides with increased risk of lead exposure, we also incorporate measures of housing renovations to account for the general maintenance level of a home. Since the presence of lead paint is heavily concentrated in older residential neighborhoods, standard errors are two-way clustered by CBG and by year-quarter of sale.

The top part of Table A2 provides estimates of β_1 for a series of models that estimates the marginal effect of a 1 unit increase in mean BLL previously tested at a home. Column 1 provides standard hedonic estimates of a 1.3% decrease in property values for a 1 unit increase in prior BLL tests for a given property sale. The bottom part of Table A2 estimates a series of dummies for BLL levels of concern as recommended by the Center for Disease Control (CDC). In these models, the excluded category is homes with average BLL less than 2, which indicates no lead exposure.[29] Column 1 shows larger effects for higher previous lead tests with an average BLL of 10 or more generating a 12% decrease in home values. Column 2 adds an additional control variable for housing renovations prior to the home's sale and Column 3 adds CBG fixed effects. The inclusion of CBG fixed effects generates a substantial decline in the relationship between lead tests and property values. These nosier results with CBG fixed effects highlight some issues with using BLL tests as a measure of lead exposure risk. First, BLL tests are not necessarily known to homebuyers because lead disclosure laws only require disclosure of known lead inspections in the home. Second, the general condition of the home impacts BLL tests and home values and thus estimates may capture the effects of both home maintenance and lead exposure risk. The controls for prior renovations as well as neighborhood fixed effects mitigate some of the effects of home maintenance, but we are not able to completely address this concern. Therefore, we focus on our main model that identifies the relationship between exposure and housing prices using large shocks to exposure and information generated by remediation.

[28] We include previous BLL test values back to 1993, but results are similar if we use only the previous 3 years of BLL tests.
[29] The lowest possible BLL is 1 and we exclude a few BBL tests of greater than 44.

Table B3
Effects on other outcomes residential mobility using public school records.

	(1)	(2)
	Moved by school start	Moved by school start
Leadsafe remediation*post	−0.190***	−0.192***
	(0.063)	(0.055)
Leadsafe remediation	0.002	−0.047
	(0.046)	(0.057)
Post	−0.001	0.009
	(0.071)	(0.061)
Observations	879	879
Dep. var. (mean)	0.76	0.76

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard errors robust to arbitrary correlation within CBG and year of birth.
These results estimate the impact of LeadSafe remediation on movements using CMS pupil records linked to BLL records. This data limits our analysis only to parcels with BLL tests. Columns 2 includes CBG fixed effects. Dependent variable is equal to one if the home address in the BLL test data for a given child is different than the first home address reported in the first year of public school data.

A.2. Effects of remediation on residential mobility using public school and blood lead surveillance data

Since our measure of residential movement is not ideal, we also estimate the effects of remediation on residential mobility using a dataset of children in public schools. This dataset, which is described in more detail in Billings and Schnepel (2017), includes all public school children and their residential address during their first year of attending school. We first link individuals to our sample of LeadSafe applicant properties at the time of a first blood lead test (typically between the age of one and two) using blood lead surveillance data and then measure whether the address reported when the individual first enters school (typically between the age of five and six) has changed from the address first reported in the blood lead testing data. Table B3 reports estimated effects of remediation on this indicator of residential mobility. We estimate a significant decrease in the probability of moving between blood lead testing and school entry for those living in LeadSafe remediation properties. These results generate the same conclusions as Table 6 in that individuals in lead-remediated properties are less likely to move.[30]

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[30] The magnitudes of these results are not directly comparable to Table 6 for two reasons. First, these results are looking at any residential moves by the time a child starts school (different time period). Second, school moves are based on a cross-section of applicant parcels and not the panel dataset used in Table 6.