DOES CLEANUP OF HAZARDOUS WASTE SITES RAISE HOUSING VALUES? EVIDENCE OF SPATIALLY LOCALIZED BENEFITS[1]

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Abstract

Economists often rely on publicly available data provided at coarse geographical resolution to value spatially localized amenities. We propose a simple refinement to the hedonic method that accommodates this reality: specifically, we measure localized benefits from the cleanup of hazardous waste sites at the sub-census tract level by examining the *entire within-tract housing value distribution*, rather than simply focusing on the tract median. Our point estimates indicate that the cleanup leads to larger appreciation in house prices at the lower percentiles of the within-tract house value distribution than at higher percentiles. Though not statistically different from one another, the estimates are monotonically ordered from 24.4% at the 10th percentile, 20.8% at the median and 18.7% at the 90th percentile, respectively. We confirm these results in two ways. First, our analysis using restricted access census block data finds comparable results that cleanup leads to a 14.7% appreciation in the median block-level housing values. Second, our analysis of proprietary housing transactions data show that cheaper houses within a census tract are indeed more likely to be closer to a hazardous waste site, explaining the greater impacts they receive from the cleanup process.

JEL codes H41, C2, Q5

Keywords: Hedonic property method; localized public goods; heterogeneous treatment effects, hazardous waste remediation

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[1] Corresponding author: shanti@gspia.pitt.edu. We thank seminar participants at Carnegie Mellon University, University of Rome Tor Vergata, University of Madison-Wisconsin, and the California Workshop in Environmental Economics. Funding from the University of Pittsburgh's Center on Race and Social Problems and University Center for Social and Urban Research; and the National Science Foundation (ITR-0427889) for research at the Triangle RDC is gratefully acknowledged. Any opinions and conclusions expressed herein are those of the authors and do not necessarily represent the views of the U.S. Census Bureau. All results have been reviewed to ensure that no confidential information is disclosed. The U.S. Environmental Protection Agency provided data and funding under Purchase Order EP09W001911. Results have undergone Agency peer and administrative review. We gratefully acknowledge use of data compiled and published by Michael Greenstone and Justin Gallagher. All errors are our own.

1. Measuring Localized Benefits with Tract-Level Housing Data

A growing number of studies document that amenities or disamenities are highly localized (e.g., at the sub-tract level) with effects that decline rapidly with distance. For example, Davis (2011) detects strong adverse effects of power plants on prices of houses that are located within two miles, weaker effects between two to five miles, and no effect beyond five miles. Campbell, Giglio and Pathak (2011) find that each nearby foreclosure lowers the price of a house by about 2% if it takes place at zero distance and 1% if it takes place at a distance of 0.05 miles. Because fine-resolution data at the house-level or block-level are often inaccessible, these benefits from spatially localized amenities may be estimated using publicly available tract, zip-code, or county-level median housing value data.[2] Using tract-level median housing values to capture benefits that are localized at the sub-tract level can, however, result in a failure to detect the true underlying benefits. Our study proposes a simple refinement to the hedonic method that overcomes this problem. Specifically, we recover localized effects by examining the *entire within-tract housing value distribution*, rather than simply focusing on the tract median.

We apply our method to estimating the benefits from the cleanup of hazardous waste under the Superfund program. Under that program, the most severely contaminated sites are placed on its National Priorities List (NPL) (Sigman 2008; Sigman and Stafford 2011) and cleanup is undertaken for a subset of these sites. Restricting our analysis to sites that have similar risk scores, we compare tract-level owner-occupied housing values in neighborhoods located within three miles of sites that have been cleaned up with corresponding neighborhoods around sites that have not been cleaned. The appreciation in housing values in response to

[2] Recent examples include Bui and Meyer (2003), Chay and Greenstone (2005), Hanna (2007), Greenstone and Gallagher (2008), Grainger (2012), and Sanders (2011).

cleanup (measured with the deletion milestone in the Superfund process) is defined relative to the pre-proposal baseline. In response to cleanup, our tract-level analysis detects larger appreciation at the 10th percentile of the within-tract housing value distribution (24.4%) than at the median (20.8%) and the 90th percentile (18.7%). A cost-benefit analysis based on these results indicates that cleanup under the Superfund program yields net benefits for 39 out of 52 sites that have been deleted from the NPL by 2000.

We find that examining the full housing value distribution can have important policy implications for the results of a hedonic analysis. In our example of valuing Superfund cleanup, we find a monotonic decline in the point estimates from the lower to the upper percentiles of within tract housing values, though these point estimates are not statistically different from one another at the 5% level. A focus on the median housing value would have understated the larger effects at the lower tails of the housing value distribution. One can imagine other situations in which the distribution of benefits is such that a focus on the mean or median could lead to a failure to detect any treatment impacts, should those impacts exist only in the tails of the distribution of housing values.

Our analysis of high geographical resolution data (i.e., restricted-access block data) supports this finding. We re-run our analysis for those blocks contained in the tracts lying within three miles of these sites and find that housing values appreciate by 14.7% with deletion. While we do not expect to recover identical estimates of the effects of cleanup from the block and tract analyses (the neighborhoods' exposure to sites at various stages of cleanup cannot be defined identically in these separate analyses), the block level analysis does provide a valuable check on our tract-level results.

As further supporting evidence, we examine geocoded proprietary housing transactions data from ten different states. These data show explicitly that it is, in fact, the cheaper houses within each tract that are more likely to be exposed to waste sites within one kilometer. This pattern is less evident when we consider exposure at greater distances (e.g., two or three kilometers). The results of this transaction-level analysis are particularly useful in explaining the greater appreciation from the deletion of sites in the lower tail of the housing value distribution that we find in our tract-level analysis.

Our proposed hedonic refinement proves to be important when the analysis of coarse resolution data results in a failure to detect localized benefits. We note that many hedonic studies are forced to rely on coarse resolution data because of its nationwide coverage and public availability, but demonstrate that the benefits of spatially localized amenities could be both substantial (particularly in densely populated areas) and likely missed by analyses focused on mean or median values. While our refinement cannot detect all forms of heterogeneity across housing markets that could, for example, be evident with transaction-level data, it does avoid an important source of bias without saddling the researcher with difficult (often prohibitive) data expenses.

2 Potential Benefits from Superfund Cleanup

In the late 1970's, events at Love Canal and the Valley of Drums raised public concern over the health and environmental risks associated with contaminated waste sites.[3] In response to these and other similar incidents, the US Congress enacted the 1980 Comprehensive

[3] A recent study documents that mothers' residence close to a Superfund site before cleanup is associated with a 20 to 25% increase in the risk of congenital anomalies (Currie, Greenstone, Moretti, 2011).

Environmental Response, Compensation and Liability Act (CERCLA). Under that law, the most hazardous sites are placed on the National Priorities List (NPL). There are four major milestones in the NPL process – proposal, listing, construction complete, and deletion – at which the EPA publicizes information about the site, sometimes entering information into the Federal Register and soliciting public comment. These milestones, by providing information to the housing market, have the potential to influence housing values.

The NPL process begins with a preliminary assessment and site inspection; based on that assessment, the EPA may propose a site to the NPL in the Federal Register. Information collected during the preliminary assessment and site inspection is used to calculate a Hazard Ranking System (HRS) score. The EPA then lists the site on the final NPL if it meets at least one of three criteria – (i) the HRS is of sufficient magnitude, (ii) the state environmental authority designates the site to be a top priority, or (iii) the US Public Health Service recommends removing all people in close proximity to the site. The construction complete designation indicates the physical construction phase of the cleanup process has been completed and immediate public health threats have been addressed, though other remedial actions have yet to be completed. Finally, deletion of a site from the NPL requires that the necessary actions for remediation have been completed and the site no longer poses a threat to human health.

There are two channels – one direct and one indirect – through which deletion from the NPL can increase housing values. First, cleanup reduces health risks and other disamenities associated with a site. Second, cleanup may prompt further development in the area surrounding a site, including the potential for re-zoning from a lower-value commercial use to higher-value residential (even luxury) development. As long as this sort of development occurs *conditional* on cleanup being undertaken, our study correctly considers the benefits from it to be part of the benefits from Superfund cleanup. Such an outcome would represent one mechanism through which remediation can be translated into higher housing prices. For the sites in our analysis described below, it is unlikely that the causality went in the opposite direction – i.e., developers decided to build a luxury resort (which was going to raise nearby housing prices regardless of EPA actions), and the EPA then responded by listing the site on the NPL. Instead, the EPA ranked sites by their HRS scores and placed the first 400 sites ranked by their severity of HRS scores on the NPL list (Greenstone and Gallagher, 2008). Moreover, our analysis employs (i) sample restrictions to ensure that we are making comparisons among tracts that are similar to one another aside from their receipt of cleanup, and (ii) panel methods to control for time-invariant unobservable differences in tracts.

Any hedonic estimates of the benefits of Superfund cleanup come with five caveats. First, benefits are understated if homeowners ignore benefits that accrue outside their property, for example, groundwater improvements beyond their property boundaries, or redevelopment benefits that may occur in future. Second, the appreciation of housing values reflects homebuyers' perceptions of risk reductions, and these perceptions, though influenced by the information that EPA provides (Gayer, Hamilton, Viscusi, 2000), may not fully reflect true reductions in risks. Third, we cannot account for changes in housing values that result from the cleanup of nearby sites undertaken outside the Superfund program because data describing these sites are unavailable.[4] Fourth, like previous studies, we treat Superfund cleanup as a marginal change to the overall housing market. With the assumption that the hedonic price schedule does not shift, we can interpret our capitalization results in a marginal willingness-to-pay framework.

[4] The EPA does not maintain a list of verified coordinates of non-NPL sites at the national level. This data limitation has constrained other studies (Kiel and Williams 2007; Noonan, Krupka and Baden 2007; Greenstone and Gallagher 2008).

Without this assumption, our results can be interpreted as capitalization effects, which are also important to policy makers (Kuminoff and Pope 2010). Finally, we follow the majority of the hedonics literature and simply analyse the value of marginal changes along the hedonic price function. We do not attempt to identify the marginal willingness to pay function, given the difficulties inherent in such a task (Kuminoff, Smith and Timmins, 2010).

While our study focuses on the effects of deletion from the NPL, we note that at least three other Superfund milestones can also influence nearby housing values *measured relative to the pre-proposal stage.* Proposal of a site to the NPL may reduce neighborhood housing prices when this action provides new information to the housing market that contamination is severe enough to warrant the potential listing of that site on the NPL (although, if the housing market expects that proposal signals that the site is likely to be remediated, this countervailing factor will dampen the extent of that depreciation). Housing prices have been found to decline due to perceived increases in health risks (Hamilton and Viscusi 1999; Davis, 2004) and stigma associated with a contaminated site (Fischoff 2001; Messer et al. 2006). Unlike proposal and deletion, listing of an NPL site is associated with two countervailing forces. (i) It may reduce housing prices by confirming the severe nature contamination of that site, but (ii) it may also increase housing prices by signaling that a site has been placed on the path towards remediation. The construction complete designation, which indicates the physical construction phase of the cleanup process has been completed and immediate threats have been addressed, is likely to raise housing values. In the case the market is forward looking and treats listing as indicative that the site will be cleaned, the additional appreciation experienced at the construction complete and deletion milestones would be smaller than it would be otherwise.

2.1 Previous Studies on Valuing Superfund Benefits

The large literature that seeks to measure the value of Superfund site remediation has been exhaustively reviewed in Schultze et al. (1995), Kiel and Williams (2007), Sigman (2008), EPA (2009) and Sigman and Stafford (2011). We briefly describe the hedonic approach that examines median housing values in locations that vary in the number or characterization of sites contained within. Greenberg and Hughes (1992) study seventy-seven communities in New Jersey and find that sale prices of houses in Superfund communities appreciate by less than those in non-Superfund communities. Noonan, Krupka and Baden (2007) study the effect of Superfund remediation activities on housing values measured at the block-group level using a national sample, and employ an instrumental variables approach to separate direct and indirect effects of cleanup. Their comparison of those block groups that are close to waste sites with other block groups across the contiguous US, however, could lead to bias because unobservables are likely to differ systematically across these two sets of block groups.[5]

We build most directly upon Greenstone and Gallagher (2008) (hereafter GG) who examine how tract *median* housing prices vary depending upon whether they contain a site that has been listed on the NPL or one that has narrowly missed being listed on the NPL. GG's important methodological contribution is to restrict their comparison to sites that are similar in their risk scores, but that differ in their Superfund status. As described in GG, in the early years of the Superfund program, budget constraints forced the EPA to choose only 400 sites to list on the NPL (out of 690 potential sites that the EPA had identified). The EPA employed the HRS ranking, which uses information from initial limited investigations, to choose those sites that

[5] Table II in Greenstone and Gallagher (2008) shows that tracts that host and do not host waste sites differ significantly in their observables and by extension, are likely to differ in their unobservables.

posed the greatest risks. It turned out that an HRS score of 28.5, as recorded in 1982, served as the cutoff between the 400th listed and 401st non-listed sites. GG argues that the comparison should be made among (i) sites with 1982 HRS scores; and (ii) sites whose 1982 HRS scores are 12 points above or below the 28.5 regulatory cutoff. Their regression discontinuity (RD) analysis exploits the dichotomous treatment (listing versus non-listing) at the 28.5 regulatory cutoff, while assuming that the unobservables are continuous across that cutoff.

As their units of observations, GG's analysis examines (i) 487 sites out of 690 sites with 1982 HRS scores and (ii) 227 sites out of 332 sites whose 1982 HRS scores fall within a narrow interval. They drop 203 out of the 690 sites and 95 out of 332 sites, respectively.[6] GG's instrumental variable strategy, which compares sites that are listed versus sites that narrowly missed listing, concludes that *cleanup* of Superfund sites has little to no effect on median housing values. One important drawback in that study is its examination of "listing" as the milestone to capture the benefits of cleanup instead of deletion, which is the milestone that marks the completion of cleanup activities. Their comparison of "listed sites" (which combines listed and deleted sites) with sites that have not yet reached the listing designation leads a downward bias because listing has ambiguous overall effects on housing prices, while deletion is likely to raise housing prices (Smith 2006).[7] In contrast to their approach, our study estimates the effect

[6] GG's specification relates 2000 prices to listing status in 2000, with 1980 covariates as explanatory variables. The 1980 covariates are unavailable for tracts associated with these 95 sites in the RD sample. Covariates also are unavailable for tracts associated with the 203 sites in the 1982 HRS sample (GG 2008).

[7] This combination is necessitated by their instrument. GG use the 1982 HRS score to instrument for the variable indicating that a site has been listed on (or deleted from) the NPL by 2000; that one variable cannot separately instrument for the two milestones of listing and deletion.

of deletion from the NPL to capture the benefits from remediation, and we measure the effect of deletion separately from other Superfund milestones.[8]

3 Estimation Method

Our approach to measuring *localized* benefits is three-fold. First, we demonstrate a refinement of the hedonic method that is aimed at providing more accurate estimates of localized benefits when analysts are restricted to using publicly available tract-level (or other similarly geographically coarse) data. We examine numerous points along the within-tract distribution of housing values (including, but not limited to, the median) in order to measure the heterogeneous appreciation of housing values in response to cleanup. Second, we recover these benefits directly using high geographic resolution data measured at the census *block level.* The block analysis reveals that benefits from cleanup are sizable but highly localized. Finally, we provide supplementary analysis using geo-coded house-level data to document the spatial pattern of housing values within tracts and their proximity to Superfund sites. Our tract-level finding that cleanup causes greater appreciation at the lower percentiles of the within-tract house value distribution is consistent with our finding that Superfund sites are in closer proximity to the lower-value houses within each tract.

To identify the effect of Superfund milestones on housing prices, we rely on two complementary strategies: (i) we restrict our comparison to sites whose 1982 HRS scores are within a narrow interval, as in GG; and (ii) we rely on a panel model to examine how the changes in the exposure of neighborhoods to various Superfund milestones affect changes in the

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[8] Other studies have measured the distinct effects of these various milestones (Kiel and Zabel 2001; Cameron and McConnaha 2006; Kiel and Williams 2007) or treated these milestones as distinct (Sigman 2001).

housing prices. We restrict our analysis to 321 out of 322 sites whose 1982 HRS scores are within the narrow (16.5 to 40.5) interval (we drop one site for which geocoordinates are unavailable). The progression of these sites through the Superfund milestones is shown in the Online Appendix to this paper.[9] Our observations are tracts that fall at least partially in a 3 mile buffer around each of these sites (our block-level analysis uses all blocks contained in these tracts). Our choice of the 3 mile buffer is based on panel data studies on the association between hazardous waste sites and housing prices that have detected effects at a maximum distance of 2 to 2.5 miles with a mean estimated price effect of 7.4% (reviewed in Jenkins et al. 2006).

Our tract (and block) analyses take snapshots of the NPL status of each site in 1990 and 2000.[10] We compare changes in owner-occupied housing values in census units lying in 3 mile buffers surrounding sites between 1990 and 2000 to changes in exposure to (i) sites that are proposed for the NPL but not listed, (ii) sites that are listed on the NPL but where construction is not yet completed, (iii) sites where construction is completed, but which are not yet deleted, and (iv) sites that are deleted from the NPL. Our study measures the cleanup "treatment" by examining the effect of *deletion from the NPL*.

To summarize, we rely on the sample restriction to the neighborhoods around sites whose 1982 HRS scores fall within a narrow interval, (i.e., comparing neighborhoods near sites that are listed with those near that missed listing), primarily to identify the effect of listing. To identify the effects of construction complete and deletion, we rely on the panel methods to further control for time-invariant unobservables.

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[9] This appendix can be assessed at www.aere.org/journals.
[10] Ideally, we would examine changes over a long enough time period to detect changes in housing prices, but over a short enough time-period so that parameters of the hedonic price function are stable. Like other decennial census based studies, we are constrained by the decadal frequency in data collection. More frequently collected census data, such as the American Community Survey, is not collected at a sufficient level of geographic density for our analysis.

4 Regression Models

4.1 Census Tract - Specification

We begin with a basic hedonic regression model relating owner-occupied housing prices to the characteristics of the house and the neighborhood, including exposure to the 331 sites.

$$(1) \qquad lnH_{k,t}^{\theta} = \beta_{1,t}^{\theta}P_{k,t} + \beta_{2,t}^{\theta}L_{k,t} + \beta_{3,t}^{\theta}C_{k,t} + \beta_{4,t}^{\theta}D_{k,t} + \beta_{5,t}^{\theta}X_{k,t} + \nu_{k}^{\theta} + \varepsilon_{k,t}^{\theta}$$

The subscript k indexes tracts that lie within a 3 mile buffer of a site. A tract is included as long as any part of it falls within the 3 mile buffer. $lnH_{k,t}^{\theta}$ is the natural log of the θ^{th} percentile of owner-occupied housing values in tract k in year t ($t = 1990, 2000$). X is a vector containing characteristics of the housing stock along with the socioeconomic and demographic attributes of the tract.[11] These variables and the housing value distributions are summarized in Table 1. ν_{k}^{θ} are time-invariant tract-level unobservables specific to houses in the θ^{th} percentile, and $\varepsilon_{k,t}^{\theta}$ is a tract-percentile-year unobservable.

Our main variable of interest is the exposure of the tract in 1990 or 2000 to sites that are deleted by that time period. Other variables of interest are exposure of the tract to sites that are proposed, listed, or where construction has been completed. Exposure is defined as the share of the land area in a tract that falls into 3 mile buffers surrounding sites.[12] Specifically, we first use

[11] Our estimates of the benefits from cleanup examine the 'direct effects' on housing values. Covariates control for the other changes that might occur in response to Superfund cleanup that in turn affect housing values. Gamper-Rabindran and Timmins (2011) documents changes in neighborhood socio-deomographics associated with Superfund cleanup using block-level data.
[12] Note that EPA defines site location by the geocoordinates of the site's centroid. Sites may vary greatly in size, however, and we would expect the geographic "reach" of larger sites to be

GIS to draw 3 mile buffers around each site. A tract's exposure to sites at each stage of remediation is then defined as the ratio of its area of overlap with the 3 mile buffers drawn around sites at that stage to its total area.[13] $D_{k,1990}$ represents the exposure of tract k to sites that are deleted by 1 Jan 1990, and $D_{k,2000}$ represents the corresponding measure for 1 Jan 2000. $P_{k,1990}$ and $P_{k,2000}$ correspond to proposed status; $L_{k,1990}$ and $L_{k,2000}$ correspond to listed status; and; $C_{k,1990}$ and $C_{k,2000}$ correspond to construction complete.

Next, we take the difference between the 1990 and 2000 regression models (restricting parameters to be constant over time), thereby removing the effect of time-invariant tract-percentile unobservables.[14]

$$\text{(2)} \quad lnH^{\theta}_{k,2000} - lnH^{\theta}_{k,1990} = \beta^{\theta}_1\left(P_{k,2000} - P_{k,1990}\right) + \beta^{\theta}_2\left(L_{k,2000} - L_{k,1990}\right) + \beta^{\theta}_3\left(C_{k,2000} - C_{k,1990}\right) + \beta^{\theta}_4\left(D_{k,2000} - D_{k,1990}\right) + \beta^{\theta}_5\left(X_{k,2000} - X_{k,1990}\right) + \left(\varepsilon^{\theta}_{k,2000} - \varepsilon^{\theta}_{k,1990}\right)$$

greater. Without specific GIS information describing the boundaries of all sites, our best option is to use centroid geocoordinates to indicate location.

[13] Further detail on the calculation of tract exposures, including illustrative maps, is included in Gamper-Rabindran, Mastromonaco and Timmins (2011) in Appendix A2. We also describe in more detail below how we handle situations in which a tract is simultaneously exposed to multiple sites at the same stage of the remediation process.

[14] Our conservative interpretation of the coefficients in the panel analysis is that they measure the capitalization into the housing values resulting from the cleanup (Kuminoff and Pope 2010). Capitalization into housing values is in itself valuable information for policymakers in judging the benefits from Superfund cleanup and affects the local economy including the property tax base. If the coefficients are, in fact, stable over time, the estimates can be further interpreted as measures of willingness-to-pay. Without access to some other form of quasi-experimental variation in the data, it is not possible to test this assumption of stability of coefficients.

Looking across deciles, we assume only that the tract-level unobservable affecting the θ^{th} percentile house in 1990 has to be the same tract-level unobservable affecting the θ^{th} percentile house (whatever house that may be) in 2000. We do not take the restrictive interpretation that the θ^{th} percentile house in 1990 has to be the same θ^{th} percentile house in 2000.

The coefficient β_4^θ measures the appreciation of house values at the θ^{th} percentile as a result of a one unit (i.e., 0 to 1) increase in exposure of the tract to deleted site(s). Recognizing the log dependent variable, a positive β_4^θ indicates that house values appreciate by $100\left[exp\left(\beta_4^\theta - \frac{1}{2}V\left(\beta_4^\theta\right)\right) - 1\right]$ percent as a result of a one unit (i.e., 0 to 1) increase in the exposure to deleted sites (Kennedy 1981). In practice, this transformation has little impact on our block and tract results, so we ignore it in order to simplify the discussion of our estimates. The changes in exposure to (i) proposed sites, (ii) listed sites and (iii) construction completed sites similarly capture the changes in house values associated with these steps in the remediation process. Table 2 summarizes the interpretation of all the coefficients.

We weight observations in our preferred specification by the number of owner-occupied housing units in each census tract. Section 6.3 shows that our main conclusions are not sensitive to this decision. To account for spatial correlation in the error terms, we cluster the standard errors on groups of contiguous adjacent tracts. In turn, two tracts are defined as being adjacent if their centroids fall within a 1 mile buffer of other tract's centroid. Consider the case in which tract A lies adjacent to B, tract B lies adjacent to tract C, and tract C, D and E do not lie adjacent to each other. In this example, tracts A, B and C are in the first group of contiguous adjacent tracts and tract D is in the second group of contiguous adjacent tracts. Section 6.3 shows that the estimates for deletion remain statistically significant even when larger buffers (2 and 3 miles) are used to define adjacent tracts.

4.2 Census Block - Specification

Our tract analysis contains all tracts that have some overlap with the 3 mile buffer surrounding the sites. Correspondingly, our block analysis examines all blocks contained in these tracts. The cross-section and panel regression models for census blocks are defined analogously to equations (1) and (2), except that (i) block median values replace within-tract percentiles of the house value distribution, and (ii) exposure is defined by a count of Superfund sites at each stage of remediation lying within 2 miles of the centroid of each block. The exposure variables are counts of sites located less than 2 miles from the centroid of census block k at time t that are proposed ($P_{k,t}$), listed ($L_{k,t}$), construction completed ($C_{k,t}$), and deleted ($D_{k,t}$).

5 Data

Restricted-access census block data for 1990 and 2000 are from the US Census Bureau. Proprietary housing transactions data are from Dataquick Information Systems and are used under a licensing agreement with the Duke Department of Economics. Census tract data come from the Geolytics Neighborhood Change Database, which has reapportioned census data from 1980, 1990 and 2000 into census tract boundaries that are fixed in 2000. The Decennial Census provides counts of houses with owners' stated values in various intervals, allowing us to calculate the discrete distribution of house values within each tract.[15] We use straight lines to connect the midpoints of these intervals portrayed in a cumulative distribution function histogram; we then read the cumulative distribution function of house values in each census tract from those lines. Percentiles read off of these distribution functions are then used as dependent variables in our empirical analysis. Data on sites are from the EPA. The 1982 HRS scores come from the dataset compiled and published by GG. The Consumer Price Index used to deflate

[15] For details on the intervals, see Online Appendix Table A1.

housing prices is compiled by the Bureau of Labor Statistics and is based upon a 1982 Base of 100. Table 1 reports summary statistics for census tracts.[16]

6 Results

6.1 Tract Results: Evidence of Localized Benefits from Deletion

Observations are weighted by tract counts of owner-occupied housing units, and standard errors are clustered on groups of contiguous adjacent tracts. Overall, our tract analysis indicates that the appreciation of housing values varies within the tract, with greater percentage appreciation in the lower tail of the housing price distribution. Table 3 presents results from the tract analysis using 3 mile buffers around the sites. The results indicate that the deletion of a site from the NPL raises nearby housing values, but the appreciation, in percentage terms, is more prominent at the lower deciles of the within-tract housing value distribution. As seen in Panel A, carrying a site through the remediation process to deletion raises house values by 24.4% at the 10% percentile, 20.8% at the median, and 18.7% at the 90th percentile. The estimate at the 10th percentile is statistically significant at the 1% level, while estimates at other percentiles are statistically significant at the 5% level. The pattern of declining point estimates from the lower to the higher percentiles of housing values is evident from Panel A, although we note that the standard errors indicate that these estimates are not statistically different from one another at the 95% level.

Panel B presents the results using housing value levels as the dependent variable. Appreciation attributable to deletion increases as one moves from the 10th percentile ($9,305) to the 90th percentile ($17,772); as shown in Panel A, however, these increases are not rapid enough

[16] Similar summary statistics for the block sample were not released by the Census Bureau due to confidentiality concerns.

to prevent appreciation as a percentage of housing value from falling across the percentiles. Interestingly, even in levels, appreciation attributable construction complete falls as one moves from the 10th to the 90th percentile, and is not significant above the 10th percentile.

6.2 Other Superfund Milestones

For all milestones, we find point estimates that indicate heterogeneity in the within-tract house value distribution, but these estimates are statistically significant for only construction complete and deletion. This pattern is consistent with our finding in section 6.8 that lower-value houses tend to be located closer to Superfund sites and are therefore more impacted as those sites progress through the Superfund milestones. We next consider each of the individual milestones preceding deletion – proposal, listing, and construction completion – in turn.

The estimates for proposal are not statistically different from zero. Therefore, we cannot rule out that proposal does not affect housing values. Noting this caveat, the point estimates do correspond to depreciation in housing values, by 11.4% at the 10th percentile, 9.4% at the median, and 2.9% at the 90th percentiles.[17] Depreciation in nearby housing values in response to the proposal of a site to the NPL can be explained by two channels. First, the proposal of the site provides new information to the market about the presence of a harmful site, or about its severity. Second, even if the market is already aware of the site and the extent of contamination,

[17] To be clear, even though proposal leads to depreciation in housing values, the Superfund remediation process, taken in its entirety, leads to an overall appreciation in housing values even at the bottom of the within-tract house value distribution. As described in section 6.2, our estimated coefficients on deletion, which measure the effect of deletion on housing values relative to values at the pre-proposal stage, indicate that the Superfund remediation process, taken in its entirety, leads to an overall appreciation in housing values.

the proposal of the site to the NPL may further decrease housing values by stigmatizing the neighborhood (Messer et al. 2006).

Similarly, the estimates for listing are not statistically significant; therefore, we cannot rule out that listing does not affect housing values. Again, noting this caveat, the point estimates do correspond to an appreciation in housing values, by 8.7% appreciation at the 10th percentile, 5.9% at the median, and 2.9% at the 90th percentiles. The smaller magnitude of appreciation from listing compared to deletion can be explained by the countervailing pressures on housing values that arise when a site is listed – i.e., listing reduces housing values by confirming the severe nature of site contamination, but it also increases housing values by signaling that the site will be remediated. Nevertheless, the promise of cleanup associated with final listing appears to outweigh the effect of confirming a site's contamination level.

Achieving the construction complete milestone leads to statistically significant appreciation in housing values. These effects are larger at lower percentiles – 13.1% at the 10th percentile, 11.5% at the median and 7.1% at the 90th percentile. The estimate at the 10th percentile is statistically significant at the 5% level, while estimates from the 20th to the 70th percentiles are statistically significant at the 10% level. As might be expected, completion of construction leads to a smaller appreciation in housing values than does deletion. This can be explained by the additional value the market places on moving the site from the completion of the physical infrastructure required for the cleanup to the stage where all remedial actions have been completed.

6.3 Deletion of sites from the NPL – Sensitivity Analysis

First, we estimate an unweighted specification. Results from those regressions, presented in Table 4 columns 1-5 are comparable to those from the weighted regressions. We continue to find that carrying a site through the remediation process to deletion leads to larger percentage appreciation at the lower deciles of housing values than at the upper deciles. In particular, the unweighted regressions indicate that house values appreciate by 29.0% at the 10th percentile, 24.7% at the median and 19.4% at the 90th percentile.

Second, we check the robustness of our results to the clustering of standard errors on groups of contiguous adjacent tracts. We re-run our analysis, defining two tracts as being adjacent if their centroids fall within a 2 mile buffer of other tract's centroid and creating groups of contiguous adjacent tracts that are larger in size than in our main analysis in Table 3. Clustering the standard errors over a larger area may to reduce the precision of the estimates, and thus, it is unsurprising that we find larger standard errors in the new set of estimates. As seen in Table 4, columns 6-10, the estimate for deletion at the 10th percentile is statistically significant at the 5% level, while other estimates are statistically significant at the 10% level. The estimate for construction complete is no longer statistically significant at conventional levels. The statistical significance of estimates based on a 3 mile buffer to generate the groups of contiguous adjacent tracts, available from authors, are compatible to those using a 2 mile buffer.

Third, to explore the spatial extent of the effects of deletion, we repeat our analysis using 2 mile buffers to define the extent of exposure to the sites (instead of the 3 mile buffers used in our earlier analysis in Table 3). Table 5 reveals that using the narrow definition of neighborhoods near sites yields larger point estimates of appreciation in response to deletion. House values appreciate by 31.1% at the 10th percentile, 27.8 % at the median and 21.7% at the 90th percentile. Comparison of these estimates with our earlier results from Table 3, in which neighborhoods are defined more broadly using 3 mile buffers, suggests that the larger neighborhood lumps nearby affected houses with more distant unaffected houses, thereby diluting the effects of deletion. Nevertheless, the estimates from neighborhoods that are defined using 2 mile buffers around sites and using 3 mile buffers around sites are not statistically different at the 5% level.

6.4 Sensitivity Analysis: Exposure to Overlapping Site Buffers

Consider a tract that can be divided into three sections. The first is exposed only to the buffer surrounding site A (x% of the area of the tract), the second is exposed to only to the buffer surrounding site B (y%), and the third is exposed to buffers surrounding both sites A and B (z%). To fix ideas, suppose these two sites have progressed from proposed status in 1990 to deleted status in 2000. Based on our definition of exposure in our main analyses (Table 3, 4, and 5), the tract's exposure to deletion will be (x+y+z)%. This definition treats the exposure of z% of the tract similarly whether that section of the tract is exposed to one or more site.

As an alternative approach, we implement a second definition of exposure, which accounts for a tract's exposure to more than one site. For the example above, the exposure of z% of the tract is multiplied by the number deleted sites to which it is exposed (n). Based on this second definition, the tract's exposure to deletion will be (x+y+nz)%. The model accounting for the tracts' exposure to more than one site, shown in Table A2, yields larger price effects from deletion than that which treats exposure similarly where the tracts are exposed to one or more sites (Table 3). The model accounting for the tracts' exposure to more than one site indicates an appreciation from deletion of 28.9% at the 10th percentile and 21.7% at the median.

Comparison of results from these two models indicates that our definition of exposure in the main analysis does not lead to an overstatement of the benefits of deletion relative to the alternative definition of exposure. One potential explanation for the smaller estimates from the first definition of exposure is that tracts exposed to multiple deleted sites may face larger increases in house prices. Our first definition forces the larger change in house prices to be explained by a smaller change in the exposure variable, making it appear that the explanatory variable (the change in exposure to deletion) has only a small effect on housing prices. In contrast, our second definition allows tracts that face the change in exposure to multiple deleted sites to reflect that change, thus avoiding the downward bias on the estimated effect of cleanup. We use the first definition of exposure in our main analyses in order to provide more conservative measures of benefits from the cleanup, even though arguably the second alternative definition of exposure can be easily approximated at the block-level (see section 6.5).

6.5 Block Results: Direct Evidence of Localized Effects

Our analysis at the tract level finds of evidence of heterogeneity in the response to cleanup across the within-tract housing value distribution. This heterogeneity stems from the relatively larger size of the tract, while the benefits from cleanup are spatially localized within the tract. Blocks are smaller geographical units than are tracts. At the block-level, the benefits of the cleanup are thus likely to extend to the entire block, and the median block housing values would capture the price effect in response to cleanup. Therefore, analysis of median housing values at the block level can provide direct evidence for the localized benefits from Superfund cleanup. These results are described in Table 6. Taking a site through the remediation process from proposal to deletion results in statistically significant appreciation of median house values by 14.7% in blocks lying less than 2 miles from the site. Moreover, this estimate continues to be statistically significant at conventional levels when the standard errors are clustered at the tract-level. These block results complement our tract results that deletion from the NPL raises housing values by 24.4% at the 10th percentile, 20.8% at the median, and 18.7% at the 90th percentile of tract-level housing values. We attribute the smaller magnitudes to the different definition of exposure used in the block-level analysis. In particular, in the tract-level analysis, variation in the exposure to deleted sites is captured by the ratio of the area of the tract that overlaps with the 3 mile buffer surrounding the deleted sites to the total area of the tract. At the block level, exposure of the 59,055 block observations to deleted sites is measured using counts of sites located within 2 miles from the block centroid.

Looking at the other milestones, the block results indicate a comparable level of depreciation (-18.8%) associated with proposal. They also indicate a sizable appreciation in housing values relative to the pre-proposal stage occurs when the site is listed, with only small additional appreciation occurring at construction complete and deletion.[18] In contrast, when we carried out the tract-level analysis, we found that a sizable (but statistically insignificant) appreciation in housing values occurred at listing for houses in the lower percentiles, but that there was appreciation that occurred at construction complete for all percentiles. Compared with the tract-level results, the block-level results therefore suggest that the market is more forward looking in treating the listing of a site on the NPL as a strong indication that the site will be cleaned. Again, these differences may be ascribed to differences in the definitions of exposure used in the two analyses.

[18] From our tests of the equality of coefficients, we are able to conclude that the estimates for listing and construction complete are statistically different, as are the estimates for construction complete and deletion.

6.6 Other Potential Estimation Issues for the Tract and Block Analysis

Our identification of the cleanup effect is based on a comparison of houses around sites that have been cleaned up with houses around sites that have yet to be cleaned. We discuss two potential estimation issues, and our strategies to address these issues. The first issue arises if cleaned sites are located in areas with stronger local economic growth than are sites yet to be cleaned; in this case, it would be more difficult to isolate the effects of cleanup on housing values. To address this concern, our model includes control variables to account for time-varying factors that are related to local economic growth. Indeed, the model which includes time-varying covariates (Table 3) yields smaller estimates of appreciation in response to deletion than does the model that excludes the time-varying covariates (results are available from authors). These smaller estimates suggest that the included time-varying control variables are controlling for time-varying factors, including those related to local economic growth, that influence housing values.[19] However, if any remaining unobservable factors were to contribute to stronger economic growth around cleaned sites, this would bias our estimates in direction of overstating the benefits from the cleanup.

A second related issue is whether sites that receive the cleanup treatment get systematically more intensive cleanup activities (leading to lower risk levels and bigger increases in housing values) than would comparison sites that have yet to receive cleanup. If this were true, our estimates would overstate the benefits from the cleanup from future sites. Again, our estimation strategy address this concern by applying fixed effects and by restricting our

[19] Altonji, Elder and Taber (2005) suggest one potential check for the ability of observed variables to control for unobservables is to sequentially add new control variables and see if the estimates stays remain similar with the addition of the last control variables. Results demonstrating that this is the case are available from the authors upon request.

comparisons to sites that are similar in terms of their 1982 HRS scores, which reduces the possibility for variation in the extent of cleanup to arise from time-varying unobservables. Moreover, previous studies suggest that the extent of cleanup does not vary systematically with observed neighborhood characteristics. For instance, the EPA did not choose less permanent cleanup options for sites with lower median household income or with greater shares of non-white residents at the zip-code level (Gupta et al. 1996). Similarly, the expenditure to avert an average cancer case in NPL sites was not influenced by mean income or minority population within a 1-mile ring of NPL sites; among the less hazardous sites, however, variation can arise from constituents' political activity (Hamilton and Viscusi 1999). Hamilton and Viscusi (1999) note that although EPA's directive set a baseline for cleanup standards, cleanup is set at more stringent levels in states with stricter standards. However, the state-level source of variation in the extent of cleanup does not bias our study because we do not systematically compare cleanup in sites located more stringent states relative to sites yet to be cleaned located less stringent states.

6.7 Supporting Evidence for Tract Analysis From House-Level Data

Our tract results are consistent with the observation that NPL sites are located closer to the lower-value houses within each tract. We provide direct evidence for this spatial distribution using geo-coded transactions data from Dataquick Information Systems drawn from ten states.[20] Table 7 summarizes the distribution of housing data and Superfund sites by states and site status. Superfund sites included in this analysis are sites that were scored in 1982 that had the same status in both 1990 and 2000. We have 68 sites that never reached the proposal stage, 94 sites

[20] Specifically, these include Arizona, California, Connecticut, Massachusetts, New Jersey, North Carolina, Oregon, Rhode Island, Tennessee and Washington.

that were listed in both years, and 2 sites that were deleted in both years. Considering only sites where status did not change over the course of that decade, it is a simple matter to assign each house in the tracts surrounding these sites to deciles of the within-tract price distribution without worrying that changing house prices (caused by changing site status) would alter that assignment.

We begin by taking all houses that transacted during the period 1990 - 2000 in the 3 km buffer surrounding each site. We subtract the mean of the prices of all houses sold in a particular tract-year from the price of each house sold in that tract-year. We then pool all of these mean-differenced transaction prices within each tract over the course of the decade. Next, we allocate each house to a decile of the within-tract distribution of mean-differenced transaction prices. Finally, we calculate the percentage of houses in each decile that are within X km of a Superfund site (X = 1, 2, and 3 km). We then normalize by the average probability of exposure in the entire sample (i.e., approximately 5%).

Figures 1 through 4 describe the results of this exercise. Figure 1 uses all sites regardless of status (as long as site status was the same in 1990 and 2000). The first panel shows that houses in the lowest decile are 40.8% more likely than those in the highest decile to be exposed to a site at 1 km. 95% confidence intervals show that this difference is statistically significant. The remaining two panels show that this difference disappears as we consider larger exposure buffers.

Figures 2, 3 and 4 repeat this exercise using only sites that are pre-proposal, listed, or deleted in both 1990 and 2000, respectively. We find patterns similar to those in Figure 1. Considering exposure defined at 1 km, Figure 2 shows that houses in the lowest decile are 27.7% more likely to be exposed than houses in the highest decile. Figure 3 puts this difference at

43.4% for listed sites. Figure 4 reveals a difference of 90.6% for deleted sites (although this last difference is not statistically significant, owing to the smaller sample size for deleted sites). In all cases, these differences disappear as we consider exposure defined at larger distances.

Together, these figures provide direct evidence that exposure to Superfund sites is heterogeneous within tracts. This explains the patterns revealed by our tract-level results, and suggests that a focus on within-tract medians might therefore be misleading.

7. Comparison of Our Results with Greenstone and Gallagher (2008)

Our conclusions that cleanup leads to appreciation in tract-level housing values (and the point estimates are larger at the lower percentiles of the within tract house price distribution than at the median) stand in contrast with GG's conclusions that cleanup leads to no or little effect in raising median tract-level housing values. The contrasting results in these two studies do not stem merely from our focus on the entire tract-level distribution of the housing values and GG's focus on the median. Instead, our study differs from GG's in at least four important ways, leading to our contrasting conclusions. First, we examine deletion, which signals the end of cleanup, separately from listing. Second, we rely on panel methods instead of instrumental variables to control for time-invariant unobservables in order to separately estimate the effects of deletion and listing.[21] In contrast, GG examine the effect of a variable that combines two distinct milestones in the Superfund remediation process – listing and deletion. This combination, which allows for their instrumental variables strategy, comes at the cost of biasing downward their estimate of cleanup; listing has ambiguous overall effects on housing prices, while deletion is

[21] We describe evidence from previous studies as an indirect strategy to address concerns from time-varying unobservables in section 6.7.

likely to raise housing prices.[22] We argue that our approach of measuring cleanup using the deletion milestone (relying on panel variation instead of the GG IV strategy) will incur less bias than GG's approach of measuring cleanup by conflating the deletion and listing milestones. Our tract-level analysis reveals that listing on the NPL per se does not lead to a statistically significant appreciation at the tract-level median housing values or any other parts of the within-tract housing price distribution. Instead, the appreciation across the within-tract housing price distribution occurs mainly after some cleanup measures are undertaken, both after the completion of physical construction and after the completion of all remedial actions.

A third difference between these studies is the unit of observation. Our observations are tracts that fall at least partially within 3 miles of the sites. In contrast, in their analysis of tract in buffers surrounding a site, GG aggregate the observations from the collection of tracts surrounding a site to one observation per site. This reduces the information available to estimate the impact of cleanup, potentially contributing to estimates that are imprecise and not statistically distinguishable from zero.

The fourth difference between these studies is the model specification. As described in section 4.1, we begin with the standard hedonic model that relates tract-level housing values with *contemporaneous* tract attributes, and we then difference across the 2000 and 1990 specifications in order to control for time-invariant unobservables at the tract level. In contrast, GG's regression model relates 2000 tract median housing values to 1980 tract characteristics and 1980 tract median values; they argue that 1980 tract attributes are correlated with the 2000 attributes, but are pre-determined with respect to Superfund site status. Deriving the GG regression

[22] GG use the 1982 HRS score to instrument for the variable indicating that a site has been listed on (or deleted from) the NPL by 2000; that one variable cannot separately instrument for the two milestones of listing and deletion.

specification from 1990 and 2000 hedonic price functions, however, we find that the resulting regression error will be correlated with the key variables appearing on the right-hand-side of the regression, biasing parameter estimates. Their regression discontinuity and IV approaches would therefore need to eliminate any bias stemming from this correlation. Detailed discussion about these model specifications and further comparisons of our study and GG's study can be found in the Online Appendix.

We are able to rule out the possibility that our detection of appreciation in our tract-analysis and the non-detection in the GG analysis stems from the differences in the composition of sites examined in these two studies. To recall, our study examines 321 out of the 322 sites whose HRS scores fall within in (16.5, 40.5) (we drop one site with missing geocoordinates). GG examine 227 out of the 322 sites, dropping 95 sites because of missing 1980 covariates. We re-estimate our panel model using the tracts that fall at least partially in the 3 mile buffer around these 227 sites. Results from this analysis (shown in the Online Appendix Table A4), which are similar to results from our main analysis (see Table 3), indicate that cleanup raised housing values by 24.3% at the 10th percentile, 21.4% at the median and 19.5% at the 90th percentile of tract-level housing values.

8. Cost-Benefit Analysis

Our finding that benefits are highly localized within the tract – relative to the case if benefits were to appear over a larger area – may make it more difficult for the aggregate benefits of a cleanup to exceed the costs. Next, we estimate benefits associated with cleanup for sites that have been deleted from the NPL as of 2000. Out of 57 sites that have been deleted by 2000, cost data, described below, are available for 55 sites. For 50 sites, the 3 mile buffers drawn around the sites do not overlap with buffers around other sites, allowing us to treat these as individual sites. Out of the remaining five sites, the 3 mile buffers around a group of three sites and around a group of two sites do overlap. We thus treat each of these groups as combined sites. For the combined sites, segment of tracts exposed to more than one site are counted only once in the calculation of benefits to ensure a conservative measure of benefits. For these 50 sites and 2 combined groups of sites, we then compare benefits and costs from the cleanup.

In calculating the benefits for each site (or combined group of sites), we consider tracts within the 3 mile buffer drawn around the site. The benefit per tract for houses at the θ^{th} percentile is obtained by multiplying the share of the tract exposed to the deleted sites, the deletion coefficient for θ^{th} percentile (from Table 3), one-tenth of the number of owner occupied housing units in the tract, and the housing value at the θ^{th} percentile. We then sum the benefits within each tract for houses from the 10^{th} to the 90^{th} percentiles. Finally, we sum the benefits for all tracts within the 3 mile buffer of a given site or combined site.

For comparison, we use actual cleanup costs by site published by GG (2005), based on their "best effort to calculate the actual amount spent on remedial action at each site by the EPA, state governments, and responsible parties."[23] GG note that their cost figures may not account for all state costs, and hence may be underestimates. (GG 2005). Still, they are the best cost estimates that we were able to obtain. Next, we compare the estimated benefits and actual cleanup costs by each site or combined site.

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[23] GG reports that these costs are "the sum of the EPA actual costs and the PRP estimated costs. Direct costs include remedial action and operations and management costs. Indirect costs are the EPA's estimate of the portion of the Superfund program costs (personnel wages, travel costs to inspect the sites, etc.) that are attributed to each site. These are EPA estimates for additional Potential Responsible Party costs" (GG 2005).

The estimated benefits and the actual cleanup costs across these sites show considerable heterogeneity. The mean and standard deviation of the estimated benefits are $71 million and $113 million respectively; while the mean and standard deviation for costs are $14 million and $28 million respectively. The histogram of the net estimated net benefits plotted in Figure 5. For 39 out of 52 sites or combined sites, we find that cleanup yields positive net benefits. These results suggest that for the majority of the deleted sites, the Superfund program does pass a simple cost-benefit test, where benefits are estimated from the appreciation in housing values. We note several outliers with very large net benefits, which may be implausibly large. These outliers may have arisen from our approach of estimating the average treatment effects of cleanup across sites, suggesting the need for future work to examine the heterogeneity of cleanup effects across sites. Finally, to provide a conservative measure of the total benefits summed across sites, we drop one site from the 52 sites or combined sites in Figure 5, which may be an outlier in light of its very large net benefits. The total benefits and the total costs from cleanup across the 51 sites or combined sites, which have been deleted from the NPL as of 2000, amount to $3,080 million and $728 million, respectively.

9. Conclusion

Our study shows that benefits from Superfund remediation activities can be highly localized. Our proposed refinement to the hedonic method – i.e., consideration of the entire distribution of the housing values within the tract – enables the possible detection of localized benefits at the sub-tract level using tract-level data. When we apply this refined method to the evaluation of the benefits from Superfund remediation, we find evidence of within-tract heterogeneity. Cleanup causes greater appreciation (in percentage terms) of housing prices at the lower deciles – i.e., by 24.4% at the 10th percentile, 20.8% at the median, and 18.7% at the 90th percentile of the within tract distribution. While the point estimates are not statistically different from one another in our particular example, a focus on the median would nevertheless understate the appreciation at the lower tails of within-tract the housing price distribution. One can imagine other situations in which the distribution of benefits is such that a focus on the mean or median could lead to a failure to detect any treatment impacts, should those impacts exist only in the tails of the distribution of housing values.

Restricted access block data, observed at a fine level of geographical resolution, confirms the appreciation in housing value in response to the cleanup; in particular, we find that owner-occupied housing values appreciate by 14.7% for blocks lying less than 3 miles from remediated sites. Further investigation reveals that within-tract heterogeneity is partly explained by the spatial distribution of Superfund sites. Geo-coded housing transactions data from ten states provide direct evidence of the proximity of these sites to the cheaper houses within each tract. Finally, our cost-benefit analysis indicates that cleanup under the Superfund program yields positive net benefits for 39 out of 52 sites that have been deleted from the NPL by 2000.

The localized nature of these benefits (e.g., at the sub-tract level) has important methodological implications for analysts who are forced to rely on coarse-resolution, publicly available (e.g. tract-level) data. In particular, the analyst must consider heterogeneity within those units, paying particular attention to the tails of the housing value distribution. Otherwise, the standard hedonic approach of focusing on *median* housing values may understate or fail to detect these benefits altogether.

Bibliography

Altonji, Joseph G., Todd E. Elder and Christopher R. Taber, "Selection on Observed and Unobserved Variables: Assessing the Effectiveness of Catholic Schools," *Journal of Political Economy* 113(1) (2005): 151-184.

Bui, Linda T. M and Christopher J. Mayer, "Regulation and Capitalization of Environmental Amenities: Evidence from the Toxic Release Inventory in Massachusetts," *The Review of Economics and Statistics*, 85(3) (2003), 693-708.

Cameron, Trudy Ann, and Ian T. McConnaha, "Evidence of Environmental Migration," *Land Economics,* 82 (2006), 273-290.

Campbell, John Y., Stefano Giglio, and Parag Pathak, "Forced Sales and House Prices." *American Economic Review,* 101(5) (2011), 2108–31.

Chay, KennethY., and Michael Greenstone, "Does Air Quality Matter? Evidence from the Housing Market," *Journal of Political Economy,* 113 (2005), 376-424.

Currie, Janet, Michael Greenstone and Enrico Moretti, Superfund Cleanups and Infant Health *American Economic Review*, 101(3) (2011), 435-441.

Davis, Lucas W., "The Effect of Health Risk on Housing Values: Evidence from a Cancer Cluster," *American Economic Review,* 94 (2004), 1693–1704.

Davis, Lucas W., "The Effect of Power Plants on Local Housing Values and Rents," *Review of Economics and Statistics,* 93(4) (2011), 1391–1402.

Environmental Protection Agency, "Challenges in Applying Property Value Studies to Assess the Benefits of the Superfund Program," Office of Superfund Remediation and Technology Innovation (2009).

Fischhoff, Baruch, "Defining Stigma," in *Risk, Media, and Stigma,* James Flynn, Paul Slovic and Howard Kunreuther, eds. (Sterling, VA: Earthscan, 2001).

Gamper-Rabindran, Shanti and Christopher Timmins, "Hazardous Waste Cleanup, Neighborhood Gentrification, and Environmental Justice: Evidence from Restricted Access Census Block Data," *American Economic Review Papers and Proceedings*, May 2011.

Gamper-Rabindran, Shanti, Ralph Mastromonaco, and Christopher Timmins, "Valuing the Benefits of Superfund Site Remediation: Three Approaches to Measuring Localized Externalities," National Bureau of Economic Research Working Paper 16655, 2011.

Gayer, Ted, James T. Hamilton, and W. Kip Viscusi, "Private Values of Risk Tradeoffs at Superfund Sites: Housing Market Evidence on Learning about Risk," *Review of Economics and Statistics,* 82 (2000), 439-451.

Grainger, Corbett A., "The Distributional Effects of Pollution Regulations: Do Renters Fully Pay for Cleaner Air?" *Journal of Public Economics,* 96 (9-10) (2012), 840–852 .

Greenberg, Michael, and John Hughes, “The Impact of Hazardous Waste Superfund Sites on the Value of Houses Sold in New Jersey,” *The Annals of Regional Science,* 26 (1992), 147-153.

Greenstone, Michael, and Justin Gallagher, “Does Hazardous Waste Matter? Evidence from the Housing Market and the Superfund Program,” NBER Working Paper No. 11790 (2005).

Greenstone, Michael, and Justin Gallagher, “Does Hazardous Waste Matter? Evidence from the Housing Market and the Superfund Program,” *The Quarterly Journal of Economics,* 123 (2008), 951-1003.

Gupta, Shreekant, George Van Houtven, and Maureen Cropper, “Paying for Permanence: An Economic analysis of EPA's Cleanup Decisions at Superfund Sites,” *The Rand Journal of Economics,* 27 (1996), 563-582.

Hamilton, James T. and Kip W. Viscusi (1999). “Are Risk Regulators Rational? Evidence from Hazardous Waste Cleanup Decisions.” *American Economic Review*. 89(4), 1010-1027.

Hanna, Bríd Gleeson, “House Values, Incomes, and Industrial Pollution,” *Journal of Environmental Economics and Management*, 54 (2007), 100-112.

Jenkins, Robin, Elizabeth Kopits, and David Simpson, “Measuring the Social Benefits of EPA Land Cleanup and Reuse Programs,” National Center for Environmental Economics, Working Paper No. 06-03, 2006.

Kiel, Katherine A., and Michael Williams, “The Impact of Superfund Sites on Local Property Values: Are all Sites the Same?” *Journal of Urban Economics*, 61 (2007), 170-192.

Kiel, Katherine A., and Jeffrey E. Zabel, “The Economic Benefits of Cleaning Superfund Sites,” *Journal of Real Estate Finance and Economics,* 22 (2001), 163-184.

Kennedy, Peter E., “Estimation with Correctly Interpreted Dummy Variables in Semilogarithmic Equations,” *American Economic Review*, 71 (1981), 801.

Kuminoff, Nicolai V., and Jaren C. Pope, “Hedonic Equilibria, Land Value Capitalization, and the Willingness to Pay for Public Goods,” Arizona State University, Working Paper, 2010.

Kuminoff, Nicolai V., V. Kerry Smith and Christopher Timmins (2010). “The New Economics of Equilibrium Sorting and Its Transformational Role for Policy Evaluation,” NBER Working Paper #16349, 2010.

Messer, Kent D., William D. Schulze, Katherine F. Hackett, Turdy A. Cameron, and Gary H. McClelland, “Can Stigma Explain Large Property Value Losses? The Psychology and Economics of Superfund,” *Environmental and Resource Economics,* 33 (2006), 299-324.

Noonan, Douglas S., Douglas J. Krupka, and Brett M. Baden, “Neighborhood Dynamics and Price Effects of Superfund Site Clean-up,” *Journal of Regional Science,* 47 (2007), 665-692.

Sanders, N., “Toxic Assets: How the Housing Market Responds to Environmental Information Shocks.” Stanford Institute for Theoretical Economics Summer Workshop (2011), Stanford University

Schultze, William, Gary McClelland, Ed Balistreri, Rebecca Boyce, Michael Doane, Brian Hurd, and Ronald Simenauew, “An Evaluation of Public Preferences for Superfund Site Cleanup. Volume 1: Preliminary Assessment*”* Environmental Protection Agency: Office of Policy, Planning, and Evaluation, Publication EE-0255A-01, (1995).

Sigman, Hilary (ed.), *Economics of Hazardous Waste and Contaminated Land,* (Cheltenham, UK: Edward Elgar, 2008).

Sigman, Hilary, “The Pace of Progress at Superfund Sites: Policy Goals and Interest Group Influence,” *Journal of Law and Economics*, 44 (2001), 315–344.

Sigman, Hilary and Sarah Stafford, “Management of Hazardous Waste and Contaminated Land,” *Annual Review of Resource Economics*, 3(1) (2011), 255-275.

Smith, Kerry V., “Methods for Estimating the Social Benefits of EPA Land Cleanup and Reuse Programs,” Summary Report of the Workshop on Methods for Estimating the Social Benefits of EPA Land Clean Up and Reuse Programs, Environmental Protection Agency, Publication EE-0506-01 (2006).

Table 1: Summary statistics for tracts within 3 mile buffers of 321 sites (No. obs.=3,584)				
	1990	1990	2000	2000
	Mean	Std. Dev.	Mean	Std. Dev.
Housing value distribution				
10th percentile	$46,918	$37,940	$48,222	$38,483
20th percentile	$56,291	$43,197	$57,212	$45,645
30th percentile	$63,344	$47,136	$64,178	$50,251
40th percentile	$69,790	$50,731	$70,664	$54,495
50th percentile	$76,225	$54,448	$77,358	$59,180
60th percentile	$83,310	$58,729	$84,651	$64,370
70th percentile	$91,520	$63,249	$93,386	$70,419
80th percentile	$102,410	$69,174	$105,424	$78,586
90th percentile	$120,717	$78,996	$127,079	$94,576
Share of tract exposed to a Superfund milestone				
Proposal	0.008	0.082	0.006	0.068
Listing	0.356	0.418	0.184	0.354
Construction complete	0.024	0.146	0.130	0.300
Deletion	0.021	0.129	0.107	0.283
Other variables				
% units occupied	92.2	7.0	92.8	6.7
% owner occupied	64.8	21.9	65.2	22.7
Housing unit density	0.001	0.002	0.001	0.002
Population density	0.002	0.004	0.002	0.004
% Black	12.3	22.7	14.3	23.1
% Hispanic	6.8	13.3	10.0	16.6
% under 18 years old	25.0	6.2	25.2	6.3
% high school dropout	25.5	13.6	20.4	12.8
% college educated	19.3	14.4	23.1	16.7
% below poverty line	12.6	12.0	12.6	10.9
% public assistance	8.0	7.9	8.7	7.6
% female head of household	23.9	16.0	25.9	15.7
Mean household income	$38,733	$16,996	$55,744	$24,863
% attached homes	7.7	16.7	8.3	16.7
% mobile homes	5.7	11.1	5.4	10.8
% 0-2 bedrooms	28.8	16.7	28.7	16.8
% 3-4 bedrooms	66.4	16.2	66.5	16.3
% units built within 5 years	7.9	10.4	6.8	9.3
% units built within 10 years	13.8	16.2	12.3	14.3
% living in the same house in the last 5 years	55.7	12.7	56.1	12.3

Notes: Housing unit density and population density are in counts per m^2.

Table 2. Interpretation of Coefficients	
Change in Superfund milestone	Estimated
Not Proposed to Proposed	β_1
Not Proposed to Listed	β_2
Not Proposed to Construction Completed	β_3
Not Proposed to Deleted	β_4
Proposed to Listed	$\beta_2 - \beta_1$
Proposed to Construction Completed	$\beta_3 - \beta_1$
Proposed to Deleted	$\beta_4 - \beta_1$
Listed to Construction Completed	$\beta_3 - \beta_2$
Listed to Deleted	$\beta_4 - \beta_2$
No change in status	Omitted case

Notes: The coefficients refer to Equation 2 in Section 4.

Table 3: Panel analysis of tracts within 3 mile buffers of 321 sites whose 1982 HRS scores are in (16.5, 40.5)

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
Percentile	10	20	30	40	50	60	70	80	90
Panel A: Dependent variable: Δ Log price of owner-occupied housing units at the θth percentile									
ΔProposal	-0.114	-0.116	-0.111	-0.102	-0.094	-0.083	-0.066	-0.055	-0.029
	(0.268)	(0.253)	(0.242)	(0.235)	(0.235)	(0.244)	(0.251)	(0.242)	(0.223)
ΔListing	0.087	0.069	0.060	0.060	0.059	0.056	0.057	0.045	0.029
	(0.064)	(0.062)	(0.062)	(0.061)	(0.061)	(0.062)	(0.062)	(0.059)	(0.055)
ΔConstruction	0.131**	0.125*	0.119*	0.118*	0.115*	0.113*	0.115*	0.100	0.071
complete	(0.064)	(0.065)	(0.065)	(0.066)	(0.065)	(0.066)	(0.065)	(0.061)	(0.058)
ΔDeletion	0.244***	0.214**	0.211**	0.210**	0.208**	0.205**	0.198**	0.187**	0.187**
	(0.086)	(0.085)	(0.084)	(0.083)	(0.083)	(0.084)	(0.085)	(0.081)	(0.077)
R-sqr	0.239	0.279	0.277	0.262	0.259	0.277	0.286	0.287	0.268
Panel B: Dependent variable: ΔPrice of owner-occupied housing units at the θth percentile									
ΔProposal	-2,162	-1,928	-2,166	-3,008	-3,248	-2,992	-2,558	-2,043	-669
	(10,740)	(11,772)	(12,167)	(11,852)	(13,320)	(15,087)	(17,361)	(18,086)	(17,298)
ΔListing	3,415	2,824	2,314	1,855	2,073	1,736	2,213	1,478	-2,024
	(2,563)	(3,067)	(3,464)	(3,785)	(4,147)	(4,515)	(4,862)	(4,977)	(5,341)
ΔConstruction	4,972*	4,693	4,639	4,291	4,517	4,324	5,033	4,345	-296
complete	(2,656)	(3,394)	(3,919)	(4,418)	(4,835)	(5,213)	(5,540)	(5,755)	(6,222)
ΔDeletion	9,305***	10,327**	11,588**	12,021**	12,893**	13,320**	12,799*	13,371*	17,772**
	(3,548)	(4,259)	(4,714)	(5,044)	(5,556)	(6,121)	(7,105)	(7,289)	(8,140)
R-sqr	0.130	0.170	0.180	0.170	0.171	0.189	0.210	0.226	0.235

Notes: Panel A Columns 1-9 represent 9 different regressions of the change in the log of housing prices at the θth percentile on the change in exposure to Superfund milestones. Panel B Columns 1-9 represent 9 other regressions with the change in housing prices as the dependent variable. Exposure to deletion is measured as the ratio of the area of the tract that falls in the 3 mile buffer of deleted sites to the total area of the tract. Segments of a tract exposed to more than one deleted site is counted only once in calculating the area of the tract exposed to deletion. The change in exposure to deletion is measured between 1990 and 2000. The change in exposure to other Superfund milestones are defined analogously. The control variables (in changes between 1990 and 2000) are listed in Table 1. The regression is weighted using the number of owner-occupied housing units. No obs.=3,584. Standard errors are clustered on 2,026 groups of contiguous adjacent tracts (Section 4.1). Estimates are statistically significant at ***1%, **5% and *10%.

Table 4: Panel analysis of tracts within 3 mile buffers of 321 sites whose 1982 HRS scores are in (16.5, 40.5)

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]
Dependent variable: Log price of owner-occupied housing units at the θth percentile.										
	Not weighted					Weighted with the no. of owner-occupied housing units				
	Standard errors clustered on groups of tracts defined with 1 mile buffers (2,026 groups)					Standard errors clustered on groups of tracts defined with 2 mile buffers (1,109 groups)				
Percentiles	10	30	50	70	90	10	30	50	70	90
Δ Proposal	-0.122	-0.128	-0.093	-0.069	-0.032	-0.114	-0.111	-0.094	-0.066	-0.029
	(0.289)	(0.257)	(0.244)	(0.256)	(0.234)	(0.321)	(0.297)	(0.286)	(0.306)	(0.274)
Δ Listing	0.140*	0.087	0.099	0.087	0.064	0.087	0.060	0.059	0.057	0.029
	(0.083)	(0.078)	(0.077)	(0.077)	(0.071)	(0.090)	(0.091)	(0.085)	(0.087)	(0.081)
Δ Construction complete	0.180**	0.152*	0.173**	0.164**	0.119	0.131	0.119	0.115	0.115	0.071
	(0.083)	(0.081)	(0.080)	(0.080)	(0.074)	(0.099)	(0.102)	(0.095)	(0.095)	(0.087)
Δ Deletion	0.290***	0.230**	0.247**	0.225**	0.194**	0.244**	0.211*	0.208*	0.198*	0.187*
	(0.105)	(0.100)	(0.097)	(0.100)	(0.095)	(0.115)	(0.114)	(0.110)	(0.114)	(0.106)
R-sqr	0.144	0.207	0.223	0.235	0.210	0.239	0.277	0.259	0.286	0.268

Notes: Each column represents a separate regression. These regressions are analogous to the main regressions in Table 3. Regression models in Columns 1-5 are not weighted, while those in Columns 6-10 are weighted using the number of owner occupied housing units. Standard errors are clustered on groups of contiguous adjacent tracts (see section 4.1). Tracts are defined as neighbors if the centroid of a tract falls within a given distance from the centroid of the other tract. The distance is 1 mile in columns 1-5, while the distance is 2 miles in columns 6-10. No. obs.=3,584. Estimates are statistically significant at ***1%, **5% and *10%.

Table 5: Panel analysis of tracts within 2 mile buffers of 321 sites whose 1982 HRS scores are in (16.5, 40.5)

	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]
	10	20	30	40	50	60	70	80	90
Δ Proposal	-0.206	-0.183	-0.175	-0.161	-0.165	-0.172	-0.159	-0.137	-0.113
	(0.233)	(0.218)	(0.217)	(0.217)	(0.217)	(0.221)	(0.221)	(0.214)	(0.210)
Δ Listing	0.115	0.096	0.097	0.098	0.092	0.080	0.081	0.075	0.048
	(0.079)	(0.074)	(0.075)	(0.076)	(0.075)	(0.076)	(0.074)	(0.072)	(0.076)
Δ Construction	0.184**	0.176**	0.176**	0.177**	0.168*	0.152*	0.151*	0.135*	0.086
complete	(0.085)	(0.084)	(0.086)	(0.087)	(0.086)	(0.087)	(0.084)	(0.080)	(0.083)
Δ Deletion	0.311***	0.290***	0.289***	0.288***	0.278***	0.260***	0.259***	0.250***	0.217**
	(0.098)	(0.096)	(0.097)	(0.098)	(0.097)	(0.098)	(0.095)	(0.093)	(0.096)
R-sqr	0.253	0.303	0.301	0.309	0.305	0.299	0.295	0.298	0.266

Notes: The regressions in this table are analogous to the main regressions in Table 3. However, regressions in this table examine the tracts that overlap with 2 mile buffers around sites whose HRS scores are in (16.5, 40.5). Each column represents a separate regression of the change in the log of housing price at the θth percentiles on the change in exposure to Superfund milestones. The exposure to deletion is measured using the ratio of the area of the tract that falls in the 2 mile buffer of deleted sites to the total area of the tract. The change in exposure to deletion is measured between 1990 and 2000. The change in exposure to other Superfund milestones area measured analogously. The regresions are weighted using the number of owner-occupied housing units. No. obs.=2,246. Standard errors are clustered on 1,383 groups of contiguous adjacent tracts (see Section 4.1). Estimates are statistically significant at ***1%, **5% and *10%.

Table 6: Panel analysis of census block median housing values on counts of Superfund sites at various milestones.

Dependent variable: Change in the log census block median housing price		
Variables of interest:		
Change in the counts of sites that are Proposed	-0.188	***
	(0.021)	
Change in the counts of sites that are Listed	0.118	***
	(0.013)	
Change in the counts of sites that are Construction Completed	0.131	***
	(0.014)	
Change in the counts of sites that are Deletion	0.147	***
	(0.015)	
Number of observations	59,055	
Test statistics that Superfund milestones have equal coefficients		
Coefficients for Proposal and Listing	0.000	
Coefficients for Listing and Construction Complete	0.009	
Coefficients for Construction Complete and	0.027	

Notes: The observations are blocks that are contained within the tracts that lie within 3 mile buffers around the sites whose 1982 HRS lie within (16.5, 40.5). In other words, the panel analysis examines blocks within tracts that were examined in the tract panel analysis in Table 3. Counts of sites are measured 2 miles from the block centroid. The panel analysis measures changes between 1990 and 2000. Control variables (in changes) are analogous to those listed in Table 1. Robust standard errors are in parenthesis. Statistically significant at ***1%, **5% and *10%.

Table 7: Housing Transactions and Site Counts by State and Site Status

State	All		Listed		Deleted		Pre-Proposal	
	Houses	Sites	Houses	Sites	Houses	Sites	Houses	Sites
AZ	27,892	5	27,892	5				
CA	77,376	29	55,263	16			22,113	13
CT	29,504	12	16,090	8			13,414	4
MA	68,231	15	46,865	10			21,366	5
NJ	65,459	62	40,647	37	781	1	24,031	24
NC	1,634	2					1,634	2
OR	13,723	6	5,108	1			8,615	5
RI	36,346	13	18,162	8			18,184	5
TN	21,739	7	4,179	1			17,560	6
WA	78,067	13	44,794	8	1,296	1	31,977	4
Total	419,971	164	259,000	94	2,077	2	158,894	68

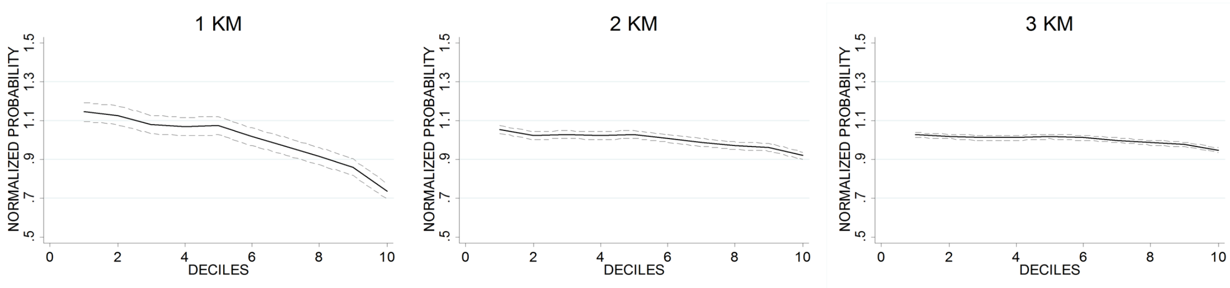

FIG. 1: HOUSING TRANSACTION EXPOSURE BY DECILE (POOLED SITES)

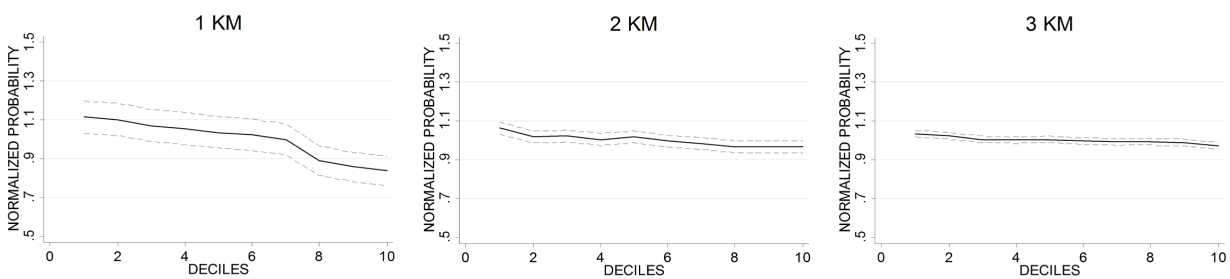

FIG. 2: HOUSING TRANSACTION EXPOSURE BY DECILE (PRE-PROPOSED SITES)

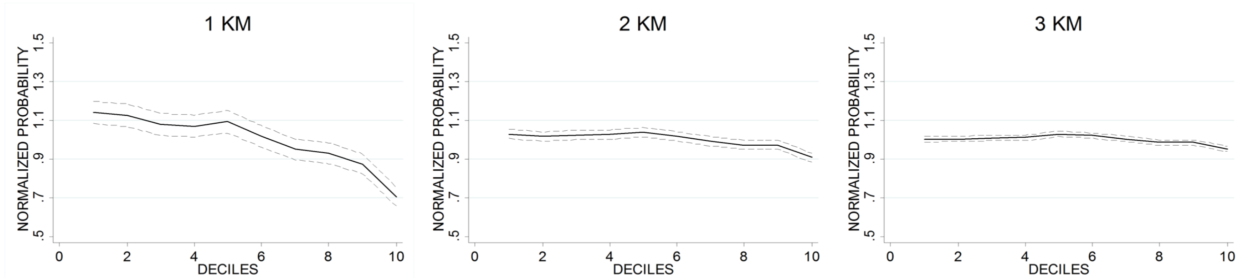

FIG. 3: HOUSING TRANSACTION EXPOSURE MEASURE BY DECILE (LISTED SITES)

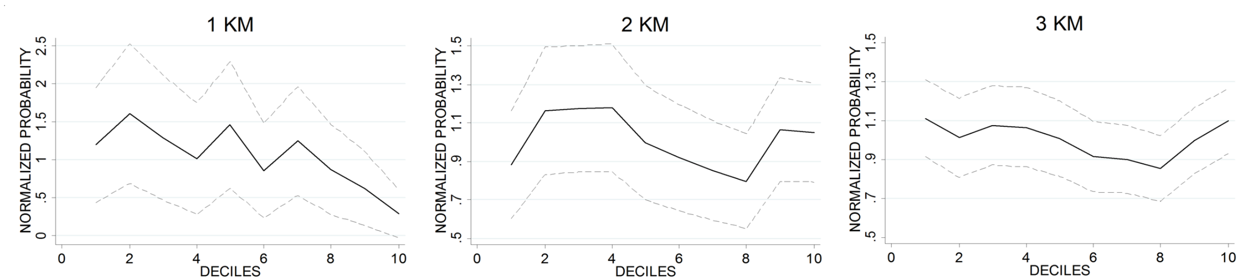

FIG. 4: HOUSING TRANSACTION EXPOSURE MEASURE BY DECILE (DELETED SITES)

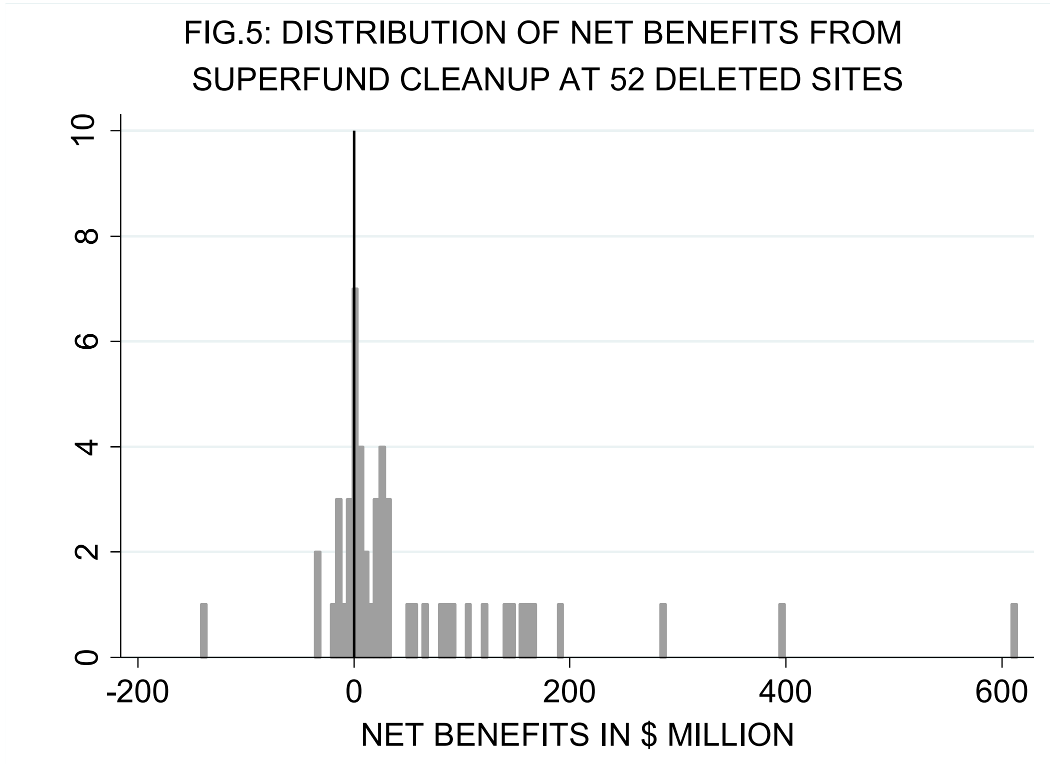
FIG.5: DISTRIBUTION OF NET BENEFITS FROM
SUPERFUND CLEANUP AT 52 DELETED SITES
0
2
4
6
8
10
-200
0
200
400
600
NET BENEFITS IN $ MILLION