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Does Hazardous Waste Matter? Evidence from the Housing Market and the Superfund Program*

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DOES HAZARDOUS WASTE MATTER? EVIDENCE FROM THE HOUSING MARKET AND THE SUPERFUND PROGRAM*

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This paper uses the housing market to develop estimates of the local welfare impacts of Superfund-sponsored cleanups of hazardous waste sites. We show that if consumers value the cleanups, then the hedonic model predicts that they will lead to increases in local housing prices and new home construction, as well as the migration of individuals that place a high value on environmental quality to the areas near the improved sites. We compare housing market outcomes in the areas surrounding the first 400 hazardous waste sites chosen for Superfund cleanups to the areas surrounding the 290 sites that narrowly missed qualifying for these cleanups. We find that Superfund cleanups are associated with economically small and statistically insignificant changes in residential property values, property rental rates, housing supply, total population, and types of individuals living near the sites. These findings are robust to a series of specification checks, including the application of a regression discontinuity design based on knowledge of the selection rule. Overall, the preferred estimates suggest that the local benefits of Superfund cleanups are small and appear to be substantially lower than the $43 million mean cost of Superfund cleanups.

I. INTRODUCTION

The estimation of individuals' valuations of environmental amenities with revealed-preference methods has been an active area of research for more than three decades. There are now theoretical models outlining revealed-preference methods to recover economically well-defined measures of willingness in a variety of settings, including housing markets, recreational choices, health outcomes, and the consumption of goods designed to protect individuals against adverse environmentally induced outcomes

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(Champ, Boyle, and Brown [2003] and Freeman [2003] contain reviews). The application of these approaches, however, is often accompanied by seemingly valid concerns about misspecification that undermine the credibility of any findings. Consequently, many are skeptical that markets can be used to determine individuals' valuations of environmental amenities.[1]

Hazardous waste sites are an example of an environmental disamenity that provokes great public concern. The 1980 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), which became known as Superfund, gave the Environmental Protection Agency (EPA) the right to place sites that pose an imminent and substantial danger to public welfare and the environment on the National Priorities List (NPL) and to initiate remedial cleanups at those sites. Through 2005, approximately $35 billion (2005 dollars) in federal monies and an unknown amount of private funding had been spent on Superfund cleanups, and yet remediations are incomplete at roughly half of the nearly 1600 sites.[2] The combination of these high costs and the absence of convincing evidence of its benefits makes Superfund a controversial program (Environmental Protection Agency 2005).

This paper uses the housing market to estimate the welfare consequences of Superfund-sponsored cleanups of hazardous waste sites. The empirical challenge is that the evolution of housing market outcomes (e.g., prices) proximate to the Superfund sites in the absence of the cleanups is unknown. The development of a valid counterfactual is likely to be especially challenging, because the sites assigned to the NPL are the most polluted ones in the United States. For example, what would have happened to housing prices in Love Canal, New York, in the absence of the famous Superfund cleanup there?

As a solution, we implement a quasi-experiment based on knowledge of the selection rule that the EPA used to develop the first NPL in 1983. The EPA was allocated only enough money to conduct 400 cleanups. After cutting the list of candidate sites from 15,000 to 690, the EPA invented and implemented the Hazardous

1. Further, the increasing reliance on stated-preference techniques to value environmental amenities is surely related to dissatisfaction with the performance of revealed-preference techniques. See Diamond and Hausman (1994) and Hanemann (1994) for discussions of stated preference techniques.

2. Throughout the paper, monetary figures are reported in year-2000 dollars, unless otherwise noted.

Ranking System (HRS) that assigned each site a score from 0 to 100 based on the risk it posed, with 100 being the most dangerous. The 400 sites with the highest HRS scores (i.e., exceeding 28.5) were placed on the initial NPL in 1983, making them eligible for Superfund remedial cleanups. We compare the evolution of housing market outcomes between 1980 and 2000 in areas near sites that had initial HRS scores above and below the 28.5 threshold. We also implement a regression discontinuity (RD) design (Cook and Campbell 1979) to focus the comparisons among sites with scores near the threshold.

To structure the analysis, we model the consequences of a quasi-experiment that leads to an exogenous change in a local amenity in the context of the hedonic method (Freeman 1974; Rosen 1974). We show that if consumers value the cleanups, then there are two empirical predictions. First, the improvement at the site should lead to increases in the demand and supply of local housing and, in turn, increases in the prices and quantities of houses. Second, the improvement should lead to sorting such that an increased proportion of people living near the improved sites value environmental quality highly. The implication is that an exclusive focus on housing prices as in previous quasi-experimental hedonic studies (Chay and Greenstone 2005; Linden and Rockoff 2006) may obscure part of the welfare gain.

The results suggest that individuals place a small value on a hazardous waste site's inclusion on the NPL and subsequent cleanup. Specifically, we find that a site's placement on the NPL is associated with economically small and statistically insignificant changes in residential property values, property rental rates, housing supply, total population, and types of individuals living near the site. These findings are robust to a wide variety of specification checks, and they hold whether they are measured seven (in 1990) or seventeen (in 2000) years after placement on the NPL. Overall, these findings suggest that the mean local benefits of a Superfund cleanup as measured through the housing market are substantially lower than our estimated average cost of $43 million per Superfund cleanup.

The conventional hedonic approach compares areas surrounding NPL sites with the remainder of the United States. In contrast to the HRS research design, the conventional approach produces estimates that suggest that gains in property values exceed the mean costs of cleanup. However, these regressions also produce a number of puzzling results that undermine confidence in the approach's validity. Further, there is evidence that the conventional approach is likely to confound the effect of the presence of an NPL site with other determinants of housing market outcomes. Notably, the HRS research design appears to greatly reduce the confounding.

The study is conducted with the most comprehensive data file ever compiled by the EPA or other researchers on the Superfund program and its effects. The resulting database has information on all 1,400 Superfund hazardous waste sites as of 2000, the sites that narrowly missed placement on the initial NPL, and Census-tract-level housing market outcomes for 1980 (before the release of the first NPL), 1990, and 2000. Consequently, this study is a substantial departure from the previous Superfund/hazardous waste site hedonic literature, which is entirely composed of examinations of one or a handful of sites and collectively covers just thirty different sites (Schmalensee et al. 1975; Michaels and Smith 1990; Kohlhase 1991; Kiel 1995; Gayer, Hamilton, and Viscusi 2000, 2002; Kiel and Zabel 2001; McCluskey and Rausser 2003; Farrell 2004; Ihlanfeldt and Taylor 2004; Messer et al. 2004).[3]

The paper proceeds as follows. Section II provides background on the Superfund program and how the HRS research design may allow for credible estimation of the effects of Superfund cleanups on housing market outcomes. Section III discusses how to use hedonic theory to provide an economic interpretation for the results from the HRS research design. Section IV details the data sources and provides some summary statistics. Sections V and VI report on the econometric methods and empirical findings, respectively. Section VII interprets the results, while VIII concludes.

II. The Superfund Program and a New Research Design

II.A. History and Broad Program Goals

Before the regulation of the disposal of hazardous wastes by the Toxic Substances Control and Resource Conservation and

3. Using EPA estimates of the probability of cancer cases and the costs of Superfund cleanups, Viscusi and Hamilton (1999) find that at the median site expenditure the average cost per cancer case averted by the cleanup exceeds $6 billion. This health-effects approach requires knowledge of the toxics present and the pathways they travel, the health risk associated with a toxic by pathway pair, the size of the affected population, the pathway-specific exposure, and the willingness to pay to avoid mortality/morbidity. Because of the state of scientific uncertainty associated with each step, we think this approach is unlikely to produce credible benefit estimates.

Recovery Acts of 1976, industrial firms frequently disposed of wastes by burying them in the ground. Love Canal, New York, offers perhaps the most infamous example of these disposal practices. Throughout the 1940s and 1950s, this area served as a landfill for industrial waste, receiving more than 21,000 tons of chemical wastes. After New York state investigators found high concentrations of dangerous chemicals in the air and soil at Love Canal, concerns about the safety of this area prompted President Carter to declare a state of emergency in 1978, an action that led to the relocation of the area's 900 residents. The Love Canal incident helped to galvanize support for addressing the legacy of industrial waste, a movement that culminated in the creation of the Superfund program in 1980.

The centerpiece of the Superfund program, and this paper's focus, is the long-run remediation of hazardous waste sites.[4] These multi-year remediation efforts aim to permanently reduce the serious, but not imminently life-threatening, dangers caused by hazardous substances. By the end of 2005, the EPA had placed 1,552 sites on the NPL, thereby choosing them for long-run cleanups. The next subsection describes the selection process, which forms the basis of our research design.

II.B. Site Assessment and Superfund Cleanup Processes

As of 1996, environmental activities, neighborhood groups, and other interested parties had referred more than 40,000 hazardous waste sites to the EPA for possible inclusion on the NPL. Since there are limited resources available for these cleanups, the EPA follows a multistep process to identify the most dangerous sites.

The final step of the assessment process involves the application of the HRS, a rating system reserved for the most dangerous sites. The EPA developed the HRS in 1982 as a standardized approach to identify the sites that pose the greatest threat to humans and the environment. The original HRS evaluated the risk for exposure to chemical pollutants along three migration pathways: groundwater, surface water, and air. The major determinants of risk along each pathway for a site are the toxicity and

4. The Superfund program also funds immediate removals, which are short-term responses to environmental emergencies aimed at diminishing an immediate threat. These actions are not intended to remediate the underlying environmental problem and are not exclusive to hazardous waste sites on the NPL.

concentration of chemicals present, the likelihood of exposure and proximity to humans, and the size of the potentially affected population. EPA officials also consider nonhuman impacts, but they play a relatively minor role in determining the HRS score.

The HRS produces a score that ranges from 0 to 100, with 100 being the highest level of risk. From 1982 to 1995, the EPA assigned all hazardous waste sites with a HRS score of 28.5 or greater to the NPL. Only these sites are eligible for Superfund remedial cleanup. The Data Appendix provides further details on the determination of HRS test scores and their role in assignment to the NPL.

Once a site is moved onto the NPL, it generally takes many years until the cleanup is complete. The first step is a further study of the extent of the environmental problem and how best to remedy it, an assessment that is summarized in the Record of Decision (ROD), which also outlines recommended cleanup actions for the site. After workers finish physical construction of all cleanup remedies, removing immediate threats to health, and putting long-run threats "under control," the EPA gives a site a "construction complete" designation. The final step is the agency's deletion of the site from the NPL.

II.C. 1982 HRS Scores as the Basis of a New Research Design

This paper's goal is to obtain reliable estimates of the effect of Superfund-sponsored cleanups of hazardous waste sites on housing market outcomes in areas surrounding the sites. The empirical challenge is that NPL sites are the most polluted in the United States, and so it is likely that there are unobserved factors that covary with both proximity to hazardous waste sites and housing prices. Although this possibility cannot be tested directly, it is notable that proximity to a hazardous waste site is associated with lower population densities, lower household incomes, higher percentages of high school dropouts, and a higher fraction of mobile homes among the housing stock.

Consequently, cross-sectional estimates of the association between housing prices and proximity to a hazardous waste site may be severely biased due to omitted variables.[5] In fact, the possibility

5. Cross-sectional models for housing prices have exhibited signs of misspecification in a number of other settings, including the relationships between land prices and school quality, air pollution, and climate variables (Black 1999; Chay and Greenstone 2005; Deschenes and Greenstone 2007). Incorrect choice of functional form is an alternative source of misspecification (Halvorsen and Pollakowski

of confounding due to unobserved variables has been recognized as a threat to the use of the hedonic method to develop reliable estimates of individuals' willingness to pay (WTP) for environmental amenities since its invention (Small 1975). This paper's challenge is to develop a valid counterfactual for the housing market outcomes near Superfund sites in the absence of their placement on the NPL and cleanup.

A feature of the initial NPL assignment process that has not been noted previously by researchers may provide a credible solution to the likely omitted-variables problem. In the first year after the legislation's passage, groups and individuals referred 14,697 sites to the EPA, which then investigated them as potential candidates for remedial action. Through an initial assessment process, the EPA winnowed this list to the 690 most dangerous sites. Although the Superfund legislation directed the EPA to develop an NPL of "at least" 400 sites (Section 105(8)(B) of CERCLA), budgetary considerations caused the EPA to set a goal of placing exactly 400 sites on the NPL.

The EPA developed the HRS to provide a scientific basis for determining the 400 of the 690 sites that posed the greatest risk. Pressured to initiate the cleanups quickly, the EPA developed the HRS in about a year, applied the test to the 690 worst sites, and ranked their scores from highest to lowest. A score of 28.5 divided numbers 400 and 401, and so the initial NPL published in September 1983 was limited to sites with HRS scores exceeding 28.5. See the Data Appendix for further details.

The central role of the HRS score provides a compelling basis for a research design that compares housing market outcomes near sites with initial scores above and below the 28.5 cutoff for at least three reasons. First, it is unlikely that sites' HRS scores were manipulated to affect their placement on the NPL, because the 28.5 threshold was established *after* the testing of the 690 sites was completed. The HRS scores therefore reflected the EPA's assessment of the risks posed by each site, *rather* than the expected costs or benefits of cleanup.

Second, the HRS scores are noisy measures of risk, and so it is possible that true risks are similar above and below the threshold. This noisiness results from the scientific uncertainty about the

1981; Cropper, Deck, and McConnell 1988). Other potential sources of biases of published hedonic estimates include measurement error and publication bias (Black and Kneisner 2003; Ashenfelter and Greenstone 2004).

health consequences of exposure to the tens of thousands of chemicals present at these sites.[6] Further, there was no evidence that sites with HRS scores below 28.5 posed little risk to health. The *Federal Register* specifically reported that the "EPA has not made a determination that sites scoring less than 28.50 do not present a significant risk to human health, welfare, or the environment" and that a more informative test would require "greater time and funds" (*Federal Register*, 1984).[7]

Third, the selection rule that determined placement on the NPL is a highly nonlinear function of the HRS score. This allows for a quasi-experimental RD design that compares outcomes at sites "near" the 28.5 cutoff. If the unobservables are similar or change smoothly around the regulatory threshold, then the RD approach will produce causal estimates of the impact of Superfund cleanups on housing market outcomes.[8]

An additional feature of the analysis is that an initial score above 28.5 is highly correlated with eventual NPL status but is not a perfect predictor of it. This is because some sites were rescored, with the later scores determining whether they ended up on the NPL.[9] The subsequent analysis uses an indicator variable for whether a site's initial (i.e., 1982) HRS score was above 28.5 as an instrumental variable for whether a site was on the NPL in order to purge the potentially endogenous variation in NPL status.

6. A recent history of Superfund makes this point. "At the inception of EPA's Superfund program, there was much to be learned about industrial wastes and their potential for causing public health problems. Before this problem could be addressed on the program level, the types of wastes most often found at sites needed to be determined, and their health effects studied. Identifying and quantifying risks to health and the environment for the extremely broad range of conditions, chemicals, and threats at uncontrolled hazardous wastes sites posed formidable problems. Many of these problems stemmed from the lack of information concerning the toxicities of the over 65,000 different industrial chemicals listed as having been in commercial production since 1945" (Environmental Protection Agency 2000, p. 3–2).

7. One way to measure the crude nature of the initial HRS test is by the detail of the guidelines used for determining the HRS score. The guidelines used to develop the initial HRS sites were collected in a 30-page manual. Today, the analogous manual is more than 500 pages.

8. The research design of comparing sites with HRS scores "near" the 28.5 cutoff is unlikely to be valid for sites that received an initial HRS score after 1982. This is because once the 28.5 cutoff was set, the HRS testers were encouraged to minimize testing costs and simply determine whether a site exceeded the threshold. Consequently, testers generally stop scoring pathways once enough pathways are scored to produce a score above the threshold.

9. As an example, 144 sites with initial scores above 28.5 were rescored, which led to 7 sites receiving revised scores below the cutoff. Further, complaints by citizens and others led to rescoring at a number of sites below the cutoff. Although there has been substantial research on the question of which sites on the NPL are cleaned up first (see, e.g., Sigman [2001]), we are unaware of any research on the determinants of a site being rescored.

III. Using Hedonics to Value Changes in Local Environmental Quality due to Superfund Cleanups

An explicit market for a clean local environment does not exist. The hedonic price method is commonly used to infer the economic value of nonmarket amenities such as environmental quality. To date, its empirical implementation has generally been in cross-sectional settings where it is reasonable to assume that consumers and producers have already made their optimizing decisions. This section briefly reviews the cross-sectional equilibrium. It then discusses how an improvement in local environmental quality due to a Superfund cleanup leads agents to alter their utility- and profit-maximizing decisions and the resulting new equilibrium. The purpose of this discussion is to devise an empirical strategy to infer the welfare consequences of Superfund cleanups using Decennial Census data.

III.A. A Brief Review of Equilibrium in the Hedonic Model

Economists have estimated the association between housing prices and environmental amenities at least since Ridker (1967) and Ridker and Henning (1967). However, Rosen (1974) and Freeman (1974) were the first to give this correlation an economic interpretation. In the Rosen formulation, a differentiated good is described by a vector of its characteristics, $\mathbf{C} = (c_1, c_2, \ldots, c_n)$. In the case of a house, these characteristics may include structural attributes (e.g., number of bedrooms), neighborhood public services (e.g., local school quality), and local environmental amenities (e.g., distance from a hazardous waste site). Thus, the market price of the *i*th house can be written as

$$P_i = P(c_{i1}, c_{i2}, \ldots, c_{in}). \tag{1}$$

The partial derivative of $P(\bullet)$ with respect to the *j*th characteristic, $\partial P/\partial c_j$, is referred to as the marginal implicit price. It is the marginal price of the *j*th characteristic implicit in the overall price of the house, holding constant all other characteristics.

In the hedonic model, the locus between housing prices and a characteristic, or the hedonic price schedule (HPS), is generated by the equilibrium interactions of consumers and producers. It is assumed that markets are competitive, all consumers rent one house at the market price, and utility depends on consumption of the numeraire, X (with price equal to 1), and the vector of house

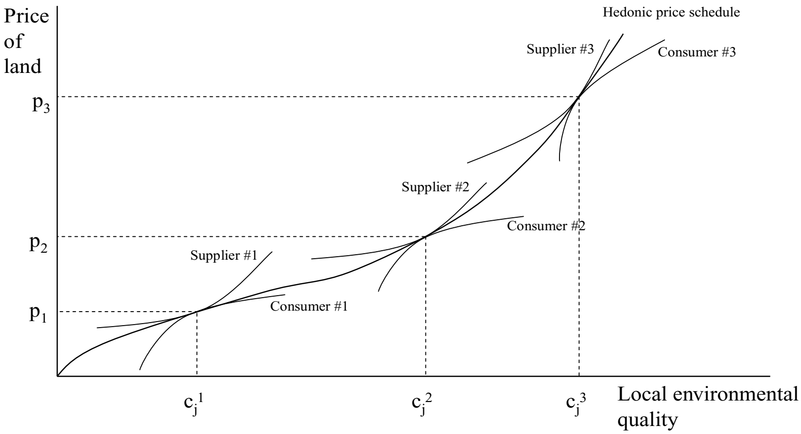

FIGURE Ia
Bid Curves, Offer Curves, and the Equilibrium Hedonic Price Schedule in a Hedonic Market for Local Environmental Quality

characteristics:

$$u = u(X, \mathbf{C}). \tag{2}$$

The budget constraint is expressed as $I - P - X = 0$, where I is income.

Maximization of (2) with respect to the budget constraint reveals that individuals choose levels of each of the characteristics to satisfy $(\partial U/\partial c_j) / (\partial U/\partial x) = \partial P/\partial c_j$. Thus, the marginal WTP for c_j (e.g., local environmental quality) must equal the marginal cost of an extra unit of c_j in the market.

It is convenient to substitute the budget constraint into (2), which gives $u = u(I - P, c_1, c_2, \ldots, c_n)$. By inverting this equation and holding constant all characteristics of the house except j, an expression for WTP for c_j is obtained:

$$B_j = B_j(I - P, c_j, \mathbf{C}^*_{-J}, u^*). \tag{3}$$

Here, u^* is the highest level of utility attainable given the budget constraint and $\mathbf{C}^*_{-j}$ are the optimal quantities of other characteristics. This is referred to as a bid (or indifference) curve, because it reveals the maximum amount that an individual would pay for different values of c_j, holding utility constant.

Heterogeneity in individuals' bid functions due to differences in preferences and/or incomes leads to differences in the chosen quantities of a characteristic. This is depicted in Figure Ia, which plots the HPS and bid curves for c_j of three consumer types. The consumers are denoted as Types 1, 2, and 3, and potentially there are an unlimited number of each type. Each bid function reveals the standard declining marginal rate of substitution between c_j and X (because $X = I - P$). The three types choose houses in locations where their marginal WTP for c_j is equal to the market-determined marginal implicit price, which occurs at c_j^1, c_j^2, and c_j^3, respectively. Given market prices, these consumers' utilities would be lower at sites with higher or lower levels of local environmental quality.

The other side of the market is composed of suppliers of housing services. We assume that suppliers are heterogeneous because of differences in their cost functions. This heterogeneity may result from differences in the land they own. For example, it may be very expensive to provide a high level of local environmental quality on a plot of land located near a steel factory. By inverting a supplier's profit function, we can derive its offer curve for the characteristic c_j:

$$O_j = O_j(c_j, \mathbf{C}^*_{-j}, \pi^*), \tag{4}$$

where π^* is the maximum available profit given its cost function and the HPS. Figure Ia depicts offer curves for three types of suppliers. With this setup, individuals who live in a house that they own would be both consumers and suppliers and their supplier self would rent to their consumer self.

The HPS is formed by tangencies between consumers' bid and suppliers' offer functions. At each point on the HPS, the marginal price of a housing characteristic is equal to an individual consumer's marginal WTP for that characteristic and an individual supplier's marginal cost of producing it. From the consumer's perspective, the gradient of the HPS with respect to local environmental quality gives the equilibrium differential that compensates consumers for accepting the increased health risk and aesthetic disamenities associated with lower local environmental quality. Put another way, areas with poor environmental quality must have lower housing prices to attract potential homeowners, and the HPS reveals the price that allocates consumers across locations. Thus, the HPS can be used to infer the welfare effects of a marginal change in a characteristic. From the suppliers' perspective, the gradient of the HPS reveals the costs of supplying a cleaner local environment.

III.B. What Are the Consequences of a Large Change in Environmental Quality in the Hedonic Model?

This study assesses the impacts of Superfund remediations of hazardous waste sites, which intend to cause nonmarginal improvements in environmental quality near the site. This subsection extends and fleshes out the hedonic model to describe the theoretical impacts of these cleanups on consumers, suppliers, and social welfare. Any impacts on the labor market are ignored, because wage changes do not affect welfare since any gains (losses) for workers are offset by losses (gains) for firms (Roback 1982).

We focus on the case in which the overall HPS does not shift in response to the increased supply of "clean" sites and so there are not changes in relative prices.[10] The assumption of a constant HPS may be valid because to date only 670 Superfund sites have been completely remediated. They are located in just 624 of the 65,443 U.S. Census tracts, which constitute a small part of the U.S. housing market.

Now, consider the cleanup of a hazardous waste site that increases local environmental quality in the neighborhood surrounding the site from c_j^1 to c_j^3 as in Figure Ia. It is evident from the HPS that the rental price of housing near the improved site will rise to p_3. For Type 1 consumers, the increase in the rental rate exceeds their WTP for the cleanup. Consequently, their neighborhood has become too expensive, given their preferences and income, and the cleanup reduces their utility.

The result is that consumers will migrate between communities to restore the equilibrium. The Type 1 consumers that had chosen the improved site based on its previous rental price and environmental quality will move to a house with their originally chosen and optimal values of p and c_j (i.e., p_1 and c_j^1). Additionally, some Type 3 consumers will move near the newly cleaned-up site, where they will consume c_j^3 at a price of p_3. So assuming zero moving costs,[11] the key result is that some consumers will change locations, but their utility will be unchanged because they choose locations with their original c_j and p.

10. See Bartik (1988) and Freeman (2003) for more general discussions of the welfare impacts of nonmarginal amenity improvements (including price changes). Greenstone and Gallagher (2005) also present a brief discussion of these issues.

11. For simplicity, we assume zero moving costs although this surely is not correct. In the presence of moving costs, renters are made worse off by the amount of the moving costs. See Bayer, Keohane, and Timmins (2006) on the impacts of moving costs on the valuation of air pollution.

One consequence of this taste-based sorting is that the residents of the improved neighborhood will have greater unobserved taste for environmental quality and/or higher incomes.[12] Thus, the marginal resident will be less tolerant of exposure to hazardous waste. We test for this taste-based sorting below.

In this setup, landowners near the site are the only agents whose welfare is affected by the cleanup. If residential and commercial land markets are perfectly integrated, then the higher rental rates are a pure benefit for all landowners because the change in environmental quality is costless for them. In this case, the supply of residential land is effectively fixed, and so all adjustments occur through prices.

It is possible that the residential and nonresidential land markets are not perfectly integrated, perhaps due to zoning laws, which are costly to change (Glaeser and Gyourko 2003). In this case, the increase in rental prices is still a pure benefit for owners of residential land near the site. The higher rents for residential land will cause some owners of nonresidential land to find it profitable to convert their land to residential usage. Presumably, the pre-cleanup rental rate of the converted land had been higher when in the nonresidential sector and/or there may be costs associated with conversion (e.g., legal fees associated with rezoning). Thus the benefits for owners of converted land are smaller than for owners of land that was already used for residential housing. Ultimately, the benefits of conversion determine the shape of the supply curve of residential land near the site and the welfare gain for these landowners. The empirical analysis tests for supply responses.

To summarize, there are four predicted impacts of an amenity improvement. First, the price of land (and housing) near the improved site will increase (except in the unlikely case in which the supply of residential land is perfectly elastic). Second, consumers will respond with taste-based sorting. Third, the supply of residential land (and housing) near the site is likely to increase. Fourth, the entire welfare gain accrues to landowners. We next discuss how to test these predictions with Decennial Census data.

12. See Banzhaf and Walsh (2005) and Cameron and McConnaha (2005) for evidence of migration induced by environmental changes. In principle, the new residents' incomes could have a direct effect on individuals' valuations of living in the community. We ignore this possibility here because this will not create any social benefits as long as the benefits from living near high-income individuals are sufficiently linear.

III.C. Can We Learn about the Welfare Effects of Superfund Cleanups from Decennial Census Data?

Three decades after the publication of the original Rosen article, the hedonic approach to estimating the value of nonmarginal amenity changes has not met with great empirical success for at least three reasons. First, the consistent estimation of the HPS, which is the foundation of all welfare calculations, has proven to be extremely challenging because of omitted variables (Chay and Greenstone 2005; Deschenes and Greenstone 2007). Second, the estimation of even a single individual's or taste type's bid function is also made quite difficult, because it is impossible to observe the same individual facing two sets of prices in a cross section.[13] The difficulty of this task was underscored by Epple (1987) and Bartik (1987) who showed that taste-based sorting undermines efforts to infer consumers' bid functions from the HPS.[14] Third, the implementation of the full-blown approach requires estimates of bid functions for *all* consumers and cost functions for *all* suppliers in the economy. This is a tremendous amount of information, and there is a consensus that existing data sources are not up to the task.

In light of these challenges to implementing the hedonic approach, this subsection considers how Decennial Census data on housing and demographic variables can be used to learn about the welfare effects of Superfund cleanups. There are at least two features of these data that merit noting because they affect the form and interpretation of the subsequent empirical analysis.

The first feature is that Census tracts are the smallest unit of observation that can be matched across the 1980, 1990, and 2000 Censuses. This means that it is infeasible to observe individuals over time and therefore to obtain estimates of their bid and cost functions. Consequently, we consider the impacts of a cleanup in the context of Census tract-level demand and supply functions for residential land, which are determined by the bid and cost functions of local consumers and suppliers.

We begin with the case in which the supply curve for residential land near a hazardous waste site is perfectly inelastic, which

13. Rosen (1974) proposed a two-step approach for estimating bid functions (and offer curves). He later wrote, "It is clear that nothing can be learned about the structure of preferences in a single cross-section" (Rosen 1986, p. 658).

14. In a recent paper, Ekeland, Heckman, and Nesheim (2004) outline the assumptions necessary to identify the demand (and supply) functions in an additive version of the hedonic model with data from a single market.

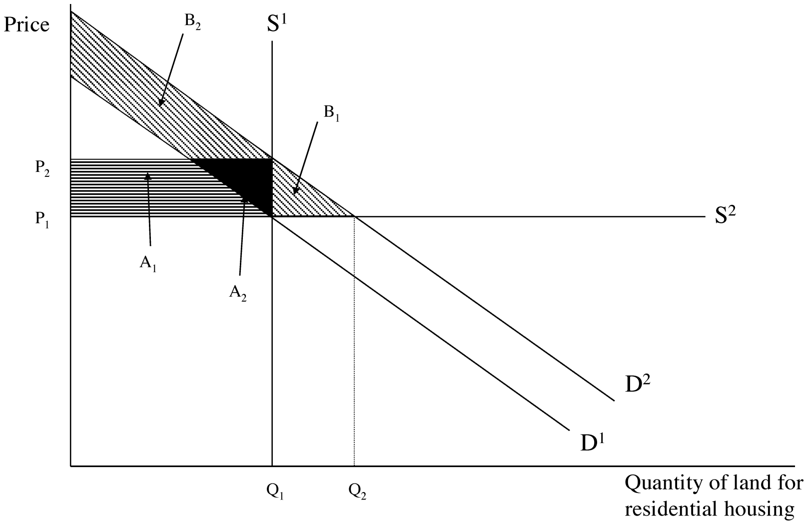

FIGURE Ib
Welfare Gains due to Amenity Improvements with Two Supply Curves

is likely to be the case in the short run, and demand is downward sloping. This is depicted in Figure Ib with S^1 and D^1 and equilibrium outcome (P_1, Q_1). Now, consider an exogenous increase in environmental quality due to a cleanup. The improvement raises current residents' valuation of living near the formerly dirty site and, as sketched out in the preceding subsection, with free migration, individuals with even higher valuations of environmental quality will move in. The net result is that the demand curve for residential housing near the improved site shifts out. This is depicted as D^2 and causes prices to increase to P_2 but leaves quantities unchanged.

With a parallel shift in the demand curve and no change in the HPS, the welfare gain is the sum of the shaded areas A_1 and A_2 in Figure Ib. This equals the mean change in price times the number of residential plots of land and entirely accrues to suppliers or landowners. From a practical perspective, the challenge is to accurately measure the change in house or residential land prices near the improved site.

In the longer run, supply is likely to be more elastic due to the conversion of nonresidential land, and the remediation will lead to changes in prices *and* quantities. Figure Ib depicts the unrealistic polar case in which supply is perfectly elastic as S_2. With this supply curve, the new equilibrium combination is (P_1, Q_2), which reflects a substantial gain in quantities but no change in prices. The gain in welfare is entirely an increase in consumer surplus and is the sum of the shaded areas B_1, B_2, and A_2. Previous applications of the hedonic method have generally examined prices only, and so they may have understated (potentially dramatically) the welfare gain associated with amenity improvements.

It is evident that with Census tract data the development of a full welfare measure requires knowledge of the shapes of the supply and demand curves. We are unaware of a credible strategy for separately identifying supply and demand over the ten-year periods between Censuses. In this situation, precise welfare calculations require ad hoc assumptions about the elasticities of supply and demand, except for the case in which neither prices nor quantities change. In fact, the subsequent analysis finds small changes in prices and quantities, and so our primary conclusion is that Superfund remediations did not substantially increase social welfare.

The Census tract-level demographic data can also be used to test the theoretical prediction of taste-based sorting in response to remediations. An increase in the number of high-income individuals or people who are likely to place a high value on environmental quality in areas near the remediated sites would provide complementary evidence that the cleanups are valued. In contrast, a failure to find these population shifts near the sites would suggest that the cleanups did not lead to substantial welfare gains.

The second feature of the data that merits highlighting is that they are only available in 1980, 1990, and 2000. Ideally, we would like to measure the impact of a site's placement on the NPL immediately after the announcement. This is because all benefits accrue in the future and homeowners will naturally discount them by the rate of time preference. Furthermore, the cleanup itself may reduce the consumption value of living near a site in the short run (e.g., because of increased presence of trucks).

An immediate measurement of the impact on prices would ensure that we have captured the impact of the cleanup on the value of housing services in all years. However, the first NPL was released in 1983, and housing prices cannot be observed again until 1990 or 2000. By then, some of the cleanups will have been completed, and the time to completion for the others (relative to 1983) will have been greatly reduced. For this reason, the measurement of the impacts of the NPL designation with 1990 or 2000 Census data will overstate the properly measured benefits.

IV. Data Sources and Summary Statistics

IV.A. Data Sources

We constructed the most comprehensive data file ever compiled on the Superfund program. It contains detailed information on all hazardous waste sites placed on the NPL by 2000, as well as the hazardous waste sites with 1982 HRS scores below 28.5. It also includes housing price, housing characteristic, and neighborhood demographic information for areas surrounding the sites. This subsection briefly describes the data sources. The Data Appendix and Greenstone and Gallagher (2005) provide additional details.

The housing, demographic, and economic data come from Geolytics's Neighborhood Change Database, which includes information from the 1970, 1980, 1990, and 2000 Censuses. Importantly, the 1980 data predate the publication of the first NPL in 1983. We collected the longitude and latitude for each of the hazardous waste sites and used this information to place all sites in a unique Census tract.

The Geolytics data are used to form a panel of Census tracts based on year-2000 Census tract boundaries, which are drawn so that they include approximately 4,000 people in 2000. Census tracts are the smallest geographic unit that can be matched across the 1970–2000 Censuses. The Census Bureau placed the entire country in tracts in 2000. Geolytics fitted 1970, 1980, and 1990 Census tract data to the year-2000 Census tract boundaries to form a panel. The primary limitation of this approach is that in 1970 and 1980, the U.S. Census Bureau only tracted areas that were considered "urban" or belonged to a metropolitan area. The result is that the remaining areas of the country cannot be matched to a 2000 Census tract, and so the 1970 and 1980 values of the Census variables are missing for year-2000 tracts that include these areas.

The analysis is restricted to the 48,147 of the 65,443 year-2000 Census tracts that have nonmissing housing price data in 1980, 1990, and 2000. This sample includes 985 of the 1,398 sites listed on the NPL before January 1, 2000, and 487 of the 690 sites that were tested for inclusion on the initial NPL. The addition of the sample restriction that 1970 housing prices be nonmissing would have further reduced the sample to include just 37,519 Census tracts, 708 of the NPL sites, and 353 of the 1982 HRS sites.

The subsequent analysis uses three different groupings of Census tracts. The first conducts the analysis at the Census tract level. The second implements an analysis among Census tracts that share a border with the tracts that contain the hazardous waste sites (but excludes the tracts that contain the sites). In this case, each observation is composed of the weighted average of all variables across these neighboring tracts, where the weights are the 1980 populations of the tracts.

The unit of observation in the third grouping is the land area within circles of varying radii that are centered at the sites. For these observations, the Census variables are calculated as the weighted means across the portion of tracts that fall within the relevant circle. The weights are the fraction of each tract's land area within the relevant circle multiplied by its 1980 population.[15] In choosing the optimal radius, we attempted to balance the conflicting goals of requiring houses to be near enough to the sites so that it is plausible that residents would value a cleanup and making the area large enough so that implausibly large increases in housing prices are not required for cleanups to pass a cost-benefit test. In the subsequent tables, we focus on circles with radii of two miles and three miles.[16] The mean 1980 values of the housing stocks in these circles are \$311 million and \$736 million and the mean (median) number of Census tracts that are at least partially inside these circles are 9.9 (8) and 18.2 (12), respectively.

We also collected a number of variables about the hazardous waste sites. All HRS composite scores, as well as separate groundwater, surface water, and air pathway scores, were obtained from various issues of the *Federal Register*. The same source was used to determine the dates of NPL listing. The EPA provided a data file that reported the dates of the release of the ROD, initiation of

15. A limitation of the geographic information system (GIS)-determined circle approach is that street-address-level data on housing prices and the covariates is unavailable. We assign a Census tract's average to the portion of the tract that falls within the circle, which is equivalent to assuming that there is no heterogeneity in housing prices or other variables within a tract.

16. The use of a three-mile radius is consistent with EPA's and the scientific community's positions on the distance from a Superfund site that the contaminants could be expected to impact human health. The 1982 *Federal Register* reports, "The three-mile radius used in the HRS is based on EPA's experience that, in most cases currently under investigation, contaminants can migrant to at least this distance. Note that no commentators disagreed with the selection of three miles for technical or scientific reasons" (*Federal Register*, July 16, 1982).

cleanup, completion of remediation (i.e., construction complete), and deletion from the NPL for sites that achieved these milestones. Information on each NPL site's size in acres comes from the RODs. Finally, we collected data on the expected costs of cleanup before remediation was initiated and estimated actual costs for sites that reached the construction complete stage. Greenstone and Gallagher's (2005) Data Appendix provides more information on the costs of cleanups (also see Probst and Konisky [2001]).

IV.B. Summary Statistics

The analysis is conducted with two samples of hazardous waste sites. The first is called the "All NPL Sample" and includes the 1,398 hazardous waste sites in the 50 U.S. states and the District of Columbia that were placed on the NPL by January 1, 2000. The second is the "1982 HRS Sample" and is composed of the 690 hazardous waste sites tested for inclusion on the initial NPL.

Table I presents summary statistics on the hazardous waste sites in these samples. The entries in column (1) are from the All NPL Sample and are limited to sites in a Census tract for which there is nonmissing housing price data in 1980, 1990, and 2000. After these sample restrictions, there are 985 sites, which is more than 70% of the sites placed on the NPL by 2000. Columns (2) and (3) report data from the 1982 HRS Sample. The column (2) entries are based on the 487 sites located in a Census tract with complete housing price data. Column (3) reports on the remaining 189 sites located in Census tracts with incomplete housing price data (generally due to missing 1980 data). Fourteen sites outside of the continental United States were dropped from the sample.

Panel A reports on the timing of the sites' placement on the NPL. Column (1) reveals that about 75% of all NPL sites received this designation in the 1980s. Together, columns (2) and (3) demonstrate that 443 of the 676 sites in the 1982 HRS Sample eventually were placed on the NPL. This number exceeds the 400 sites that Congress set as an explicit goal. This is because some sites with initial scores below 28.5 were retested and received scores above the threshold qualifying them for the NPL. Panel B demonstrates that mean HRS scores are similar across the columns.

Panel C reports on the size of the hazardous waste sites measured in acres, which is available for NPL sites only. The median

TABLE I
SUMMARY STATISTICS ON THE SUPERFUND PROGRAM

	All NPL sites w/ nonmissing house price data (1)	1982 HRS sites w/ nonmissing house price data (2)	1982 HRS sites w/ missing house price data (3)
Number of sites	985	487	189
1982 HRS score above 28.5	—	306	95
A. Timing of placement on NPL			
Total	985	332	111
# 1981–1985	406	312	97
# 1986–1989	340	14	9
# 1990–1994	166	4	3
# 1995–1999	73	2	2
B. HRS information			
Mean scores | HRS $\geq$ 28.5	41.89	44.47	43.23
Mean scores | HRS < 28.5	—	15.54	16.50
C. Size of site (in acres)			
Number of sites with size data	920	310	97
Mean (median)	1,187 (29)	334 (25)	10,507 (35)
Maximum	195,200	42,560	405,760
D. Stages of cleanup for NPL sites			
Median years from NPL listing until:			
ROD issued	—	4.3	4.3
Cleanup initiated	—	5.8	6.8
Construction complete	—	12.1	11.5
Deleted from NPL	—	12.8	12.5
1990 status among sites NPL by 1990			
NPL only	394	100	31
ROD issued or cleanup initiated	335	210	68
Construction complete or deleted	22	16	7
2000 status among sites NPL by 2000			
NPL only	137	15	3
ROD issued or cleanup initiated	370	119	33
Construction complete or deleted	478	198	75
E. Expected costs of remediation (millions of year-2000 $)			
No. of sites with nonmissing costs	753	293	95
Mean (median)	$28.3 ($11.0)	$27.5 ($15.0)	$29.6 ($11.5)
95th percentile	$89.6	$95.3	$146.0
F. Actual and expected costs conditional on construction complete (millions of year-2000 $)			
Sites w/both costs nonmissing	477	203	69
Mean (median) expected costs	$15.5 ($7.8)	$20.6 ($9.7)	$17.3 ($7.3)
Mean (median) actual costs	$21.6 ($11.6)	$32.0 ($16.2)	$23.3 ($8.9)

Notes: Column (1) includes information for sites placed on the NPL before December 31, 1999. The estimated cost information is calculated as the sum across the first RODs for each operating unit associated with a site. See the Data Appendix for further details.

site size ranges between 25 and 35 acres across the samples. The means are substantially larger due to a few very large sites. The modest size of most sites suggests that any expected effects on property values are likely to be confined to relatively small geographic areas around the sites.

Panel D reveals that the cleanup process is slow. The median time until the different milestones are achieved is reported, rather than the mean, because many sites have not reached all of them yet. Of the NPL sites in column (2), 198 received either the construction complete or deleted designation by 2000, and 16 received that designation by 1990. For this reason, we focus on changes in housing prices and quantities between 1980 and 2000. We also assess how rental rates change as sites progress through the cleanup process.

Panel E reports the expected costs of cleanup for NPL sites. Panel F details expected and actual costs among sites designated construction complete or deleted. The expected costs are measured before any remediation activities have begun, while actual costs are our best estimates of total remediation-related expenditures assessed after the site is construction complete. We believe this is the first time these variables have been reported for the same sites. In the 1982 HRS Sample that we focus on (i.e., column (2)), the mean and median expected costs are $27.5 million and $15.0 million, respectively.

Among the construction complete sites in the 1982 HRS Sample, the mean actual costs exceed the expected costs by about 55%. We multiply the overall mean expected cost of $27.5 million by 1.55 to obtain an estimate of $43 million for the mean actual costs of cleanup in the 1982 HRS Sample. This estimate of costs understates the true costs, because it does not include the legal costs or deadweight loss associated with the collection of funds from private parties or taxes, nor does it include each site's share of the EPA's costs of administering the Superfund program. Nevertheless, it is the best available estimate and is contrasted with the estimated benefits of Superfund cleanups in the remainder of the paper.

A comparison of columns (2) and (3) across the panels reveals that the sites with and without complete housing price data are similar on a number of dimensions. For example, the mean HRS scores conditional on scoring above and below 28.5 are remarkably similar. Further, the median size and various cost variables are comparable in the two columns. Consequently, it seems reasonable

FIGURE IIa
Geographic Distribution of Hazardous Waste Sites in the 1982 HRS Sample Sites with 1982 HRS Scores Exceeding 28.5

to conclude that the sites without complete housing price data are similar to the column (2) sites, suggesting that the subsequent results may be externally valid for the 189 sites with missing price data.

Moreover, the sites in column (1) are similar to the sites in columns (2) and (3) in size and the two cost variables. The mean HRS scores are a few points lower, but this comparison is not meaningful because of the changes in the test over time and in how the scoring was conducted. Overall, the similarity of the column (1) sites with the other sites suggests that the results from the application of the HRS research design to the 1982 HRS Sample may be informative about the effects of the Superfund cleanups of sites that were not considered for inclusion on the initial NPL.

We now graphically summarize some features of the 1982 HRS Sample. Figures IIa and IIb present the geographic distribution of the sites with 1982 HRS scores above and below 28.5, respectively. The sites in both categories are spread throughout the United States, but the sites below 28.5 are in fewer states. For example, there are not any sites scored below 28.5 in Minnesota, Florida, and Delaware. The unequal distributions of sites across

FIGURE IIb
Geographic Distribution of Hazardous Waste Sites in the 1982 HRS Sample Sites with 1982 HRS Scores below 28.5

The 1982 HRS Sample is composed of the 487 hazardous waste sites that were placed in a Census tract with nonmissing housing price data in 1980, 1990, and 2000. Of these sites, 306 (181) had 1982 HRS scores above (below) 28.5.

the country pose a problem for identification in the presence of localized housing market shocks. To mitigate the influence of these shocks, we emphasize econometric models for changes in housing prices that include state fixed effects.

Figure III presents a histogram of the initial HRS scores where the bins are 4 HRS points wide, among the 487 sites in the 1982 HRS Sample. Notably, the EPA considered HRS scores within 4 points to be statistically indistinguishable and reflect comparable risks to human health (Environmental Protection Agency 1991). The distribution looks approximately normal, with the modal bin covering the 36.5–40.5 range. Further, there is no obvious bunching just above or below the threshold, which supports the scientific validity of the HRS scores and suggests that they were not manipulated. Importantly, 227 sites have HRS scores between 16.5 and 40.5. This set is centered on the regulatory threshold of 28.5 that determines placement on the NPL and the sites constitute the RD sample that is utilized in the subsequent analysis.

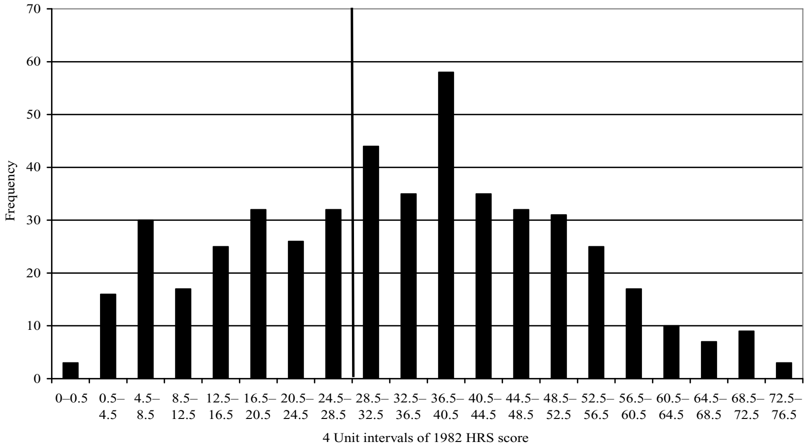

FIGURE III

Distribution of 1982 HRS Scores in the 1982 HRS Sample

The figure displays the distribution of 1982 HRS scores among the 487 hazardous waste sites that were tested for placement on the NPL (and are in Census tracts with nonmissing house price data) after the passage of the Superfund legislation but before the announcement of the first NPL in 1983. The 189 sites with missing housing data in 1980, 1990, or 2000 are not included in the subsequent analysis and hence are excluded from this figure. The vertical line at 28.5 represents the cutoff that determined eligibility for placement on the NPL.

V. ECONOMETRIC METHODS

V.A. A Conventional Approach to Estimating the Benefits of Superfund Cleanups

Here, we discuss a "conventional" econometric approach to estimating the relationship between housing prices and NPL listing. This approach is laid out in the following system of equations:

$$y_{c2000} = \theta 1(\text{NPL}_{c2000}) + \mathbf{X}'_{c1980}\beta + \varepsilon_{c2000}, \tag{5}$$

$$1(\text{NPL}_{c2000}) = \mathbf{X}'_{c1980}\Pi + \eta_{c2000}, \tag{6}$$

where y_{c2000} is the log of the median property value in Census tract c in 2000. (In practice, we examine several outcome variables, including rental rates, housing supply, and characteristics of the local population, but for clarity the remainder of this section only refers to house prices.) The indicator variable $1(\text{NPL}_{c2000})$ equals 1 only for observations from Census tracts that contain or are near a hazardous waste site that had been placed on the NPL by 2000. Thus, this variable takes on a value of 1 for any of the Superfund sites in column (1) of Table I, not just those that were on the initial

NPL. The vector $\mathbf{X}_{c1980}$ includes determinants of housing prices measured in 1980, which may also determine NPL status; ε_{c2000} and η_{c2000} are the unobservable components of housing prices and NPL status, respectively.

A few features of the **X** vector are noteworthy. First, this vector is restricted to 1980 values of the variables to avoid confounding the effect of NPL status with "post-treatment" changes in these variables that may be due to NPL status. Second, the 1980 value of the dependent variable, y_{c1980}, is included in $\mathbf{X}_{c1980}$ to adjust for permanent differences in housing prices across tracts and the possibility of mean reversion in housing prices. Third, to account for local housing market shocks, we emphasize results from specifications that include a full set of state fixed effects.

Fourth, in many applied hedonic papers, the vector of controls is limited to housing and neighborhood characteristics (e.g., number of bedrooms, school quality, and air quality). Mean household income and similar variables are generally excluded, because they are considered "demand shifters" and are needed to identify the bid function. This exclusion restriction is invalid if, for example, individuals treat wealthy neighbors as an amenity, which seems likely. The subsequent analysis is agnostic about which variables belong in the **X** vector and reports estimates that are adjusted for different combinations of the variables available in the Census data. See the Data Appendix for the full set of covariates.

The coefficient θ measures the effect of NPL status on 2000 property values, after controlling for 1980 mean property values and the other covariates. In this conventional approach, we utilize data from the entire country, so θ tests for differential housing price appreciation between Census tracts with NPL sites and the rest of the country. Consistent estimation of θ requires $E[\varepsilon_{c2000}\eta_{c2000}] = 0$ or that unobserved determinants of housing prices do not covary with NPL status (after adjustment for $\mathbf{X}_{c1980}$). This conventional approach rests on the assumption that linear adjustment for the limited set of variables available in the Census removes all sources of confounding.

V.B. A Quasi-Experimental Approach Based on 1982 HRS Scores

In this subsection, we discuss a quasi-experimental identification strategy that differs from the conventional one described above. This strategy differs in three important ways. First, we restrict the sample to the Census tracts containing the 487 sites in the 1982 HRS Sample with complete housing price data. Thus, all observations are from tracts with sites that the EPA judged to be among the nation's most dangerous in 1982. If, for example, the β's differ across tracts with and without hazardous waste sites or there are differential trends in housing prices in tracts with and without these sites, then this approach is more likely to produce consistent estimates.

Second, we use an instrumental variables (IV) strategy to account for the possibility of the endogenous rescoring of sites.

More formally, we replace equation (6) with

$$(7) \qquad 1(\mathrm{NPL}_{c2000}) = \mathbf{X}'_{c1980}\Pi + \delta 1(\mathrm{HRS}_{c82} > 28.5) + \eta_{c2000},$$

where $1(\mathrm{HRS}_{c82} > 28.5)$ serves as an instrumental variable. This indicator function equals 1 for Census tracts with a site that has a 1982 HRS score exceeding the 28.5 threshold. We then substitute the predicted value of $1(\mathrm{NPL}_{c2000})$ from the estimation of equation (7) in the fitting of (5) to obtain an estimate of θ_{IV}. In this IV framework, θ_{IV} is identified from the variation in NPL status that is due to a site having a 1982 HRS score exceeding 28.5.

For θ_{IV} to provide a consistent estimate of the HPS gradient, the instrumental variable must affect the probability of NPL listing without having a direct effect on housing prices. The next section demonstrates that the first condition clearly holds. The second condition requires that the unobserved determinants of year-2000 housing prices are orthogonal to the portion of the nonlinear function of the 1982 HRS score that is not explained by $\mathbf{X}_{c1980}$. In the simplest case, the IV estimator is consistent if $E[1(\mathrm{HRS}_{c82} > 28.5)\ \varepsilon_{c2000}] = 0$.

The third feature of the quasi-experiment is the availability of an RD design that is implicit in the $1(\bullet)$ function that determines NPL eligibility. The RD design can produce consistent estimates of θ_{IV} even if $E[1(\mathrm{HRS}_{c82} > 28.5)\ \varepsilon_{c2000}] \neq 0$ over the entire 1982 HRS Sample. It is important to highlight that the RD approach only provides estimates of the treatment effect at the regulatory discontinuity (i.e., HRS $= 28.5$). To extend the external validity of the RD estimates to the full 1982 HRS Sample, it is necessary to assume a homogeneous treatment effect in that sample.

The RD approach is implemented in three different ways. In the first, a quadratic in the 1982 HRS score is included in $\mathbf{X}_{c1980}$ to partial out any correlation between residual housing prices and the indicator for a 1982 HRS score exceeding 28.5. This approach relies on the plausible assumption that residual determinants of housing price growth do not change discontinuously at the regulatory threshold. The second RD approach involves implementing the IV estimator on the RD sample of 227 sites with 1982 HRS scores between 16.5 and 40.5. Here, the identifying assumption is that all else is held equal in the "neighborhood" of the regulatory threshold. More formally, it is $E[1(\text{HRS}_{c82} > 28.5)\, \varepsilon_{c2000} \mid 16.5 < 1982 \text{ HRS} < 40.5] = 0$.

Recall that the HRS score is a nonlinear function of the groundwater, surface water, and air migration pathway scores. The third RD method exploits knowledge of this function by including the individual pathway scores in the vector $\mathbf{X}_{c1980}$. All three RD approaches are demanding of the data and this is reflected in higher sampling errors.

The key feature of the quasi-experimental approach is to restrict the sample to the areas surrounding the 487 sites in the 1982 HRS Sample. Among these sites, a simple comparison of outcomes between NPL and non-NPL sites is likely to mitigate concerns about confounding associated with the conventional approach. The other two features refine the comparisons within this sample. The use of $1(\text{HRS}_{c82} > 28.5)$ as an instrumental variable for $1(\text{NPL}_{c2000})$ accounts for the possibility of the endogenous rescoring of sites. The RD design offers a potentially valid "control function" solution to any remaining concerns about confounding.

Finally, the primary focus of the housing price regressions is to conduct a cost-benefit analysis of Superfund cleanups. Specifically, we report p values from tests that the coefficient on the NPL indicator is large enough so that the aggregate change in housing prices exceeds the mean costs of a Superfund cleanup ($43 million in the 1982 HRS Sample). This assumes that cleanup benefits are entirely reflected in local housing prices, which is equivalent to assuming that the housing supply curve is perfectly inelastic and that all benefits occur in the local housing market. Although we report whether the estimates of θ are statistically different from zero, the cost-benefit tests are more meaningful in this setting.

VI. Empirical Results

VI.A. Are the Observable Covariates Balanced?

This subsection examines the comparisons that underlie the subsequent least-squares and quasi-experimental estimates of the effect of NPL status on housing price growth. We begin by assessing whether NPL status and the $1(HRS_{c82} > 28.5)$ instrumental variable are orthogonal to the *observable* predictors of housing prices. Formal tests for the presence of omitted-variables bias are of course impossible, but it seems reasonable to presume that research designs that balance the observable covariates across NPL status or $1(HRS_{c82} > 28.5)$ may suffer from smaller omitted-variables bias (Altonji, Elder, and Taber 2000). Further, if the observables are balanced, consistent inference does not depend on functional-form assumptions on the relations between observable covariates and housing prices.

Table II shows the association of NPL status and $1(HRS_{c82} > 28.5)$ with potential determinants of housing price growth measured in 1980. Column (1) reports the relevant means for the sample of 985 Census tracts with NPL hazardous waste sites and complete housing price data. Column (2) displays the means in the 41,989 Census tracts that neither contain an NPL site nor share a border with a tract containing one. Columns (3) and (4) report on the means in the 181 and 306 Census tracts with hazardous waste sites with 1982 HRS scores below and above the 28.5 threshold, respectively. Columns (5) and (6) repeat this exercise for the 90 and 137 tracts below and above the regulatory threshold in the RD sample. The remaining columns report *p* values from tests that the means in pairs of the first six columns are equal; *p* values less than 0.01 are denoted in bold.

Column (7) compares the means in columns (1) and (2) to explore the possibility of confounding in the least-squares approach. The entries indicate that 1980 housing prices are more than 20% lower in tracts with an NPL site. Moreover, the tracts with NPL sites have lower population densities, lower household incomes, and mobile homes account for a higher fraction of the housing stock (8.6% vs. 4.7%). Overall, the hypothesis of equal means can be rejected at the 1% level for 22 of the 26 potential determinants of housing prices. Because of this confounding of NPL status, it may be reasonable to assume that least squares estimation of equation (5) will produce biased estimates of the effect of NPL status.

Columns (8) and (9) compare all tracts with hazardous wastes that have 1982 HRS scores below and above the 28.5 regulatory threshold and those in the RD sample, respectively. It is immediately evident that by narrowing the focus to these tracts, the differences in the potential determinants of housing prices are greatly mitigated (e.g., see population density and percent mobile homes).

TABLE II
MEAN CENSUS TRACT CHARACTERISTICS BY CATEGORIES OF THE 1982 HRS SCORE

	NPL site by 2000 (1)	No NPL site by 2000 (2)	HRS < 28.5 (3)	HRS > 28.5 (4)	HRS > 16.5 & < 28.5 (5)	HRS > 28.5 & < 40.5 (6)	*p*-Value (1) vs. (2) (7)	*p*-Value (3) vs. (4) (8)	*p*-Value (5) vs. (6) (9)
No. of Census tracts	985	41,989	181	306	90	137	—	—	—
Superfund cleanup activities									
Ever NPL by 1990	0.7574	—	0.1271	0.9902	0.2222	0.9854	—	**.000**	**.000**
Ever NPL by 2000	1.0000	—	0.1602	0.9902	0.2667	0.9854	—	**.000**	**.000**
1980 mean housing prices									
Site's Census tract	58,045	69,904	45,027	52,137	46,135	50,648	**.000**	**.000**	.084
2-mile-radius circle around site	56,020	—	48,243	53,081	48,595	52,497	—	.016	.179
3-mile-radius circle around site	56,839	—	51,543	54,458	49,434	53,868	—	.257	.126
1980 housing characteristics									
Total housing units	1,392	1,350	1,357	1,353	1,367	1,319	.039	.951	.575
Mobile homes (%)	0.0862	0.0473	0.0813	0.0785	0.0944	0.0787	**.000**	.792	.285
Occupied (%)	0.9408	0.9330	0.9408	0.9411	0.9412	0.9411	**.000**	.940	.989
Owner occupied (%)	0.6818	0.6125	0.6792	0.6800	0.6942	0.6730	**.000**	.959	.344
0–2 bedrooms (%)	0.4484	0.4722	0.4691	0.4443	0.4671	0.4496	**.000**	.107	.417
3–4 bedrooms (%)	0.5245	0.5016	0.5099	0.5288	0.5089	0.5199	**.000**	.202	.586
Built last 5 years (%)	0.1434	0.1543	0.1185	0.1404	0.1366	0.1397	**.006**	.050	.844
Built last 10 years (%)	0.2834	0.2874	0.2370	0.2814	0.2673	0.2758	.506	.012	.723
No air-conditioning (%)	0.4903	0.4220	0.5058	0.4801	0.5157	0.5103	**.000**	.253	.870
Units attached (%)	0.0374	0.0754	0.0603	0.0307	0.0511	0.0317	**.000**	.040	.297

TABLE II
(CONTINUED)

	NPL site by 2000 (1)	No NPL site by 2000 (2)	HRS < 28.5 (3)	HRS > 28.5 (4)	HRS > 16.5 & < 28.5 (5)	HRS > 28.5 & < 40.5 (6)	*p*-Value (1) vs. (2) (7)	*p*-Value (3) vs. (4) (8)	*p*-Value (5) vs. (6) (9)
1980 demographics & economic characteristics									
Population density	1,407	5,786	1,670	1,157	1,361	1,151	**.000**	.067	.570
Black (%)	0.0914	0.1207	0.1126	0.0713	0.0819	0.0844	**.000**	.037	.926
Hispanic (%)	0.0515	0.0739	0.0443	0.0424	0.0309	0.0300	**.000**	.841	.928
Under 18 (%)	0.2939	0.2780	0.2932	0.2936	0.2885	0.2934	**.000**	.958	.568
Female head HH (%)	0.1616	0.1934	0.1879	0.1576	0.1639	0.1664	**.000**	.017	.862
Same house 5 yrs ago (%)	0.5442	0.5127	0.6025	0.5623	0.5854	0.5655	**.000**	**.001**	.244
> 25 no HS diploma (%)	0.3427	0.3144	0.4053	0.3429	0.3881	0.3533	**.000**	**.000**	.060
> 25 B.A. or better (%)	0.1389	0.1767	0.1003	0.1377	0.1092	0.1343	**.000**	**.000**	.036
< Poverty line (%)	0.1056	0.1141	0.1139	0.1005	0.1072	0.1115	**.003**	.109	.716
Public assistance (%)	0.0736	0.0773	0.0885	0.0745	0.0805	0.0755	.084	.041	.578
Household income	20,340	21,526	19,635	20,869	19,812	20,301	**.000**	.013	.486
1980 geographic distribution across Census regions									
Northeast (%)	0.3797	0.2116	0.3315	0.4771	0.3889	0.4234	**.000**	**.001**	.6063
Midwest (%)	0.2183	0.2320	0.3481	0.2255	0.3222	0.2847	.302	**.004**	.5507
South (%)	0.2355	0.3227	0.2155	0.1928	0.1889	0.2044	**.000**	.552	.7744
West (%)	0.1665	0.2337	0.1050	0.1046	0.1000	0.0876	**.000**	.989	.7565

Notes: Columns (1)–(6) report the means of the variables listed in the row headings across the groups of Census tracts listed at the top of the columns. In all of these columns, the sample restriction that the Census tract must have nonmissing house price data in 1980, 1990, and 2000 is added. Columns (7)–(9) report the *p*-values from tests that the means in different sets of the subsamples are equal. The 1980 mean housing price in the two-mile- and three-mile-radius circles are calculated as the weighted mean across Census tracts that fall within the circle, where the weight is the fraction of the tract's land area inside the circle multiplied by the tract's 1980 population. All other entries in the table refer to characteristics of the tracts where the sites are located (except the column (2) entries, which report the means in tracts without a site). The *p*-values less than .01 are denoted in bold. For the air-conditioning and bath questions, the numerator is year-round housing units and the denominator is all housing units. For all other variables in the "housing characteristics" category, the denominator is all housing units. In contrast to the remainder of the paper, the dollar figures are not adjusted for inflation.

This is especially so in the RD sample, where the hypothesis of equal means cannot be rejected at the 3% level for any of the 27 variables. Notably, the differences in the means are substantially reduced for many of the variables. Consequently, the higher p values do not simply reflect the smaller samples (and larger sampling errors).

One variable that remains a potential source of concern is 1980 housing prices in the sites' tracts and circles of two- and three-mile radii around the sites. The differences are greatly reduced in the 1982 HRS Sample, relative to columns (1) and (2), but they are not eliminated (although they are statistically insignificant in the circle samples). Table 4 in Greenstone and Gallagher (2005) demonstrates that the difference in prices in the sites' Census tracts disappears after adjustment for 1980 housing, economic, and demographic variables. Overall, the entries suggest that the above and below 28.5 comparison, especially in the RD sample, reduces the confounding of NPL status.

VI.B. Conventional Estimates of the Impact of Cleanups on Property Values with Data from the Entire United States

Table III presents the first ever large-scale effort to test the effect of Superfund cleanups on property value appreciation rates. Specifically, it reports the regression results from conventional approaches that involve fitting three least squares versions of equation (5) for 2000 housing prices on data from the *entire* United States. The entries report the coefficient on the NPL indicator with its heteroscedastic-consistent standard error below in parentheses. The exact covariates in each specification are noted in the row headings at the bottom of the table and are described in more detail in the Data Appendix.

In Panel A, 985 observations are from Census tracts that contain a hazardous waste site that had been on the NPL at any time prior to 2000. The remainder of the sample is composed of the 41,989 observations on the tracts with complete housing price data that neither have an NPL site nor are adjacent to a tract with an NPL site. The remaining panels use slightly different samples. In Panel B, the observations from each tract with an NPL site in the Panel A sample are replaced with observations based on the three-mile-radius circles around the NPL sites. Panels C and D are identical to A and B, except that the set of NPL sites is restricted to those in the 1982 HRS Sample placed on the NPL by

TABLE III
CONVENTIONAL ESTIMATES OF THE ASSOCIATION BETWEEN NPL STATUS AND HOUSE PRICES WITH DATA FROM THE ENTIRE UNITED STATES

	(1)	(2)	(3)
A. All NPL sample, own Census tract observation			
1(NPL status by 2000)	0.040	0.046	0.067
	(0.012)	(0.011)	(0.009)
R^2	0.579	0.654	0.779
B. All NPL sample, 3-mile-radius circle sample observation			
1(NPL status by 2000)	0.030	0.060	0.106
	(0.011)	(0.013)	(0.011)
Ho: > 0.046, p-value	.061	.862	.999
R^2	0.580	0.652	0.776
C. Restrict NPL sites to those in 1982 HRS sample, own Census tract observation			
1(NPL status by 2000)	0.071	0.076	0.057
	(0.016)	(0.015)	(0.013)
R^2	0.581	0.655	0.780
D. Restrict NPL sites to those in 1982 HRS sample, 3-mile-radius circle sample observation			
1(NPL status by 2000)	0.046	0.143	0.191
	(0.015)	(0.021)	(0.021)
Ho: > 0.058, p-value	.215	.999	.999
R^2	0.580	0.653	0.777
1980 ln house price	Yes	Yes	Yes
1980 housing characteristics	No	Yes	Yes
1980 economic and demographic variables	No	No	Yes
State fixed effects	No	No	Yes

Notes: The entries report the coefficient and heteroscedastic-consistent standard error (in parentheses) on the NPL indicator, as well as the R^2 statistic, from twelve separate regressions. The controls are listed in the row headings at the bottom of the table. Panels B and D also report p-values from tests of whether the NPL parameters multiplied by the 1980 aggregate value of the housing stock exceed the average cost of a cleanup, which is $39 million and $43 million in Panels B and D, respectively. The aggregate values of the housing stock in the three-mile-radius circles around NPL sites in Panels B and D are $855 million and $736 million, respectively. The sample size is 42,974 in Panels A and B and 42,321 in Panels C and D. In Panel A/B (C/D) 985 (332) observations are from an area containing a hazardous waste site that had been on the NPL at any time prior to the year-2000 observation on housing prices. The difference between A/B and C/D is that in C/D observations from areas with the 653 NPL sites that were not tested for inclusion in the initial NPL are dropped. The remainder of the sample is composed of the 41,989 observations on Census tracts with complete housing price data that neither have an NPL site nor are adjacent to a tract with an NPL site. In Panels A and C, the unit of observation is the tract that contains the site and in B and D it is based on the Census tracts that fall within circles centered at the site with a radius of three miles. A few Census tracts have multiple sites. Both here and in the subsequent tables, observations from these tracts are weighted by the square root of the number of sites in the regressions. See the text and Data Appendix for further details.

January 1, 2000; these results are a benchmark for comparison with the preferred quasi-experimental ones.

The Panel A results show that this conventional approach finds a positive association between NPL listing and housing price increases in the sites' tracts between 1980 and 2000. Specifically, the estimates indicate that housing prices grew by 4.0% to 6.7% (measured in ln points) more in tracts with a site placed on the NPL. All of these estimates would easily be judged statistically significant by conventional criteria. The column (3) estimate of 6.7% is the most reliable one, because it is adjusted for all unobserved state-level determinants of housing price growth.

Panel B explores the growth of housing prices within three miles of the NPL sites to summarize the total gain in housing prices. All of the estimates are statistically different from zero and imply that the placement of a site on the NPL is associated with a substantial increase in housing prices within three miles of the site. The column (3) specification indicates a precisely estimated gain in prices of 10.6%. In this sample, the 1980 aggregate value of the housing stock is \$855 million and the mean cost of a cleanup is \$39 million; so we test whether the change in housing prices exceeds 4.6%. The null that the cleanups pass the cost-benefit test cannot be rejected in any of the specifications.

The own Census tract results in Panel C are similar to those in Panel A. The three-mile-radius circle results in Panel D also indicate large increases in housing prices. The point estimates from the richer specifications are about twice as large as those in Panel B. Further, they all indicate that Superfund passes this cost-benefit test.

It is worth emphasizing that three features of the evidence presented so far suggest that the Table III estimates may be unreliable. First, Table II demonstrated that NPL status is confounded by many variables. Second, four of the six 3-mile-radius sample point estimates exceed the own Census tract estimates. This seems suspicious, because it seems reasonable to expect the impact on housing prices to be greater closer to the sites, especially in light of their relatively small size (recall that the median size is less than thirty acres). Third, the point estimates from the three-mile samples are unstable across specifications, and so the exact choice of controls plays a large role in any conclusions. For example, in Panel D, the implied increase in housing prices ranges from 4.6% to 19.1%.[17]

17. The point estimate on the NPL indicator is especially sensitive to the choice of functional form for two controls: the number of housing units and the number of owner-occupied units in both Panels B and D. This likely reflects the fact that the values of these variables differ substantially between the observations on

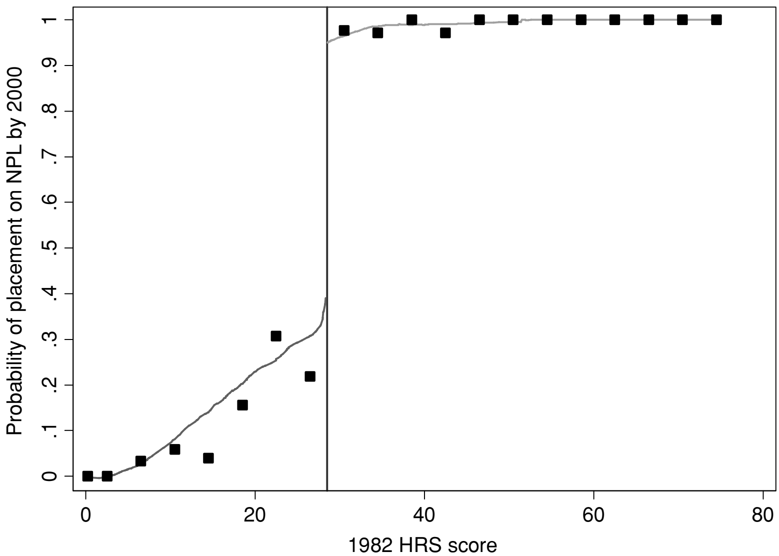

FIGURE IV

Probability of Placement on the NPL by 1982 HRS Score in the 1982 HRS Sample

The figure plots the bivariate relation between the probability of year-2000 NPL status and the 1982 HRS score among the 487 sites in the 1982 HRS Sample. These plots are done separately for sites below (dark colored line) and above (light colored line) the 28.5 threshold. They come from the estimation of nonparametric regressions that use Cleveland's (1979) tricube weighting function and a bandwidth of 0.5. The data points present the mean probabilities in the same four-unit intervals of the HRS score as in Figure III. See the text for further details.

VI.C. Quasi-Experimental Estimates of the Impact of NPL Status on Housing Prices

We now turn to the preferred quasi-experimental approach. For the remainder of the paper, we use the 1982 HRS sites as the basis for the samples. In a few cases, which are noted, we focus on the subset of sites with 1982 HRS scores between 16.5 and 40.5 that form the RD sample.

Figure IV plots the bivariate relation between the probability that a site was placed on the NPL by 2000 and its initial HRS score among the 487 sites in the 1982 HRS Sample. The plots are done separately for sites above and below the 28.5 threshold and come from the estimation of nonparametric regressions that use

the three-mile circles and the Census tracts. It also underscores the importance of unverifiable functional form assumptions when the variables are not balanced across the areas with and without NPL sites.

Cleveland's (1979) tricube weighting function and a bandwidth of 0.5. Thus, they represent a moving average of the probability of NPL status across 1982 HRS scores. The data points represent the mean probabilities in the same 4-unit intervals of the HRS score as in Figure III.

The figure presents dramatic evidence that an initial HRS score above 28.5 is a strong predictor of NPL status. Virtually all sites with initial scores greater than 28.5 were placed on the NPL by 2000. The nonzero probability of NPL placement by 2000 among sites with an initial score below 28.5 is explained by rescoring. A statistical model reveals that a HRS score above 28.5 is associated with an 83% increase in the probability of placement on the NPL. In the context of the IV approach, it is evident that there is a powerful first-stage relationship.

Table IV presents quasi-experimental estimates of the effect of NPL status on housing prices in 2000. Panel A observations are from Census tracts containing the 487 hazardous waste sites in the 1982 HRS Sample. In Panel B, each observation is composed of the average of all variables across tracts that share a border with the Panel A tracts. In Panels C and D, the sample includes the land area within circles with radii of two and three miles centered at each site's longitude and latitude. The means of the 1980 values of the total housing stock in the four samples are \$71, \$552, \$311, and \$736 million, respectively.

The column (1) specification adjusts for 1980 housing prices only and is based on the least squares fitting of equation (5). The remainder of the specifications uses the IV strategy outlined in equations (5) and (7). The controls in columns (2)–(4) are identical to the three specifications in Table III.

The specifications in columns (5)–(7) are the three RD-style approaches that all build on the column (4) specification. In column (5), the 1982 HRS score and its square are added to the column (4) specifications. In column (6), the individual pathway scores are added to the column (4) specifications. Column (7) fits the column (4) specification on the RD sample of the 227 sites with 1982 HRS scores between 16.5 and 40.5. The sample and specification details are noted in the row headings at the bottom of the table.

The Panel A results suggest that a site's placement on the NPL has a modest impact on the growth of property values in its own Census tract, relative to tracts with sites that narrowly missed placement on the NPL. The point estimates indicate an

TABLE IV
QUASI-EXPERIMENTAL ESTIMATES OF THE EFFECT OF NPL STATUS ON HOUSE PRICES, SAMPLES BASED ON THE 1982 HRS SAMPLE SITES

					RD-style estimators		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
			A. Own Census tract				
1(NPL status by 2000)	0.035	0.037	0.043	0.047	0.007	0.022	0.027
	(0.031)	(0.035)	(0.031)	(0.027)	(0.063)	(0.042)	(0.038)
			B. Adjacent Census tracts				
1(NPL status by 2000)	0.071	0.066	0.012	0.015	−0.006	−0.002	0.001
	(0.031)	(0.035)	(0.029)	(0.022)	(0.056)	(0.035)	(0.035)
			C. Two-mile radius from hazardous waste sites				
1(NPL status by 2000)	0.021	0.019	0.011	0.001	0.023	–0.018	–0.007
	(0.028)	(0.032)	(0.029)	(0.023)	(0.054)	(0.035)	(0.034)
Ho: > 0.138, *p*-value	.000	.000	.000	.000	.018	.000	.000
			D. Three-mile radius from hazardous waste sites				
1(NPL status by 2000)	0.059	0.055	0.035	–0.004	–0.027	–0.024	–0.006
	(0.033)	(0.038)	(0.031)	(0.022)	(0.051)	(0.034)	(0.034)
Ho: > 0.058, *p*-value	.483	.467	.236	.003	.048	.007	.031
1980 ln house price	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Instrument for 1 (NPL 2000)	No	Yes	Yes	Yes	Yes	Yes	Yes
1980 housing charasteristics	No	No	Yes	Yes	Yes	Yes	Yes
1980 economic and demographic variables	No	No	No	Yes	Yes	Yes	Yes
State fixed effects	No	No	No	Yes	Yes	Yes	Yes
Quadratic in 1982 HRS score	No	No	No	No	Yes	No	No
Control for pathway scores	No	No	No	No	No	Yes	No
RD sample	No	No	No	No	No	No	Yes

Notes: The entries report the results from 28 separate regressions. The ln (2000 median house price) is the dependent variable throughout the table. In Panels A and B (C and D) the samples are based on the 1982 HRS sites and N is 487 (483) in columns (1) through (6). Column (7) utilizes the RD sample of the 227 (226) sites in Panels A and B (C and D) with 1982 HRS scores between 16.5 and 40.5. The entries are the regression coefficients and heteroscedastic consistent standard errors (in parentheses) associated with the NPL indicator. The NPL indicator is instrumented with an indicator for whether the tract had a hazardous waste site with a 1982 HRS score exceeding 28.5 in columns (2) through (7); in column (1) the results come from an OLS approach. Panels C and D also report p-values from tests of whether the NPL parameters multiplied by the value of the housing stock in 1980 exceeds $43 million, which is our best estimate of the cost of the average cleanup. The values of the housing stocks in 1980 in the four panels are roughly $75, $552, $311, and $736 (millions of year-2000 $), respectively. The units of observation are the Census tract that contains the site (Panel A), tracts that share a border with the site (Panel B), the areas within a circle of two-mile radius from the site (Panel C), and the areas within a circle of three-mile radius from the site (Panel D). See the notes to Table III, the text, and the Data Appendix for further details.

increase in prices that ranges from 0.7% to 4.7%, but they all have associated t-statistics less than 2. The RD specifications in columns (5)–(6) produce the smallest point estimates (although they are also the least precise).

Panel B presents the adjacent tract results. The point estimates from the most credible specifications in columns (4)–(7) range between −0.6% and 1.5%. Further, zero cannot be rejected at conventional levels for any of them. Thus, there is little evidence of meaningful gains in housing prices outside the site's own Census tract.

Panels C and D summarize the total gain in housing prices associated with a site's placement on the NPL by using the two- and three-mile-radius circle samples. They also report whether the cleanups pass cost-benefit tests analogous to those in Table III. The threshold housing price gains are 13.8% and 5.8%.

The circle sample results provide further evidence that the NPL designation has little effect on housing prices. In the column (4)–(7) specifications, six of the eight point estimates are negative and the largest indicates an increase of just 2.3%. Further, in all seven of the two-mile specifications and the most reliable three-mile ones, the null that the gain in housing prices exceeds the break-even threshold is rejected at conventional significance levels. These findings stand in sharp contrast to the conclusions suggested by the results from the conventional approach in Table III.

Figure V provides an opportunity to better understand the source of these regression results. It plots the nonparametric regressions of year-2000 residual housing prices (after adjustment for the column (4) covariates) against the 1982 HRS score in the two-mile-radius sample. The nonparametric regression is estimated separately below (dark line) and above (light line) the 28.5 threshold. It confirms that there is little association between year-2000 residual housing prices and 1982 HRS scores. A comparison of the plots at the regulatory threshold is of especial interest in light of the large increase in NPL status there. It is apparent that the moving averages from the left and right are virtually equal at the threshold.

We conducted a number of other specification checks. We failed to find evidence of greater price responses in Census tracts with the highest population densities, where quantity responses are more constrained. Additionally, the results are robust to several other specification checks that include using the ln of the mean (rather than the median) house price as the dependent variable, using the difference between the natural logarithms of year-2000 and year-1980 house prices as the dependent variable, controlling for the fraction of Census tracts within the two-mile

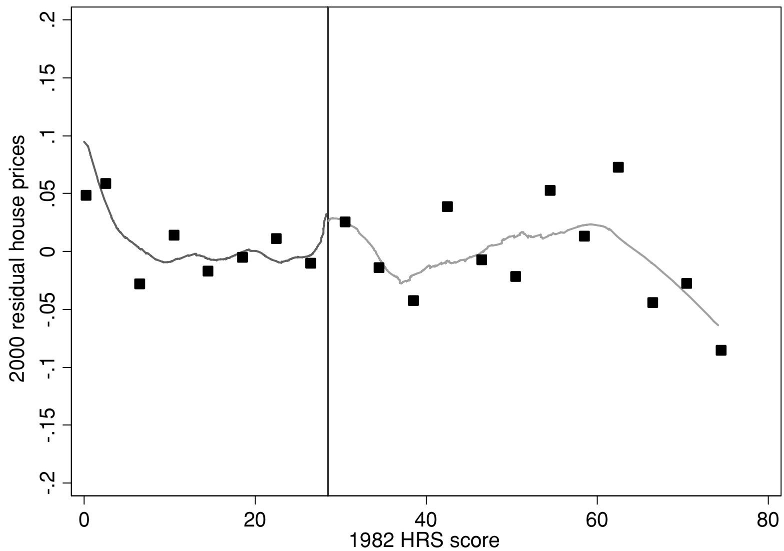

FIGURE V
Year-2000 Residual House Prices by 1982 HRS Score, Sample of Two-Mile-Radius Circles around 1982 HRS Sites

The figure plots the results from nonparametric regressions between year-2000 residual housing prices from areas within a two-mile-radius circle around the 1982 HRS Sample sites after adjustment for the covariates in the column (4) specification of Table IV (except the indicator for an HRS score above 28.5) and the 1982 HRS scores. The figure provides a *qualitative* graphical exploration of the regression results. The relationship between housing prices and 1982 HRS scores cannot be exactly inferred from this graph, because the HRS score has not been adjusted for the column (4) covariates. However, the meaningfulness of this graph is supported by Table II's finding that the covariates are well balanced among sites with 1982 HRS scores above and below the regulatory threshold, especially close to it.

The nonparametric regressions use Cleveland's (1979) tricube weighting function and a bandwidth of 0.5. These plots are done separately for sites below (dark-colored line) and above (light-colored line) the 28.5 regulatory threshold. The data points present the mean probabilities in the same four-unit intervals of the HRS score as in Figures III and IV. The finding of little association between year-2000 residual housing prices and the 1982 HRS score is robust to the use of a rectangular weighting function and alternative bandwidths. See the notes to Figure IV and the text for further details.

circles with a boundary change between 1980 and 2000, testing for a price response in 1990, and adding the 1970 values of the controls (including ln 1970 housing prices) as separate covariates to adjust for preexisting trends in the subsample where these variables are available.[18]

18. The own Census tract sample regression results for some of these specification checks are presented by Greenstone and Gallagher (2005). That version of

These specification checks all lead to the same qualitative finding that a site's addition to the NPL has little effect on the growth of nearby housing prices nearly twenty years later. It is impossible to rule out positive impacts on prices, but the most reliable specifications fail to provide a single case where the estimated price increases exceed the costs of the cleanups.

VI.D. Quasi-Experimental Estimates of the Impact of Superfund Cleanups on Rental Rates

We now turn to using the ln median rental rates as the outcome variable. Rental units account for roughly 20% of all housing units and generally differ on observable characteristics from owner-occupied homes. Part of this outcome's appeal is that rental rates are a measure of the current value of housing services, and so it is possible to abstract from the problem with the housing price outcome that individuals' expectations about time until the completion of the cleanup are unknown. Further, it is possible to test whether the impact on the value of local housing services varies at different stages of the cleanups.

Table V presents separate estimates of the effect of the different stages of the remediation process on the ln median rental rate from the two-mile-radius circle sample. We stack equations for 1990 and 2000 ln rental rates, and so there are two observations per county. The 1980 housing characteristic variables are calculated across rental units, rather than across owner-occupied units as in housing price analysis. The effects of the controls listed in the row headings are allowed to differ in 1990 and 2000.

The indicator variable for NPL status is replaced by three independent indicator variables. They are equal to 1 for sites that at

the paper also reports on a test of whether there was greater housing price appreciation near sites where the groundwater was heavily contaminated and residents used well water for drinking. We assumed that cleanups would be highly valued in these areas; however, this test failed to find significant evidence of differential house price appreciation in these areas. No remediation activities took place at the eleven sites in the 1982 HRS sample for which all RODs received the "no further action" classification. When observations from near these sites are dropped, the regression results are virtually identical to those in Table IV. Additionally, we implemented the regression discontinuity estimators without instrumenting for NPL status. This approach produced generally smaller estimated increases in house prices than those in Table IV (in fact, they are generally negative). Finally, we would have liked to test whether the effects of cleanups differed for large sites or ones where the estimated costs of cleanup are high (so-called megasites) but the size and estimated cost data are only available for NPL sites.

TABLE V

QUASI-EXPERIMENTAL ESTIMATES OF STAGES OF SUPERFUND CLEANUPS ON HOUSING RENTAL RATES, SAMPLE OF TWO-MILE-RADIUS CIRCLES AROUND 1982 HRS SAMPLE SITES

			RD-style estimators		
	(1)	(2)	(3)	(4)	(5)
1(NPL only)	0.126	−0.018	−0.040	−0.054	−0.043
[115 sites, mean HRS = 40.2]	(0.046)	(0.033)	(0.049)	(0.037)	(0.051)
1(ROD & incomplete remediation)	0.106	−0.017	−0.045	−0.059	−0.075
[329 sites, mean HRS = 44.3]	(0.030)	(0.022)	(0.041)	(0.028)	(0.032)
1(construction complete or NPL deletion)	0.062	0.002	−0.023	−0.036	−0.034
[214 sites, mean HRS = 41.6]	(0.032)	(0.021)	(0.041)	(0.028)	(0.031)
p-value from F-test of equality	.22	.59	.51	.47	.37
1980 rental rate	Yes	Yes	Yes	Yes	Yes
1980 housing characteristics of rental units	No	Yes	Yes	Yes	Yes
1980 economic and demographic variables	No	Yes	Yes	Yes	Yes
State fixed effects	No	Yes	Yes	Yes	Yes
Quadratic in 1982 HRS score	No	No	Yes	No	No
Control for pathway scores	No	No	No	Yes	No
RD sample	No	No	No	No	Yes

Notes: The entries report the results from five separate instrumental variable regressions. The ln (median rental rate) is the dependent variable throughout the table. The sample is composed of two-mile-radius circles around the 1982 HRS sample sites. There are two observations per circle, one for 2000 and one for 1990. The resulting sample sizes in columns (1) through (4) are 966, 960, 960, and 452, respectively. Here, the indicator variable for NPL status has been replaced by three independent indicator variables. They are equal to 1 for sites that by 1990 or 2000 were placed on the NPL but no ROD had been issued, had been issued an ROD but remediation was incomplete, and had been diagnosed "construction complete" or deleted from the NPL, respectively. The instruments are the interactions of the indicator for a 1982 HRS score above 28.5 and these three independent indicators. The table reports the instrumental-variable parameter estimates and standard errors clustered at the site level for the three indicators of cleanup status. The table also reports the p-value associated with an F-test that the three parameters are equal. The effect of all of the controls listed in the row headings are allowed to differ in 1990 and 2000. See the notes to the previous tables and the text for further details.

the time of the observation (i.e., 1990 or 2000) were placed on the NPL but no ROD had been issued; issued a ROD but were not completely remediated; and "construction complete" or deleted from the NPL. The instruments are the interactions of the indicator for a 1982 HRS score above 28.5 and these three independent indicators. Table V reports the three point estimates and their standard errors, which allow for clustering at the site level. It also reports the p-value from an F-test of the null hypothesis that the three estimated parameters are equal. The number of sites in each category and the mean HRS score are listed in brackets.

There is some evidence that higher voter turnout and per capita income are associated with the speed with which a site moves through the cleanup process and the stringency of cleanups (Gupta, Van Houtven, and Cropper 1995, 1996; Viscusi and Hamilton 1999; Sigman 2001). For this reason, the two-stage least-squares strategy is unlikely to purge these sources of endogeneity. Consequently, these three parameter estimates should be considered associational or descriptive.

There are a few important findings. First, sites in the "NPL Only" category have been on the NPL for either 7 or 17 years, but the EPA has not developed a remediation plan for them yet. The estimates from the more reliable specifications in columns (2) through (5) suggest that there is little effect on rental rates near these sites. This finding *contradicts* the key prediction of the "stigma" hypothesis[19] that a site's placement on the NPL leads to an immediate reduction in the value of housing services near the site. This would occur as residents revise upward their expectation of the risks from living near the site.

Second, in the more reliable specifications, three of the four estimates for the "Construction Complete or NPL Deletion" indicator are negative, and zero cannot be rejected for any of them. This finding is telling, because these sites have been fully remediated and yet there is little effect on rental rates.

Third, the null that the three parameter estimates are equal cannot be rejected in any of the specifications. This finding demonstrates that the approximately zero effect on housing prices is not due to the averaging of a positive effect at fully remediated sites and a negative effect at sites where remediation is incomplete or has not been initiated. Overall, these results complement the housing price findings that Superfund cleanups have small effects on the value of local housing services.

VI.E. Quasi-Experimental Estimates of the Impact of NPL Status on Sorting

If consumers value Superfund cleanups, then the cleanups should cause individuals to sort such that there is an increase in

19. The stigma hypothesis is poorly defined, but one version is that a site's placement on the NPL causes nearby residents to revise their expectation of its health risk upward permanently so that the value of nearby housing services is lower even after remediation is completed. Harris (1999) reviews the stigma literature. McCluskey and Rausser (2003) and Messer et al. (2004) provide empirical case study tests.

the number of people who place a high value on environmental quality living near NPL sites. Table VI tests for changes in residents' income and wealth (i.e., education) and demographic characteristics that proxy for taste for environmental quality, as well as total population. The entries report the parameter estimate and standard error on the dummy for NPL status from the same five specifications in Table V. The sample is the two-mile-radius circle sample based on the 1982 HRS Sample sites. The means of the 1980 variable and its 2000–1980 change are in square brackets.

The estimated impacts of the NPL designation on the measures of income and wealth are inconsistent across specifications with about half positive and half negative. The null of a zero impact cannot be rejected in any of the more reliable specifications. We had hypothesized that the cleanups would increase the demand for these areas among families with young children. However, Panel B fails to provide any meaningful evidence that the NPL designation leads to changes in the age composition of a tract's population. It is unclear how to apply the environmental justice hypothesis to a setting where environmental quality increases but prices are largely unchanged. Although the interpretation is unclear, there is some evidence that the percentage of blacks declines but none of the estimates would be judged to be statistically different from zero. Finally, the instability of the point estimates across specifications in Panel C suggests that there is little effect on total population.

Notably, this table's qualitative findings are unchanged by the inclusion of 1980 housing prices and housing characteristics as covariates. Overall, there is little evidence that the NPL designation is associated with changes in variables that proxy for shifts in demand for environmental quality.

VI.F. Quasi-Experimental Estimates of the Impact of NPL Status on Housing Supply

An increase in the supply of housing units in the vicinity of an NPL site would provide evidence that Superfund cleanups increase the value of the surrounding land. In Table VII, we test this possibility with the two- and three-mile-radius samples, using the same five specifications from Tables V and VI. These results are also inconsistent across specifications. The most reasonable conclusion is that the assignment of the NPL designation has little effect on the supply of housing.

TABLE VI
QUASI-EXPERIMENTAL ESTIMATES OF 2000 NPL STATUS ON 2000 DEMAND SHIFTERS, SAMPLE OF TWO-MILE-RADIUS CIRCLES AROUND 1982 HRS SAMPLE SITES

			RD-style estimators		
	(1)	(2)	(3)	(4)	(5)
		A. Income and wealth			
Household income	2,698	1,431	−1,232	123	−593
[1980 mean: 42,506;	(1237)	(1302)	(3130)	(1900)	(2227)
2000–1980 mean: 14,301]					
Public assistance (%)	−0.007	−0.005	0.008	0.003	0.004
[1980 mean: 0.078;	(0.003)	(0.003)	(0.007)	(0.004)	(0.005)
2000–1980 mean: 0.000]					
College graduates (%)	0.001	−0.001	−0.009	−0.005	−0.010
[1980 mean: 0.134;	(0.007)	(0.007)	(0.019)	(0.011)	(0.013)
2000–1980 mean: 0.082]					
		B. Demographics demand shifters			
Population under age 6 (%)	0.000	−0.000	0.002	0.000	0.001
[1980 mean: 0.086;	(0.001)	(0.001)	(0.003)	(0.002)	(0.002)
2000–1980 mean: −0.019]					
Population over age 65 (%)	−0.000	−0.003	−0.014	−0.007	−0.005
[1980 mean: 0.106;	(0.004)	(0.004)	(0.009)	(0.005)	(0.005)
2000–1980 mean: 0.019]					
Black (%)	−0.015	−0.016	−0.007	−0.012	−0.008
[1980 mean: 0.088;	(0.008)	(0.007)	(0.018)	(0.010)	(0.009)
2000–1980 mean: 0.026]					
		C. Total population			
Total population	1,864	514	−2,342	−23	−289
[1980 mean: 18,038;	(526)	(522)	(1,556)	(809)	(811)
2000–1980 mean: 1,226]					
1980 dependent variable	Yes	Yes	Yes	Yes	Yes
State fixed effects	No	Yes	Yes	Yes	Yes
Quadratic in 1982 HRS score	No	No	Yes	No	No
Control for pathway scores	No	No	No	Yes	No
RD sample	No	No	No	No	Yes

Notes: The entries report the results from 35 separate instrumental variable regressions. The year-2000 values of the italicized variables are the dependent variables. The unit of observation is the area within a circle of a two-mile radius around the 1982 HRS sample sites. The sample sizes are 483 in columns (1) through (4) and 226 in column (5). The variable of interest is an indicator that equals 1 for observations from tracts with a hazardous waste site that was placed on the NPL by 2000, and this variable is instrumented with an indicator for whether the tract had a hazardous waste site with a 1982 HRS score exceeding 28.5. The entries are the regression coefficients and heteroscedastic consistent standard errors (in parentheses) associated with the NPL indicator. The mean of the dependent variable in 1980 and the mean change between 2000 and 1980 are reported in square brackets (household income is reported in year-2000 dollars). See the notes to the previous tables and the text for further details.

VII. INTERPRETATION AND POLICY IMPLICATIONS

This paper has shown that across a wide range of housing market outcomes, there is little evidence that Superfund cleanups

TABLE VII
QUASI-EXPERIMENTAL ESTIMATES OF THE EFFECT OF YEAR-2000 NPL STATUS ON HOUSING SUPPLY, SAMPLES OF TWO-MILE- AND THREE-MILE-RADIUS CIRCLES AROUND 1982 HRS SAMPLE SITES

			RD-style estimators		
	(1)	(2)	(3)	(4)	(5)
Total housing units					
Two-mile radius from hazardous waste sites	332	94	−829	−208	−255
[1980 mean: 6,835; 2000–1980 mean: 853]	(139)	(147)	(349)	(210)	(187)
Three-mile radius from hazardous waste sites	1,046	292	−903	61	−77
[1980 mean: 15,657; 2000–1980 mean: 1,960]	(317)	(278)	(669)	(408)	(356)
1980 dependent variable and ln house price	Yes	Yes	Yes	Yes	Yes
1980 housing characteristics	No	Yes	Yes	Yes	Yes
1980 economic and demographic variables	No	Yes	Yes	Yes	Yes
State fixed effects	No	Yes	Yes	Yes	Yes
Quadratic in 1982 HRS score	No	No	Yes	No	No
Control for pathway scores	No	No	No	Yes	No
RD sample	No	No	No	No	Yes

Notes: The entries report the results from ten separate instrumental variable regressions. The dependent variables are the number of housing units. The results are reported for the cases in which the units of observation are the areas within a circle of two- and three-mile radius around the 1982 HRS sample sites. The samples sizes are 483 in columns (1) through (4) and 226 in column (5). The dependent and independent variables are calculated as weighted means across the relevant Census tracts, where the weight is the fraction of the tract that falls within the circle multiplied by the tract's 1980 population. The variable of interest is an indicator for NPL status and this variable is instrumented with an indicator for whether the tract had a hazardous waste site with a 1982 HRS score exceeding 28.5. The entries are the regression coefficients and heteroscedastic consistent standard errors (in parentheses) associated with the NPL indicator. The means of the dependent variable in 1980 and the mean change between 2000 and 1980 are reported in square brackets. See the notes to the previous tables, the text, and the Data Appendix for further details.

increase local residents' welfare substantially. In light of the significant resources devoted to these cleanups and the claims of large health benefits, this finding is surprising. This section reviews three possible explanations.

First, the individuals that choose to live near these sites before and after the cleanups may have a low WTP to avoid exposure to hazardous waste sites. In this case, society provides these individuals a good that they do not value highly. It is possible (and perhaps likely) that there are segments of the population with a high WTP to avoid exposure to hazardous waste sites. It may even be the case that the population average WTP is substantial. However, the policy-relevant parameter is the WTP of the population that lives near these sites, and this is the parameter that the paper has estimated.

Second, consumers may believe that the cleanups do not appreciably alter the health risks of living near a Superfund site. In fact, the epidemiological literature has not found decisive evidence of substantial health benefits from the cleanups (Vrijheid 2000; Currie, Greenstone, and Moretti 2008). Consequently, consumers may believe that the reductions in risk are small and rationally place a low value on them. Of course, the discovery of large health improvements in the future could cause consumers to increase their valuations of the cleanups and this would presumably be reflected in the housing market.[20]

Third, the non-NPL sites may have also received complete remediations under state or local land reclamation programs. In this case, a zero result is to be expected since both NPL and non-NPL sites would have received the same treatment. We investigated this possibility by conducting an extensive search for information on remediation activities at these sites.[21]

From these investigations, we concluded that the cleanup activities were dramatically more ambitious and costly at NPL sites. For example, we were unable to find evidence of any remediation activities by 2000 at roughly 60% of the non-NPL sites. Further, among the remaining 40% of non-NPL sites where there was evidence of cleanup efforts, the average expenditure was roughly \$3 million. This is about \$40 million less than our estimate of the average cost of a Superfund cleanup. This difference is not surprising, because the state and local cleanups were often limited to restricting access to the site or containing the toxics, rather than

20. Another possibility is that consumers are imperfectly informed about the location of Superfund sites and their cleanups. We think this is unlikely, because local media often devote extensive coverage to local Superfund sites and their cleanups. Further, at least a few states (e.g., Alaska and Arizona) require home sellers to disclose whether there are hazardous waste sites in close proximity. See Davis (2004) on the capitalization of perceived health risks.

21. Specifically, we filed Freedom of Information Act requests with the EPA for information on these sites and followed any leads from these documents. We also searched the Superfund Web site and the sites of state departments of environmental quality and used Internet search engines. Additionally, we contacted national and regional EPA personnel and state and local environmental officials. Although we expended considerable effort in these searches, there is no centralized database about these sites, and so we cannot be certain that further efforts would not turn up different information.

trying to achieve Superfund's goal of returning the site to its "natural state." Nevertheless, some remediation took place at these sites, and so it may be appropriate to interpret the results as the impact of the additional $40 million cost of Superfund cleanups.

In our view, the most likely explanations are that the people that choose to live near these sites do not value the cleanups or that consumers have little reason to believe that the cleanups substantially reduce health risks. In either case, the results mean that local residents' gain in welfare from Superfund cleanups falls well short of the costs. Unless there are substantial benefits that are not captured in local housing markets,[22] less ambitious cleanups such as the erection of fences, posting of warning signs around the sites, and simple containment of toxics might be a more efficient use of resources.

VIII. Conclusions

This study has used the housing market to develop estimates of the local welfare impacts of Superfund-sponsored cleanups of hazardous waste sites. The basis of the analysis is a comparison of housing market outcomes in the areas surrounding the first 400 hazardous waste sites chosen for Superfund cleanups to the areas surrounding the 290 sites that narrowly missed qualifying for these cleanups. We find that Superfund cleanups are associated with economically small and statistically insignificant changes in residential property values, property rental rates, housing supply, total population, and types of individuals living near the sites. These findings are robust to a series of specification checks, including the application of an RD design based on knowledge of the selection rule. Overall, the preferred estimates suggest that the local benefits of Superfund cleanups are small and appear to be substantially lower than the $43 million mean cost of Superfund cleanups.

More broadly, this paper makes two contributions. First, it models the consequences of a quasi-experiment that improves a local amenity in the context of the hedonic model. The key theoretical findings are that if consumers value the amenity, then

22. It is possible that there are other benefits of these cleanups that are not captured in the local housing market, including health and aesthetic benefits to individuals that do not live in close proximity to Superfund sites, reductions in injuries to ecological systems, and protection of groundwater.

there will be increases in local housing prices and new home construction. Further, there will be taste-based sorting such that individuals that place a high value on the amenity will move to areas where they can consume it. Second, it contributes to a growing body of research (Black 1999; Chay and Greenstone 2005; Deschenes and Greenstone 2007) demonstrating that it is possible to identify research designs that mitigate the confounding that has historically undermined the credibility of conventional hedonic approaches to valuing nonmarket goods.

Perhaps most importantly, this paper has demonstrated that the combination of quasi-experiments and hedonic theory is a powerful method for using markets to value environmental and other nonmarket goods.

Data Appendix

This Data Appendix provides information on a number of aspects of the data set that we compiled to conduct the analysis for this paper. Because of space constraints, this is an abridged version of the Data Appendix that is available in Greenstone and Gallagher (2005). The longer Data Appendix includes details on the following variables: the size of the hazardous waste sites, whether a site has achieved the construction complete designation, the placement of sites into 2000 Census tracts, and the determination of expected and actual remediation costs.

A. Covariates in Housing Price and Rental Rate Regressions

The following are the control variables used in the housing price and rental rate regressions. They are listed by the categories indicated in the row headings at the bottom of these tables. All of the variables are measured in 1980 and are measured at the Census tract level (or are the mean across sets of Census tracts, for example, tracts that share a border with a tract containing a hazardous waste site).[23]

1. *1980 ln House Price:* ln mean value of owner-occupied housing units in 1980 (note that the median is unavailable in 1980).
2. *1980 Housing Characteristics:* total housing units (rental and owner occupied); percent of total housing units (rental

23. In the rental regressions in Table V, the owner-occupied housing variables are replaced with renter-occupied versions of the variables.

and owner occupied) that are occupied; total housing units owner occupied; percent of owner-occupied housing units with 0, 1, 2, 3, 4, and 5 or more bedrooms; percent of owner-occupied housing units that are detached; percent of owner-occupied housing units that are attached; percent of owner-occupied housing units that are mobile homes; percent of owner-occupied housing units built within the past year, 2 to 5 years ago, 6 to 10 years ago, 10 to 20 years ago, 20 to 30 years ago, 30 to 40 years ago, more than 40 years ago; percent of all housing units without a full kitchen; percent of all housing units that have no heating or rely on a fire, stove, or portable heater; percent of all housing units without air-conditioning; and percent of all housing units without a full bathroom.

3. *1980 Economic Conditions:* mean household income, percent of households with income below poverty line, unemployment rate, and percent of households that receive some form of public assistance.
4. *1980 Demographics:* population density, percent of population Black, percent of population Hispanic, percent of population under age 18, percent of population 65 or older, percent of population foreign born, percent of households headed by females, percent of households residing in same house as 5 years ago, percent of individuals aged 16–19 that are high school dropouts, percent of population over 25 that failed to complete high school, and percent of population over 25 that have a B.A. or better (i.e., at least 16 years of education).

B. Assignment of HRS Scores and Their Role in the Determination of the NPL

The HRS test scores each pathway from 0 to 100, where higher scores indicate greater risk.[24] The pathway scores are a multiplicative function of the waste characteristics, likelihood of

24. The capping of individual pathways and of attributes within each pathway is one limiting characteristic of the test. There is a maximum value for most scores within each pathway category. Also, if the final pathway score is greater than 100, then this score is reduced to 100. The capping of individual pathways creates a loss of precision of the test since all pathway scores of 100 have the same effect on the final HRS score but may represent different magnitudes of risk. See the EPA's *Hazard Ranking System Guidance Manual* (1992) for further details on the determination of the HRS score.

release, and characteristics of the potentially affected population. The logic is, for example, that if twice as many people are thought to be affected via a pathway, then the pathway score should be twice as large.

The final HRS score is calculated using the following equation: HRS Score $= [(S_{\mathrm{gw}}^2 + S_{\mathrm{sw}}^2 + S_{\mathrm{a}}^2)/3]^{1/2}$, where S_{gw}, S_{sw}, and S_{a}, denote the groundwater migration, surface water migration, and air migration pathway scores, respectively. It is evident that the effect of an individual pathway on the total HRS score is proportional to the pathway score. (In 1990, the EPA revised the HRS test and soil became a fourth pathway.)

HRS scores cannot be interpreted as strict cardinal measures of risk. A number of EPA studies have tested how well the HRS represents the underlying risk levels based on cancer and noncancer risks (Brody 1998). The EPA has concluded that the late-1980s version of the HRS test is an ordinal test but that sites with scores within 4 points of each other pose roughly comparable risks to human health (EPA 1991).[25]

From 1982 to 1995, the EPA assigned all hazardous waste sites with an HRS score of 28.5 or greater to the NPL. Additionally, the original legislation gave every state the right to place one site on the NPL without the site having to score at or above 28.5 on the HRS test. As of 2003, 38 states have used their exception. It is unknown whether these sites would have received an HRS score above 28.5. Six of these "state priority sites" were included on the original NPL released in 1983, but because of their missing HRS scores, these six sites are excluded from this paper's analysis.

C. Matching of Year-2000 Census Tracts to 1980 and 1990 Censuses

The Census tract is used as the unit of analysis, because it is the smallest aggregation of data that is available in the 1980, 1990, and 2000 U.S. Census. As noted in the text, year-2000 Census tract boundaries are fixed so that the size and location of the Census tract is the same for the 1980 and 1990 Census data. The fixed Census tract data boundaries were provided by Geolytics, a private company. Information on how the 1980 and 1990 Census

25. The EPA states that the early 1980s version of the HRS test should not be viewed as a measure of "absolute risk," but that "the HRS does distinguish relative risks among sites and does identify sites that appear to present a significant risk to public health, welfare, or the environment" (*Federal Register* 1984).

tracts were adjusted to fit the 2000 Census tract boundaries can be found on their Web site (www.geolytics.com). Further, Greenstone and Gallagher (2005) provide some details.

D. Neighbor Samples

We use two approaches to define the set of houses outside each site's tract that may be affected by the cleanup. We refer to these sets of houses as "neighbors."

The first approach defines the neighbors as all Census tracts that share a border with the tract that contains the site. GIS software was used to find each primary Census tract and extract the identity of its adjacent neighbors. In the 1982 HRS Sample, the maximum number of neighboring Census tracts is 21 and the median is 7. The population of each adjacent Census tract was used to weight the housing price, housing characteristics, and demographic variables for each tract when calculating the mean adjacent neighbor values.

The second approach defines neighbors based on circles of varying radii around the exact location of the site. GIS software is used to draw a circle around the point representing the site (generally the center of the site, but sometimes the point associated with the street address). For example, in the two-mile sample, the GIS program draws circles with radii of two miles around each of the sites. For a given site, data from all Census tracts that fall within its two-mile-radius circle (including the tract containing the site) are used to calculate the mean housing values, housing and demographic characteristics, and economic variables. To calculate these weighted means, each Census tract within the circle is weighted by the product of its population and the portion of its total area that falls within the circle. For the two- (three-) mile ring the maximum number of tracts inside the ring is 80 (163), with a mean and median of 9.9 and 8 (18.2 and 12).

Finally, we were able to place 487 of the 690 sites in the 1982 HRS Sample in Census tracts with nonmissing house price data. We obtained the exact longitude and latitude for 483 of these sites. Thus, the circle samples have 483 observations, while the sample size for the own Census tract and adjacent neighbor tract samples is 487.

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