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Reviewed work(s):
Source: *The Review of Economics and Statistics*, Vol. 82, No. 3 (Aug., 2000), pp. 439-451
Published by: The MIT Press
Stable URL: http://www.jstor.org/stable/2646804
Accessed: 16/08/2012 12:52

PRIVATE VALUES OF RISK TRADEOFFS AT SUPERFUND SITES: HOUSING MARKET EVIDENCE ON LEARNING ABOUT RISK

Ted Gayer, James T. Hamilton, and W. Kip Viscusi*

Abstract—This paper incorporates a Bayesian learning model into a hedonic framework to estimate the value that residents place on avoiding cancer risks from hazardous-waste sites. We show that residents are willing to pay to avoid cancer risks from Superfund sites before the U.S. Environmental Protection Agency (EPA) releases its assessment (known as the Remedial Investigation) of the site. Residents' willingness to pay to avoid risks actually decreases after the release of the Remedial Investigation, suggesting that the information lowers the perceived levels of risk. This estimated willingness to pay implies a statistical value of cancer similar to the value-of-life estimates in labor market studies.

I. Introduction

WHEN asked to evaluate the severity of environmental hazards, people often rank hazardous-waste sites as a top environmental threat. In answering a similar question, an Environmental Protection Agency (EPA) expert panel characterized hazardous-waste sites as only a low-to-medium threat to the public.[1] The same disparity in risk rankings is evident in the McClelland, Schulze, and Hurd (1990) survey of health-risk beliefs of residents near a landfill, which finds that the residents' assessments of the risk were much higher than the assessments of experts.

These studies suggest that the public overestimates cancer risks from hazardous-waste sites, which would be consistent with evidence that people overestimate low-probability events. This overreaction to risk may generate pressure on the EPA to undertake expensive site remediations through its Superfund program. In addition, residents surrounding Superfund sites may prefer more ambitious and, consequently, more costly remediations, because costs are spread across taxpayers and consumers. Viscusi and Hamilton (1996) find that the median cleanup cost per case of cancer prevented by the Superfund program exceeds one billion dollars per expected cancer case avoided, which places it among the most expensive government programs for reducing risk.

To assess properly the benefits of cleaning up Superfund toxic-waste sites, one must distinguish between the private values that residents place on risk reduction and the values of risk reduction expressed publicly in surveys or implied in regulatory decisions. For this article, we have constructed a large risk and housing price data set for a local market using the choices people make in the greater Grand Rapids, Michigan, housing market. These data enable us to assess the value residents place on hazardous-waste risk reduction in their private decisions. By relying on market data instead of survey data, our results control for the incentive that residents have to press for stringent cleanups when others' money is being spent on risk remediation. Political pressures do appear to be consequential in driving cleanup decisions, as Viscusi and Hamilton (1999) find that the level of the EPA's remediation efforts is responsive to measures of the political participation of the surrounding community.

The greater Grand Rapids area contains seven Superfund toxic-waste sites. We formulate residents' assessments of cancer risk from these sites as a Bayesian process of updating prior assessments with information obtained from the EPA's assessment of site risks (contained in the site Remedial Investigation report) and from the local media. Using a composite measure of risk from the Superfund sites, we estimate the implicit value people place on risk reduction through the effect of risk on housing values. Our hypothesis is that residents demonstrate a willingness to pay for risk reduction even before the EPA releases its site Remedial Investigation. We also hypothesize that the EPA's release of the Remedial Investigation alters households' risk beliefs, resulting in a change in the effect of risk on housing values.

Estimation of the marginal effect of cancer risk on housing prices can generate an implied value of averting a statistical cancer. Portney (1981) was the first researcher to publish estimates of the value of life using a hedonic property model. He coupled the estimate of the price gradient with respect to total dustfall (obtained from a study on Allegheny County, Pennsylvania) with a separate EPA study that related total particulate concentration to mortality rates. By linking these studies, he demonstrated that the ratio of these two estimates is a measure of the statistical value of life, which he found to be $300,000 (1996 dollars).

We find that, before residents receive the risk information provided by the EPA's Remedial Investigation, their estimated value of a statistical cancer case is much higher than the value-of-life estimates found in job market studies. This result is consistent with broader evidence on risk-perception biases, which demonstrates that people tend to overestimate low-probability risks (Lichtenstein et al., 1978; Tversky & Kahneman, 1982). This overreaction can lead to a higher willingness to pay for a risk reduction.

After the release of the EPA's Remedial Investigation, residents update their risk perceptions. The postinformation estimated value of a statistical cancer case is similar to the value-of-life estimates found in previous labor market studies. Once residents are properly informed of the risks, their choices made in the greater Grand Rapids housing market indicate a value of hazardous-waste risk similar to the values of risk faced in other settings. This similarity between the risk–money tradeoff for avoiding hazardous-waste risks and the tradeoffs for job risks suggests that there is no evidence that consumers are overreacting to the

Received for publication May 2, 1997. Revision accepted for publication July 7, 1999.

* Georgetown University and University of California at Berkeley, Duke University, and Harvard University, respectively.

[1] See the U.S. EPA Report (1987) for a summary of the survey (conducted by the Roper Organization) and for the expert panel rankings.

The Review of Economics and Statistics, August 2000, 82(3): 439–451

hazardous-waste risks in their private decisions after the release of the EPA's Remedial Investigation.[2] Additionally, even before the release of the EPA's Remedial Investigation, residents' implied risk–money tradeoff is several orders of magnitude lower than regulatory expenditures per cancer case averted in the Superfund program. Thus, although surveys demonstrate that people express a high willingness to spend public funds on Superfund risk reduction, our results demonstrate that residents are much less willing to spend their own funds on risk reduction.

In section II, we model residents' perceptions of hazardous-waste site risks as a Bayesian learning process and link this model to a hedonic framework, which is tested by using the data described in section III. In section IV, we describe the results of different empirical specifications, which are used in section V to analyze reactions to site risks. In section VI, we offer conclusions about current assessments of individuals' reactions to Superfund site risks.

II. Theoretical Model

A. *The Hedonic Model*

We formulate individuals' subjective perceptions of the risk of cancer (π) arising from hazardous-waste risks as a Bayesian learning process. People are assumed to update their prior probability assessment of site risks based on information provided by the EPA's Remedial Investigation and by local publicity. Our learning model uses a beta distribution to characterize this Bayesian process.[3] This distribution is quite flexible and can assume a wide variety of skewed and symmetric shapes.

Individuals have a prior cancer risk assessment of p, which has associated informational content, φ_0. The information weight, φ_0, measures the precision of the prior risk assessment. It is equivalent to observing φ_0 draws from a Bernoulli urn in which a fraction, p, is occurrences of cancer. Our conjecture is that this prior probability is a function of the actual risks from the Superfund sites. People form their priors based in part on the observable characteristics of the site, past EPA involvement with the site, and local knowledge and perceptions of site hazards. People update their risk perceptions taking into account the probability, q, which is implied by information provided by the EPA's Remedial Investigation. The information provided by the EPA may serve as good news or as bad news; thus, q may be less than or greater than p. People also update their risk perceptions taking into account the probability, r, which is implied by information provided by the news media. Note that residents need not read the Remedial Investigation individually or consume each media article to be influenced by these information sources. The diffusion of information from these sources within the local real estate market can influence perceptions even among those who have not read site documents or specific media coverage. The risk implied by the Remedial Investigation has the informational content denoted as ξ_0, and the risk implied by the news media has the informational content denoted as κ_0. For simplicity, we treat φ_0, ξ_0, and κ_0 as given parameters and focus only on the risk levels p, q, and r.[4]

The cancer risk-perception function takes the form

$$\pi(p, q, r) = \frac{\varphi_0 p + \xi_0 q + \kappa_0 r}{\varphi_0 + \xi_0 + \kappa_0}. \tag{1}$$

By denoting the fraction of the total informational content associated with each information source as

$$\varphi = \frac{\varphi_0}{\varphi_0 + \xi_0 + \kappa_0}, \quad \xi = \frac{\xi_0}{\varphi_0 + \xi_0 + \kappa_0}, \quad \text{and} \quad \kappa = \frac{\kappa_0}{\varphi_0 + \xi_0 + \kappa_0},$$

the risk-perception function is rewritten as

$$\pi(p, q, r) = \varphi p + \xi q + \kappa r. \tag{2}$$

While the underlying hypothesis is that of a rational Bayesian learning model, other learning models may also be consistent with this linearly weighted average formulation. Our use of the Bayesian approach gives us a concrete economic interpretation of the coefficients, but it does not test explicitly whether people are Bayesians, as opposed to adhering to other learning frameworks in which a variety of sources of risk information may alter risk judgments.

Individuals maximize expected utility over two states of the world, with U_1 representing utility in the sick (cancer) state and U_2 representing utility in the healthy (non-cancer) state. We assume for any given level of income that people prefer being healthy ($U_2 > U_1$), that utility functions within states are risk-neutral or risk-averse, and that the marginal utility of income is greater when healthy. Utility in each state is a function of a vector of characteristics of the house, z, a composite good, x, and the visual disamenities of the site, s.[5] The consumer purchases one house at price h, which is a function of housing characteristics, risk perceptions, and the Superfund visual disamenities. The consumer's income is y.

Accounting for the separate health and visual aesthetic effects of Superfund sites yields a model in which consum-

[2] Note that the comparison is between values placed on mortality risk and values placed on cancer risk, in which type of cancer, latency period, and probability of death are considerations.

[3] Viscusi (1979) introduced this particular reparameterization of the Bayesian learning model with a beta distribution.

[4] We assume that the probabilities p, q, and r reflect the risks that are implied by a series of independent draws from the same Bernoulli urn, which reflects the risks from hazardous waste. Although these are independent sources of information, the risks implied will be related, as they all reflect the dangers of the same waste site. The overlapping information case can also yield an additive linear form, but the interpretation of the weights differs (Zeckhauser, 1971).

[5] We assume that only the closest site contributes visual disamenities.

ers maximize expected utility as follows:

$$\text{Max } V = \pi(p, q, r)U_1(x, z, s) + [1 - \pi(p, q, r)]U_2(x, z, s) \tag{3}$$

subject to

$$y = x + h(z, \pi(p, q, r), s). \tag{4}$$

By construction, consumer risk perceptions, $\pi(p, q, r)$, will be an increasing function of p and q (that is, $\xi_0/(\varphi_0 + \xi_0 + \kappa_0) > 0$, $\varphi_0/(\varphi_0 + \xi_0 + \kappa_0) > 0$). Therefore, the equilibrium conditions for the effect of higher informational risk values, p and q, on housing prices, and the expected signs are

$$\frac{\partial h}{\partial q} = \frac{(U_1 - U_2)\dfrac{\partial \pi}{\partial q}}{\pi\dfrac{\partial U_1}{\partial x} + (1 - \pi)\dfrac{\partial U_2}{\partial x}} < 0, \quad \text{and}$$
$$\frac{\partial h}{\partial p} = \frac{(U_1 - U_2)\dfrac{\partial \pi}{\partial p}}{\pi\dfrac{\partial U_1}{\partial x} + (1 - \pi)\dfrac{\partial U_2}{\partial x}} < 0, \tag{5}$$

which, because $\partial h/\partial q = (\partial h/\partial \pi)(\partial \pi/\partial q)$ and $\partial h/\partial p = (\partial h/\partial \pi)(\partial \pi/\partial p)$, reduces to

$$\frac{\partial h}{\partial \pi} = \frac{(U_1 - U_2)}{\pi\dfrac{\partial U_1}{\partial x} + (1 - \pi)\dfrac{\partial U_2}{\partial x}} < 0. \tag{6}$$

As first presented by Rosen (1974), the hedonic price function reflects the locus of tangencies between the offer and bid curves. The marginal price is equivalent to the marginal willingness to pay for an incremental decrease in objective risk. Therefore, one can compute the welfare effects of a marginal change in objective risk from the price gradient.

To estimate the welfare effects of a nonmarginal change in a characteristic, we would need to know the willingness-to-pay function. The endogeneity of marginal prices and quantities limits the use of instrumental variables in a two-stage estimation of willingness-to-pay. Bartik (1987) suggested using data from multiple markets in order to estimate the structural equations.[6] However, Epple (1987) showed that—even using multiple markets—very strong orthogonality conditions must be met to identify the equations. Bartik (1988) and Palmquist (1992) demonstrated that, for local disamenities (such as Superfund sites), the slope of the hedonic price function is an approximate measure of the willingness to pay for a nonmarginal change.

The impact of the release of the Remedial Investigation on perceptions enters the hedonic price analysis by a comparison of the price gradients before ($\partial h/\partial p$) and after ($\partial h/\partial \pi$) the EPA releases the Remedial Investigation. The Bayesian model suggests that people will demonstrate possibly different willingness to pay for risk reduction before and after the release of the Remedial Investigation. A comparison of these gradients indicates whether the willingness to pay for risk reduction increases or decreases given the information provided by the EPA's Remedial Investigation. If the information in the Remedial Investigation raises residents' perceptions of risk, then we would expect an increase in willingness to pay for risk reduction. If the Remedial Investigation information indicates that the site is not as hazardous as previously perceived, then we would expect a decrease in willingness to pay for risk reduction.

B. *The Empirical Specification*

We estimate the hedonic price function using the conventional practice of postulating the independent variable, the log of housing price adjusted for inflation (ln *Price*), as a function of a vector of structural variables (*Structural*) and a vector of neighborhood variables (*Neighborhood*).[7] These structural and neighborhood variables measure the characteristics of the house, which were denoted as z in the theoretical model. The empirical model also includes measures of the overall level of the environmental condition of the neighborhood. These measures are the number of other environmental disamenities within 0.25 mile from the house ($Sites_1$), between 0.25 and 0.5 mile from the house ($Sites_2$), between 0.5 and 0.75 mile from the house ($Sites_3$), and between 0.75 and 1.0 mile from the house ($Sites_4$). Prices are also a function of the Superfund aesthetic disamenities (*Visual*), which were denoted as s in the theoretical model. The empirical model also controls for fixed time effects and city effects by using dummy variables indicating the year of the sale (denoted with a subscript $t = 1, \ldots, 5$) and the city location of the house (denoted with a subscript $i = 1, \ldots, 4$).[8] A further enhancement, as outlined in the theoretical model, is that the model includes the role of risk from Superfund sites. The semilogarithmic form of the hedonic price function is expressed as

$$\ln Price = \alpha + \beta Structural + \gamma Neighborhood + \rho_i City_i + \tau_t Year_t + \zeta_1 Sites_1 + \cdots + \zeta_4 Sites_4 + \eta Visual + \delta\pi(p, q, r) + u. \tag{7}$$

[6] This approach results in identified structural equations only if consumer preferences are assumed to be the same across markets, while the price function is assumed to differ due to differences in the matching process (Kahn & Lang, 1988). It is difficult to assume that preferences are homogeneous across housing markets.

[7] See Bartik and Smith (1987) for a review.

[8] The omitted city dummy variable is for Grand Rapids, and the omitted annual dummy variable is for 1988.

If we expand the risk-learning model and recognize the components of risk beliefs π from equation (2), we can rewrite the hedonic price function as

$$\begin{aligned}\ln Price = \alpha &+ \beta Structural \\ &+ \gamma Neighborhood + \rho_i City_i + \tau_t Year_t \\ &+ \zeta_1 Sites_1 + \cdots + \zeta_4 Sites + \eta Visual \\ &+ \delta_1 p + \delta_2 q + \delta_3 r + u,\end{aligned} \tag{8}$$

where $\delta_1 = \delta\varphi$, $\delta_2 = \delta\xi$, and $\delta_3 = \delta\kappa$. As mentioned in the previous subsection, the prior and updated probabilities have a negative effect on housing values. The relative impact of the prior probability compared to the updated probability is $\delta_1/\delta_2 = \varphi/\xi = \varphi_0/\xi_0$. Thus, the regression estimates indicate the effect of risk on housing prices and the change in the magnitude of this effect after the release of the Remedial Investigation.

We operationalize the values of p, q, and r in the following manner. In the case of perceived cancer risk arising from Superfund sites, the prior probability, p, is characterized by the information known to the residents before the EPA's release of their Remedial Investigation.[9] In capturing the prior probability, p, we follow two approaches. In one approach, we set this value in the pre-Remedial Investigation release period equal to the objective risk level subsequently revealed in the EPA study. This approach assumes that people use observable information on risk to form accurate risk judgments in much the same manner that hedonic wage studies assume that workers are aware of Bureau of Labor Statistics objective risk measures. In a second approach, we examine the explicit influence of the observable risk factors that could potentially affect people's prior beliefs. Although it will not be possible to construct a pre-Remedial Investigation implicit value of cancer in this instance, it will be possible to assess whether the influence of these prior observable risk factors are in the expected direction and whether the post-Remedial Investigation tradeoffs reflect plausible values per expected cancer case.

The prior information available to residents includes the area of the closest Superfund site, the ranking of the closest site on the EPA's National Priorities List (which, for all sites, occurred before the housing sales examined in this study), the elapsed time since the closest Superfund site was placed on the National Priorities List, and the type of site (such as, landfill versus industrial chemical plant). A site receives a National Priorities List ranking according to its score on the Hazardous Ranking System (HRS), which is a preliminary risk assessment applied to sites to determine if the site should be designated a Superfund site. We first examine the effects of these variables on housing prices, and then we examine the effect of the actual risk on housing prices before and after the release of the Remedial Investigation. For the latter analysis, we assume that people use the observable risk factors available prior to the Remedial Investigation in order to form accurate risk judgments. We then test whether the Remedial Investigation provides new information, resulting in people updating their perceptions. This allows us to estimate the statistical value of cancer before and after the release of the Remedial Investigation.

In order to justify using the objective risk as a proxy for the prior perceptions, we test whether the prior risk indicators serve as reasonable predictors of the objective risk. We regress the objective risk level against the area of the closest site, the ranking of the closest site on the National Priorities List, the elapsed time since the closest site was placed on the National Priorities List, and the type of site. For robustness, we run an alternative functional form that includes a variable that interacts the distance measure and the NPL ranking, and another variable that interacts the distance measure and the type of site. The results suggest that the objective risk is a reasonable approximation of households' prior risk perceptions.[10]

Because the objective risk level is a reasonable approximation of prior probability, we can estimate the dollar value that people place on a reduction in Superfund risk before the release of the Remedial Investigation. We then test whether the value of the risk reduction changes after the release of the information provided in the Remedial Investigation. Our conjecture is that people tend to overestimate the prior risk before the release of the EPA's Remedial Investigation. People then update their risk perceptions after the release of

[9] Sites placed on the National Priorities List (NPL) qualify for federal remediation funds. NPL sites undergo a site characterization process known as the Remedial Investigation and Feasibility Study (RI/FS). The RI/FS contains a baseline risk assessment and provides regional EPA decision-makers with a quantitative assessment of human health risk at a site, a description of remedial action objectives, and an analysis of the alternatives proposed to reach these objectives. After evaluating an RI/FS, the EPA selects a remedial action and then documents the reasons for its selection in the Record of Decision.

[10] The equation results are as follows (with t-statistics in parentheses):

1) $$\begin{aligned}\ln \hat{Risk} = &-7.424 - 0.012\,Area\ of\ Site - 0.006\,NPL Ranking \\ &\ (116.1)\qquad (18.1) \qquad\qquad (50.4) \\ &- 0.013\,Months\ Since\ NPL - 1.711\,Distance - 0.031\,Type\ of\ Site, \\ &\ (27.5) \qquad\qquad (133.5) \qquad\qquad (0.7) \\ &Adj.R^2 = 0.6062,\ F\ Statistic = 5213.168.\end{aligned}$$

2) $$\begin{aligned}\ln \hat{Risk} = &- 8.174 - 0.013\,Area\ of\ Site - 0.004\,NPL\ Ranking \\ &\ (68.4)\qquad (19.0) \qquad\qquad (19.3) \\ &- 0.013\,Months\ Since\ NPL - 1.294\,Distance - 0.516\,Type\ of\ Site \\ &\ (27.8) \qquad\qquad (25.3) \qquad\qquad (7.9) \\ &- 0.001(Distance{*}NPL\ Ranking) + 0.274(Distance{*}Type\ of\ Site), \\ &\ (10.9) \qquad\qquad (10.2) \\ &Adj.R^2 = 0.6121,\ F\ Statistic = 3816.704.\end{aligned}$$

For both equations, all the coefficient estimates are significantly different from zero at the 1% level, except for the coefficient estimate on the type of site in the first equation, which is not significantly different from zero. As expected, *Risk* decreases with the time since a site's placement on the NPL, the distance to the closest site, and the NPL ranking. *Risk* also decreases for larger sites, which suggests that houses surrounding these sites may be farther from sources of contamination at the sites.

the Remedial Investigation. An additional updating of risk perceptions occurs after receiving the newspaper publicity about all the Superfund sites in the greater Grand Rapids area.[11]

We use the distance to the closest Superfund site as a proxy for the visual disamenities of the site.[12] We incorporate into the hedonic price function the variables that serve as indicators of the actual risk before the release of the EPA information. We also include a variable measuring the publicity surrounding the sites, along with a dummy variable indicating if the house was sold after the release of the EPA's Remedial Investigation. Additionally, we include a measure of the actual risk for those houses sold after the release of the Remedial Investigation (that is, we interact the actual risk with a dummy variable indicating if the house was sold after the Remedial Investigation). The first hedonic price function to be estimated is

$$\begin{aligned}\ln \mathit{Price} = {} & \alpha + \beta \mathit{Structural} + \gamma \mathit{Neighborhood} \\ & + \rho_i \mathit{City}_i + \tau_t \mathit{Year}_t + \zeta_1 \mathit{Sites}_1 + \cdots \\ & + \zeta_4 \mathit{Sites}_4 + \eta \mathit{Distance} + \omega_1 \mathit{Area} \\ & + \omega_2 \mathit{NPL} + \omega_3 \mathit{Type} + \omega_4 \mathit{NPLTime} \\ & + \gamma_2 \mathit{News} + \theta_1 \mathit{After} + \theta_2 (\mathit{After} \times \mathit{Risk}) \\ & + u,\end{aligned} \tag{9}$$

where *Distance* is the distance from the house to the closest Superfund site,

Area is the area of the closest Superfund site,

NPL is the National Priorities List ranking of the closest Superfund site,

Type describes what type of operations occurred at the closest Superfund site,

NPLTime is the number of months since the closest Superfund site was placed on the NPL,

News is the number of words printed in the *Grand Rapids Press* about all the Superfund sites in the year previous to the sale of the house,

After is a dummy variable indicating if the house was sold after the release of the EPA's Remedial Investigation,

After × *Risk* is an interaction variable that measures the objective lifetime excess cancer risk (described in the next section) from all the sites to those individuals in a house purchased after the release of the Remedial Investigation, and the other variables are as defined earlier.

The interaction variable tests whether housing prices react to the objective level of risk for houses sold after the release of the Remedial Investigation.

Our conjecture is that, before the release of the Remedial Investigation, *Area, NPL, Type,* and *NPLTime* serve as indicators to the residents of the actual risks from the sites. Because this information is correlated with the actual risk from the sites (see footnote 10), the housing prices should react to the level of the actual risk before the release of the Remedial Investigation. We therefore estimate another hedonic equation that replaces the risk indicators with a measure of the actual risk from the Superfund sites. This allows us to test the stability of the post-Remedial Investigation *Risk* coefficient, as well as to obtain an estimate of the dollar value of a risk reduction before the Remedial Investigation. This specification also includes an interaction term of *After* and *Risk* to test whether the effect of the actual risk on housing prices changes after the release of the Remedial Investigation. This second hedonic price function is

$$\begin{aligned}\ln \mathit{Price} = {} & \alpha + \beta \mathit{Structural} + \gamma \mathit{Neighborhood} \\ & + \rho_i \mathit{City}_i + \tau_t \mathit{Year}_t + \zeta_1 \mathit{Sites}_1 + \cdots \\ & + \zeta_4 \mathit{Sites}_4 + \eta \mathit{Distance} + \gamma_1 \mathit{Risk} \\ & + \gamma_2 \mathit{News} + \theta_1 \mathit{After} \\ & + \theta_2 (\mathit{After} \times \mathit{Risk}) + u.\end{aligned} \tag{10}$$

Among other things, *Distance* serves as a proxy for the visual disamenities associated with the Superfund sites. *News* measures the publicity about the Superfund sites and is thus a measure of the updating information, r. The effect of this publicity on housing prices is equivalent to the joint effect of news information on perceptions and perceptions on prices. (Comparing equations (8) and (10) shows that γ_2 is a measure of δ_3, or the informational weight on media coverage.) The effect of risk on housing prices before the release of the Remedial Investigation is equal to the joint effect of prior risk information on perceptions and perceptions on prices. (Comparing equations (8) and (10) shows that γ_1 is a measure of δ_1, or the weight on prior risk beliefs if these beliefs equal the value of *Risk*.) The effect of *Risk* on housing prices after the release of the Remedial Investigation is equal to the joint effect of updating risk information on perceptions and perceptions on prices. (Comparing equations (8) and (10) shows that $\gamma_1 + \theta_2$ is a measure of δ_2.)

Household risk perceptions are positively related to the risk levels associated with prior beliefs and new informa-

[11] Other studies have considered the effect that information has on the hedonic gradient, although not in a Bayesian framework. Kohlhase (1991) found that a positive relationship between distance to the closest site and the price of the house occurred only after the site was placed on the EPA's National Priorities List. Michaels and Smith (1990) found that, for certain submarkets, the price-distance gradient changes slope depending on whether the house was sold within six months of the discovery of hazardous waste at the closest site. Kiel and McClain (1995) found no price–distance relationship before the construction of an incinerator, despite rumors of its imminent construction. However, they found a positive price–distance relationship during the construction phase, and also throughout the duration of the operation of the incinerator.

[12] Most previous hedonic studies have used distance (from the house to the disamenity) as a proxy for both the (non-risky) aesthetic and (risky) health effects of the disamenity. Where more than one disamenity is present, studies have typically used the distance to the closest site as a proxy. Michaels and Smith (1990) and Harrison and Stock (1984) examined alternative measures of distance. Note that, even though we control for cancer risks generated at a site, the difficulty of indexing non-cancer health risks means that the distance variable may also reflect, in part, reactions to those health effects.

tion, because $\partial\pi/\partial p = \varphi$, $\delta\pi/\delta q = \xi$, $\partial\pi/\partial r = \kappa$, and $0 < \varphi$, ξ, $\kappa < 1$. As indicated in equation (5), the model predicts these risk levels will have a negative impact on housing prices. The effect of risk on housing prices before the release of the Remedial Investigation (as measured by γ_1) and the effect of risk on housing prices after the release of the Remedial Investigation (as measured by $\gamma_1 + \theta_2$) are both expected to be negative. However, θ_2 can either be positive or negative depending on whether the risk analysis indicates a hazard higher or lower than prior beliefs.

We estimate a separate hedonic equation to determine whether publicity serves to communicate the risks of the Superfund sites. If newspaper publicity were correlated with *Risk*, the coefficient estimate for *Risk* would be biased. Therefore, we estimate a separate equation without the *News* variable to check whether this changes the price-risk relationship. The third hedonic price function estimated is

$$\begin{aligned} \ln Price = {} & \alpha + \beta Structural + \gamma Neighborhood \\ & + \rho_i City_i + \tau_t Year_t + \zeta_1 Sites_1 + \cdots \\ & + \zeta_4 Sites_4 + \eta Distance + \gamma_1 Risk \\ & + \theta_1 After + \theta_2 (After \times Risk) + u. \end{aligned} \tag{11}$$

In addition to measuring public valuations of Superfund risk, the model also tests whether willingness to pay for risk reduction is affected by the release of the EPA's Remedial Investigation. The coefficient on the interaction term estimates the influence that the Remedial Investigation has on the valuation of the risks of the sites. For equations (10) and (11), a negative value for θ_2 would indicate that household perceptions of cancer risk increased after the release of the Remedial Investigation, and therefore drove down housing prices. A positive value for θ_2 would indicate that residents perceived the risks as smaller after the release of the Remedial Investigation, resulting in an increase in housing prices.

TABLE 1.—DESCRIPTIVE STATISTICS (N = 16,928 HOUSES)

Variable	Mean	Standard Deviation
Price (in 1996 dollars)	74,176	17,600
Bedrooms (number)	3.01	0.73
Bathrooms (number)	1.53	0.60
Fireplaces (number)	0.38	0.66
Basement (0/1)	0.79	0.41
Lot size (square feet)	10,826	20,856
Garage (0/1)	0.91	0.29
Household income (median in census tract)	37,914	5,247
Race (proportion black in census tract)	0.08	0.13
High school education (proportion in census tract)	0.80	0.08
Tax (property tax rate)	5.75	0.44
Distance to central business district (in miles)	3.83	1.74
School quality (% 7th graders in district in top category)	20.19	20.90
Under 19 (proportion in census tract)	0.28	0.04
Crime rate (per capita for city in previous year)	0.08	0.02
Grand Rapids (0/1)	0.57	0.50
Grandville (0/1)	0.03	0.17
Kentwood (0/1)	0.11	0.31
Walker (0/1)	0.04	0.21
Wyoming (0/1)	0.25	0.43
Year88 (0/1)	0.16	0.37
Year89 (0/1)	0.17	0.38
Year90 (0/1)	0.16	0.37
Year91 (0/1)	0.16	0.36
Year92 (0/1)	0.17	0.37
Year93 (0/1)	0.18	0.38
Distance (miles to the closest Superfund site)	1.90	0.93
$Sites_1$ (# of Non-NPL, RCRA, and PCS sites within 0.25 mile)	0.07	0.34
$Sites_2$ (. . . between 0.25 and 0.5 mile)	0.39	0.83
$Sites_3$ (. . . between 0.5 and 0.75 mile)	0.76	1.25
$Sites_4$ (. . . between 0.75 and 1.0 mile)	1.19	1.60
Area of the closest Superfund site (in acres)	22.52	38.01
National Priorities Listing rank of the closest Superfund site	519.61	138.40
Time since closest site was placed on NPL (in months)	57.06	30.91
Type of site (1 = landfill, 0 = chemical plant or battery repository)	0.32	0.47
Risk (lifetime excess cancer risk from Superfund sites)	1.81E-06	2.16E-05
After (0/1 if house sold after the release of the Remedial Investigation)	0.38	0.49
News (# words of Superfund newspaper coverage in last year)	4,192	1,621

III. Data Description

For our analysis, we constructed a sample of housing prices for 16,928 houses sold in the greater Grand Rapids area between January 1, 1988, and December 31, 1993. (The greater Grand Rapids area consists of the cities of Grand Rapids, Walker, Wyoming, Kentwood, and Grandville.) The area is ideal for a hedonic analysis of Superfund risk because it is a local market that contains seven Superfund sites, only one of which does not have quantitative EPA risk data.[13] A local housing market with numerous Superfund sites enhances the analysis because of a heterogeneity of risk among the households, yet there are few extraneous sites that can contaminate the analysis by contributing unmeasured risk to the households. The housing-price offer curves will also be more similar within a local market than if a national data set were used.

The price and structural data come from the Multiple Listing Service of the Grand Rapids Society of Realtors. Additionally, a Geographic Information System (GIS) analysis determined the longitude and latitude coordinates of the houses and computed the distances of each house to the neighborhood Superfund sites. Using GIS technology, we also linked each house to the demographic data of its census tract, city, and school district. Table 1 presents the descriptive statistics for the variables used in the analysis.

The mean housing sale prices for each year was $60,196 for 1988, $64,436 for 1989, $68,082 for 1990, $68,983 for 1991, $70,507 for 1992, and $72,812 for 1993. The mean housing price in 1996 dollars for the entire sample is $74,176. Of the sample of 16,957 housing transactions,

[13] The Spartan site contains only a qualitative analysis, which does not contain pathway risk estimates.

16.3% occurred in 1988, 17.2% occurred in 1989, 16.5% occurred in 1990, 15.7% occurred in 1991, 16.8% occurred in 1992, and 17.4% occurred in 1993. The structural variables include the number of bedrooms, the number of bathrooms, the number of fireplaces, whether there is a basement, the size of the lot in square feet, and whether there is a garage. The neighborhood variables include the median household income in the census tract, the proportion of blacks in the census tract, the proportion of people with a high school education in the census tract, the property tax rate, the distance to the central business district, the percentage of seventh-graders in the school district who scored in the highest category for the Michigan reading assessment test, the proportion of people in the census tract under the age of nineteen, and the per capita crime rate for the city in the previous year. The estimation utilizes a fixed-effects model, including annual dummy variables as well as city dummy variables.

The environmental variables include the measure of the distance to the closest Superfund site. Although distance of the house to the closest site is also correlated with health risks from the site, we assume it is a proxy for the Superfund aesthetic disamenities. Additionally, four variables ($Sites_1$, $Sites_2$, $Sites_3$, and $Sites_4$) serve as proxies for the overall quality of the environment within the vicinity of the house. These variables measure the sum of the non-NPL CERCLA sites (sites that are not on the NPL but fall under the Comprehensive, Environmental Response, Compensation, and Liability Act of 1980), RCRA sites (sites that fall under the Resource Conservation and Recovery Act), and PCS water-pollution sites (sites monitored by the EPA's Permit Compliance System) within quarter-mile rings around the house.[14] These quarter-mile rings are from 0 to 0.25 mile, 0.25 to 0.5 mile, 0.5 to 0.75 mile, and 0.75 to 1 mile from the house.

We also include variables that serve as prior indicators for the risks from the Superfund sites. These variables measure the area (in square acres) of the closest site, the NPL ranking of the closest site, the number of months since the placing of the closest site on the NPL, and a dummy variable that is 1 if the closest site were a landfill and 0 if it were an industrial chemical plant or battery repository.

The risk variables measure both the objective excess cancer risks to the household and the timing of the release of this information with respect to the sale of the house.[15] We measure the objective cancer risk by aggregating the soil and groundwater pathway risk estimates and coupling them with dilution estimates. We standardize the pathway definitions used in the EPA's risk assessments of the Superfund sites. Additionally, we use the mean exposure and chemical concentration levels in order to determine the cancer risk at each site.[16]

To compute the cancer risk to each household in the greater Grand Rapids area, we couple the site risk assessments with dilution estimates for soil and groundwater exposure. Soil dilution estimates come from EPA guidelines and are a function of the distances to the sites. To estimate groundwater dilution, we use maps of plumes to estimate the probability that a house is located above a contaminated plume. For each block group, we use data from the U.S. Bureau of the Census to determine the proportion of households that draw their water from groundwater.[17] Multiplying the probability of being above a contaminated plume by the probability that the house receives its drinking water from a well results in an estimate for groundwater exposure dilution. The household cancer risk from each site is the product of the soil cancer risk and the soil dilution estimate, plus the product of the groundwater cancer risk and the groundwater dilution estimate. Summing the cancer risk from each of the Superfund sites results in the total lifetime excess cancer risk to the household. The mean cancer risk to an individual in a household is 1.81E-06.[18]

We do not assume that individuals living near a site can state with precision the numbers calculated in our objective risk measure. The risk measure is meant to reflect a consistently developed point estimate of cancer risks based on risk-assessment assumptions consistent with EPA practices. To the extent that residents' assessments of site risks are related to the underlying magnitude of hazards as measured in cancer-risk assessments, we expect housing prices to react negatively to the risk measure.

A dummy variable measures the timing of the risk information. This variable has a value of 1 if the house was sold after the EPA released its Remedial Investigation and Feasibility Study (RI/FS) for the closest site, and 0 if it was sold before this release. We use press coverage in the *Grand Rapids Press,* which serves the entire greater Grand Rapids area, as the publicity measure. The publicity variable is the total number of printed words in articles about the local Superfund sites within the year before the sale of the house.

IV. Empirical Results

Table 2 presents the ordinary least-squares estimates of the hedonic price function, and the three equations correspond to equations (9), (10), and (11). Along with the structural and neighborhood variables, the specifications include measures of the environmental quality in the vicinity

[14] CERCLA and RCRA data are maintained by the EPA's Office of Solid Waste and Emergency Response. PCS tracks the National Pollutant Discharge Elimination System program under the Clean Water Act.

[15] We examine only cancer risk. For noncarcinogenic risk, the EPA's assessment entails computing the ratio of a chemical's calculated exposure intake to its reference dose, the level of exposure thought to be without appreciable risk of non-cancer effects. A ratio above 1 for a chemical triggers greater scrutiny. Because non-cancer risk varies in its severity (such as, from skin rashes to reproductive damage), there is no way to summarize accurately the aggregate non-cancer risk arising from multiple chemicals at a given site.

[16] Hamilton and Viscusi (1999) uses a similar methodology.

[17] Each block group in our data set has approximately 300 houses.

[18] The cancer-risk estimate is for an individual residing in the house. EPA guidance indicates that a site risk greater than 1.0E-04 generally warrants action and that a site risk between 1.0E-04 and 1.0E-06 is allowed discretion in the remediation consideration. The household risk used in this paper couples the site risk estimates with dilution estimates.

TABLE 2.—REGRESSION RESULTS FOR THE SEMI-LOG HEDONIC PRICE FUNCTION

	Equation (1)		Equation (2)		Equation (3)	
Variables	Coefficient	*t*-stat	Coefficient	*t*-stat	Coefficient	*t*-stat
Intercept	10.256[a]	(56.14)	10.300[a]	(56.15)	10.303[a]	(56.15)
Bedrooms	0.048[a]	(22.57)	0.050[a]	(23.69)	0.050[a]	(23.70)
Bathrooms	0.168[a]	(60.11)	0.172[a]	(61.10)	0.172[a]	(61.05)
Fireplaces	0.087[a]	(36.84)	0.087[a]	(36.77)	0.087[a]	(36.78)
Basement	0.017[a]	(4.74)	0.013[a]	(3.75)	0.013[a]	(3.73)
Lot Size	1.49E-06[a]	(21.43)	1.48E-06[a]	(21.15)	1.49E-06[a]	(21.14)
Garage	0.103[a]	(20.95)	0.102[a]	(20.59)	0.102[a]	(20.57)
Household income	8.82E-06[a]	(16.14)	9.85E-06[a]	(18.45)	9.85E-06[a]	(18.45)
Race	−0.093[a]	(5.84)	−0.125[a]	(7.92)	−0.125[a]	(7.91)
High school education	0.435[a]	(12.65)	0.414[a]	(12.59)	0.414[a]	(12.58)
Tax	−0.082[a]	(2.93)	−0.094[a]	(3.34)	−0.095[a]	(3.38)
Distance to CBD	0.051[a]	(23.33)	0.049[a]	(25.08)	0.049[a]	(25.11)
School quality	1.10E-04	(0.38)	1.86E-05	(0.07)	2.90E-05	(0.10)
Under 19	−1.030[a]	(22.77)	−1.090[a]	(23.83)	−1.089[a]	(23.81)
Crime rate	−0.560	(1.22)	−0.800[c]	(1.72)	−0.819[c]	(1.76)
Grandville	−0.020	(0.64)	−0.076[b]	(2.37)	−0.078[b]	(2.43)
Kentwood	−0.148[a]	(4.20)	−0.149[a]	(4.18)	−0.151[a]	(4.23)
Walker	−0.145[a]	(2.81)	−0.139[a]	(2.69)	−0.141[a]	(2.74)
Wyoming	−0.096[a]	(3.92)	−0.109[a]	(4.45)	−0.110[a]	(4.50)
Year89	0.032[a]	(4.10)	0.047[a]	(6.02)	0.045[a]	(5.82)
Year90	0.044[a]	(3.81)	0.074[a]	(6.63)	0.073[a]	(6.50)
Year91	0.024	(1.11)	0.076[a]	(3.54)	0.072[a]	(3.38)
Year92	−0.005	(0.21)	0.063[a]	(2.69)	0.060[b]	(2.56)
Year93	−0.043[b]	(2.01)	0.037[c]	(1.86)	0.035[c]	(1.74)
$Sites_1$	−0.021[a]	(4.83)	−0.020[a]	(4.60)	−0.020[a]	(4.60)
$Sites_2$	−0.011[a]	(5.29)	−0.009[a]	(4.55)	−0.009[a]	(4.55)
$Sites_3$	0.001	(0.96)	0.003[c]	(1.85)	0.003[c]	(1.84)
$Sites_4$	0.004[a]	(3.70)	0.006[a]	(4.96)	0.006[a]	(4.95)
Distance	0.014[a]	(7.70)	0.012[a]	(5.93)	0.012[a]	(5.91)
After	−0.006	(1.12)	−0.012[b]	(2.26)	−0.013[b]	(2.52)
Risk			−1771.214[b]	(2.27)	−1779.076[b]	(2.28)
After × risk	−139.135[b]	(2.13)	1635.245[b]	(2.09)	1644.076[b]	(2.10)
Area of site	−0.001[a]	(11.62)				
Type of site	0.095[a]	(15.03)				
NPL ranking	−1.62E-04[a]	(7.08)				
Months since NPL	0.001[a]	(9.27)				
News	−2.51E-06[b]	(2.46)	−2.31E-06[b]	(2.25)		
	Adj. R^2 = 0.6703		Adj. R^2 = 0.6649		Adj. R^2 = 0.6648	
	N = 16,928		N = 16,928		N = 16,928	

[a] Significant at the 1% level, two-sided test.
[b] Significant at the 5% level, two-sided test.
[c] Significant at the 10% level, two-sided test.

of the house. The first equation incorporates an objective risk measure only for houses sold after the release of the Remedial Investigation. This equation also includes variables that serve as indicators for the actual risks of the sites. Equations (2) and (3) each incorporate an objective risk measure, along with the term interacting the objective risk and the dummy variable indicating if the house was sold after the release of the EPA's Remedial Investigation. Equations (1) and (2) include a publicity measure to test if the probability assessment that is implied by this updating information affects housing prices. Equation (3) omits the *News* variable from the hedonic equation. The risk coefficient in this model thus captures the direct effect of risk on prices as well as the effect through newspaper coverage. If newspaper coverage of the sites communicates the level of risk, one would expect that dropping the *News* variable would result in an increase in the magnitude of the effect of the *Risk* coefficient.

A. *Estimates of the Hedonic Model*

Table 2 reports the results of the hedonic price function of equations (9), (10), and (11). As discussed previously, the hedonic price gradient with respect to a good (such as a structural or neighborhood attribute) is equal to the marginal value of the good. A priori expectations are that coefficients for the structural house variables are positive, and the regression results of the three equations are consistent with these expectations: an increase in a structural attribute of a house increases the price of the house. All the estimates for the neighborhood variables also have the expected sign (positive for goods, negative for bads). However, the parameter estimates for school quality and for the crime rate in equation (1) are not significantly different from zero. There are no a priori expectations for the signs of the coefficients of the city and annual dummy variables. The estimated coefficient for the distance to the closest Superfund site is positive and significant for each equation, suggesting that people are willing to pay to live farther away from the visual disamenities that are associated with Superfund sites.

One of the concerns about the distance proxy used in previous studies is that it also measures the distance to other neighborhood characteristics. Multiple environmental disamenities could exist at the same distance to the house as the closest Superfund site. These other disamenities would then be reflected in the estimate of the distance gradient. The ring variables $Sites_1$, $Sites_2$, $Sites_3$, and $Sites_4$ address this concern by controlling for other neighborhood environmental disamenities. The coefficient estimates of these disamenity variables indicate a negative and significant price effect of the number of such sites at 0.25 and 0.5 mile from the house.

Equation (1) tests whether certain variables act as indicators for the risks associated with the Superfund sites. The findings suggest that people do incorporate this prior information in the expected manner. Specifically, the size of the closest Superfund site and the NPL ranking of the closest Superfund site have negative effects on housing prices. The more time that has elapsed since the placing of the site on the NPL results in higher housing price, as these sites that merit lower priority may pose smaller risks. Another possibility is that alarmist responses to a site being placed on the NPL moderate over time. And homes near industrial chemical plants or the battery repository have lower prices then homes near the landfills.

As outlined in section II, we test the potential impacts that information from the EPA's Remedial Investigation and local newspaper coverage has on perceptions and, consequently, on equilibrium housing prices. The hedonic price gradient with respect to total cancer risk gives the marginal valuation of cancer risk (the value of avoiding cancer risks) for households. As was described in section II.B, the expected sign for this gradient is negative both before and after the release of the Remedial Investigation. Similarly, if publicity increases perceptions of risk, then we expect a negative sign for the price gradient with respect to publicity.

Equation (1) estimates the effect of *Risk* only after the release of the Remedial Investigation. The negative coefficient estimate suggests that people are willing to pay less for houses for which there is a Superfund cancer risk. For equations (2) and (3), we rely on the evidence presented in section II.B to claim that perceptions of the prior risk are correlated with the actual risk. Using these results, it is possible to estimate the dollar value that people place on risk reduction both before and after the Remedial Investigation. The negative coefficient estimates for *Risk* indicate that, before the Remedial Investigation, the public is willing to pay more for houses exposed to lower levels of Superfund cancer risk.

The interaction variable is the product of *Risk* and the dummy variable that indicates if the house was sold after the release of the EPA's Remedial Investigation. Using this interaction term gives the following marginal effect of *Risk* on housing prices:

$$\frac{\partial Price}{\partial Risk} = (\hat{\gamma}_1 + \hat{\theta}_2 After)Price. \quad (12)$$

The term $\hat{\gamma}_1$ represents the estimated *Risk* coefficient, and $\hat{\theta}_2$ represents the interaction term's estimated coefficient. The positive sign of the interaction term's estimated coefficient indicates that the negative effect of risk on housing prices was smaller after the EPA released their Remedial Investigation. Our conjecture is that the release of the EPA's Remedial Investigation provided risk information that lowered perceptions of the risk, which were initially alarmist, resulting in a decrease in magnitude of the price-risk gradient. It is also noteworthy that the post-Remedial Investigation price effect of *Risk* is comparable for all of the equations. The net effects on the ln *Price* variable range from −135 to −139, or a price drop that is approximately $220 less (for a change in *Risk* by the mean level) than the effect of risk beliefs before the completion of the EPA risk analysis.

The results also indicate that, controlling for the risk level, newspaper publicity about the local Superfund sites has a negative effect on housing prices. Previous studies have suggested that substantial newspaper coverage leads to overestimation of mortality risks (Combs & Slovic, 1979). However, this bias cannot be inferred from the gradient here because the effect of publicity on perceptions cannot be separated from the effect of perceptions on housing prices.

Equation (3) in table 2 presents estimates of the hedonic equation without the *News* variable. The signs, magnitudes, and significance of the estimates are virtually identical to those reported in equation (2). Dropping *News* from the regression does not significantly alter the gradients before and after the release of the Remedial Investigation. Apparently, although newspaper publicity during the time of the Remedial Investigation has a negative effect on housing prices, it does not seem to communicate new information about the Superfund cancer risks to the residents.

B. *Estimates of the Box-Cox Model*

To further explore the nature of the risk-dollar relationship, we use a Box-Cox transformation of the dependent variable to estimate the hedonic price function.[19] The transformation of the dependent variable, *Price,* yields the regression model

$$Price^{(\lambda)} = \alpha + \sum \beta_k X_k + \epsilon, \quad (13)$$

where $Price^{(\lambda)} = (Price^{\lambda} - 1)/\lambda$ and X_k are the independent variables as expressed in equation (10). The transformation

[19] Cropper, Deck, and McConnell (1988) found that a linear Box-Cox model performs well in a housing market when all attributes are observed and also in the presence of specification error.

TABLE 3.—REGRESSION RESULTS FOR THE BOX-COX TRANSFORMATION*

Variables of Interest	Coefficient	t-stat
Risk	-18.789^{b}	(2.21)
After	$-1.07\text{E-}04^{c}$	(1.86)
After × risk	17.048^{b}	(2.01)
News	$2.30\text{E-}08^{b}$	(2.06)
	Adj. $R^2 = 0.6588$	
	$N = 16{,}928$	
	$\hat{\lambda} = -0.42$	

[b] Significant at the 5% level, two-sided test.
[c] Significant at the 10% level, two-sided test.
* Other variables included in the equation are the same as in table 2.

parameter, λ, is taken to be an unknown parameter, and we scan a range of values to determine the least-squares values of λ, α, and the β_k's.

Table 3 presents the results of the Box-Cox model. The least-squares estimate for the transforming parameter, λ, is -0.42. The marginal effect of risk on housing price is

$$\frac{\partial Price}{\partial Risk} = (\hat{\beta}_1 + \hat{\beta}_2 After)Price^{(1-\hat{\lambda})}. \tag{14}$$

The negative value of $\hat{\beta}_1$ indicates that people are willing to pay for a reduction of cancer risk. The positive value of $\hat{\beta}_2$ indicates that the price-risk tradeoff is greater before the release of the EPA's Remedial Investigation.

V. Estimation of Welfare Effects

A. *The Benefits of Risk Reduction and the Value of a Statistical Cancer Case*

Remediation of Superfund sites addresses, among other objectives, the targeted reduction of cancer risks. Previous hedonic property-value studies computed cleanup benefits by equating remediation with movement of the houses to a certain distance in which the gradient levels out. (See, for example, Kohlhase (1991) and Kiel and McClain (1995).) This approach captures the distance-risk relationship imperfectly, because it assumes that remediation will alleviate both the (risky) health and (non-risky) aesthetic attributes of the site. The distance gradient is also incapable of estimating the benefits of a partial reduction in the risk, which is usually the EPA's goal.

By incorporating objective cancer-risk measures in the hedonic property model, we can estimate the change in housing prices given any level of risk reduction. To compare these implied benefits with the cost of remediation, we compute the change in prices before the release of the Remedial Investigation. For example, using the coefficient estimates of equation (2) in table 2, we find that a reduction of individual cancer risk by 1.81E-06 (the mean level of Superfund site risk to an individual in a household) before the release of the Remedial Investigation results in a price increase of $238 per household (in 1996 dollars). With 42,598 households within the relevant census tracts, the total price change (an upper-bound measure of welfare benefits) is $10.1 million for reducing cancer risks at the six sites. Using the Box-Cox coefficient estimates, a reduction of household cancer risk by the mean level before the release of the Remedial Investigation results in a price increase of $232 per household, and a total price change of $9.9 million.

These estimates of the value of risk reduction are much smaller than the EPA's estimated costs of remediating the sites. The total present value cost of the EPA's remediation plans for the six greater Grand Rapids Superfund sites is $56.8 million. By contrast, the total present value cost of only institutional controls (such as fencing and deed restrictions) would have been $5.4 million had they been implemented at the six sites.[20] Using residents' valuations of cancer-risk reductions, permanent remedies would not pass this test of cost versus implicit willingness to pay, although the use of institutional controls to restrict access to sites would.

By evaluating the price gradient with respect to cancer risk, we can estimate the value of a statistical cancer case. The methodology is similar to value-of-life studies, in which a wage hedonic is used to determine the gradient with respect to job risk (Viscusi, 1992). In the job risk literature, the wage compensation for an incremental change in job fatality risk is divided by the risk increment, resulting in the value of a statistical life. Viscusi (1981) demonstrated that value-of-life estimates are heterogeneous over different risk levels. Different members of the population attach different values to risk. People who are most tolerant of risk are drawn to the riskier jobs, and higher wages must be paid to lure additional workers into risky jobs. Such heterogeneity of risk preferences illustrates the complexity that is inherent in policy applications. Value-of-life estimates obtained from a certain population of workers may not be appropriate for another population. While hedonic wage studies have been quite successful in estimating compensation to workers for job risk, values may be quite different for populations including non-workers, white-collar workers, or children.

Previous attempts have been made to obtain risk-dollar tradeoffs in market transactions other than the job market. Unlike the labor market studies, many of these attempts rely on imputing values for at least one component of the tradeoff. For example, studies attempting to evaluate the risk-dollar tradeoff associated with aspects of auto safety (Ghosh, Lees, & Seal, 1975; Blomquist, 1979) assume that

[20] For each of the sites, the costs (converted to 1996 dollars) of the proposed remediation plans are as follows: Butterworth, $19.4 million; Chem-Central, $2.6 million; Folkertsma, $1.9 million; H. Brown, $18.8 million; Kentwood, $7.1 million; Organic Chemical, $7.4. The costs of the institutional controls had they been implemented are as follows: Butterworth, $2.3 million; Chem-Central, $0.6 million; Folkertsma, $0.7 million; H. Brown, $0.6 million; Kentwood, $0.7 million; Organic Chemical, $0.6 million. One reason for the high cleanup costs could be the EPA's preference for more-permanent remediation actions, even though the benefits of permanence are still uncertain. Gupta, Van Houtven, and Cropper (1996) show that the premium that the EPA places on onsite incineration of waste (over and above the cost of capping it) is $12 million at small sites and up to $40 million at large sites (1987 dollars).

TABLE 4.—ESTIMATES OF THE VALUE OF AVOIDING A STATISTICAL CANCER CASE (IN MILLIONS OF DOLLARS, 1996)

Equation Estimates	Value of Cancer before RI	Value of Cancer after RI
Equation (1)	NA	$4.1
Equation (2)	$51.1	$3.9
Equation (3)	$51.3	$3.9
Box-Cox	$49.9	$4.6

the wage rate equals the opportunity cost of time associated with driving fast or using seat belts.

The objective risk measures used in this study pertain to the cancer risk to an individual living in the household. To determine the value of a statistical cancer to an individual, the average household size must be divided into the risk coefficient. According to the 1990 Census, the average number of members per household in the pertinent census tracts (computed by matching block group data to the sample) was 2.573.

Table 4 lists the estimates for the statistical value of cancer given different specifications.[21] Equation (1) considers the effect of objective risk on housing prices only after the Remedial Investigation. Using this parameter estimate, the value-of-cancer estimate after the Remedial Investigation is $4.1 million. Using the estimates of equation (2) in table 2 and dividing by the number of people per household results in a value-of-cancer estimate of $51.1 million before the release of the Remedial Investigation and $3.9 million after the release of the Remedial Investigation. To test whether the publicity picks up some of the effect of risk on housing prices, equation (3) in table 2 drops the *News* variable from the regression. The value-of-cancer estimate before the Remedial Investigation increases by only approximately $200,000 dollars, and there is no change in the value-of-cancer estimate after the Remedial Investigation. Using the coefficient estimates in the Box-Cox model, the value-of-cancer estimate before the Remedial Investigation is $49.9 million. After the Remedial Investigation, the value-of-cancer estimate is $4.6 million.

The value-of-cancer estimates before the release of the Remedial Investigation are roughly an order of magnitude larger than the value-of-life estimates found in job market studies. This finding suggests that risk biases could affect individual reactions to Superfund risks before the EPA releases its Remedial Investigation.[22] Residents update their risk perceptions after the release of the Remedial Investigation, and the resulting value-of-cancer estimates of $3.9 million to $4.6 million are very similar to the value-of-life estimates found in job market studies.[23] Once the EPA releases the Remedial Investigation, the value people place on avoiding Superfund risks is similar to the value they place on job market risk.

[21] Estimates are computed at the mean housing price.

[22] Slovic, Fischhoff, and Lichtenstein (1982) and Tversky and Kahneman (1982) offer explanations of the cognitive heuristics that can lead to risk-perception biases.

[23] For example, Viscusi (1981) estimated value of life at $7.8 million, Garen (1988) at $16.1 million, Moore and Viscusi (1988) at $8.7 million (all estimates converted to 1996 dollars). See Viscusi (1992) for a complete survey.

TABLE 5.—MEAN WILLINGNESS TO PAY FOR SUPERFUND-RELATED ATTRIBUTES

Sources of Estimates	Additional Mile from Closest Site	Removal of Industrial Site within 0.25 Mile Ring	House Sold Before Release of Remedial Investigation	One Fewer Word of Publicity in Previous Year
Equation (1)	$1,085	$1,588	$ 450	$ 0.19
	(145)	(323)	(409)	(0.08)
Equation (2)	$ 859	$1,486	$ 661	$ 0.17
	(145)	(323)	(404)	(0.08)
Equation (3)	$ 857	$1,486	$ 756	NA
	(145)	(323)	(402)	NA
Box-Cox	$ 627	$1,982	$ 520	$ 0.16
	(175)	(390)	(488)	(0.08)

Note: Standard errors in parentheses.

B. *The Marginal Willingness to Pay for Housing Attributes*

The coefficient estimates of equations (1), (2), and (3), as well as the coefficient estimates of the Box-Cox equation, can determine the mean marginal willingness to pay for various attributes. The hedonic price function reflects the tangency of the consumer offer curves with the price function; thus, the marginal price of an attribute is equivalent to the marginal willingness to pay. Table 5 presents the results for multiple attributes.[24]

Using the coefficient estimates from equation (1) of table 2, we find that the marginal willingness to pay for an additional mile from the closest site is $1,085. The marginal willingness to pay for one fewer non-NPL CERCLA site, RCRA site, or PCS site within 0.25 mile of the house is $1,588. An additional printed word about any of the Superfund sites decreases a house's price by $0.19.

Replacing the variables that measure the risk indicators with the actual risk does not result in markedly different estimates for the willingness to pay for the Superfund-related attributes. The estimates from equation (2) of table 2 indicate that the marginal willingness to pay for an additional mile from the closest site is $859. The marginal willingness to pay for one fewer non-NPL CERCLA site, RCRA site, or PCS site within 0.25 mile of the house is $1,486. An additional printed word about any of the Superfund sites decreases a house's price by $0.17. With the average newspaper article on the local Superfund sites being 550 words in length, the price decrease is $94 per article.

The results indicate that a house sold before the release of the EPA risk information on the closest site sold for $661 more than one sold after the information was made public. Thus, while the impact of risk on housing prices diminishes after the release of the Remedial Investigation, housing

[24] The marginal prices are evaluated at the mean housing price. All figures are in 1996 dollars.

prices nonetheless decrease after the release of the Remedial Investigation.[25]

The coefficient estimates from equation (3) of table 2 yield very similar estimates of marginal willingness to pay for the various attributes. The marginal willingness to pay for an additional mile from the closest site is $857. A house sold before the release of the Remedial Investigation for the closest site sold for $756 more than one sold after the Remedial Investigation was made public.

The marginal willingness to pay for a unit reduction of a non-NPL CERCLA site, RCRA site, or PCS site within 0.25 mile of the house is $1,486. This estimate for the value of a removal of one non-NPL CERCLA site, RCRA site, or PCS site within 0.25 mile of the house is equivalent to a cancer-risk reduction of 1.7E-05.[26] Of the 850 RCRA sites studied in a Regulatory Impact Analysis, 640 of the sites had risk estimates between 1.0E-06 and 1.0E-04. Housing-price reactions to RCRA sites imply resident assessments of risk similar to those estimates in the RCRA Regulatory Impact Analysis. For comparison, the mean level of risk from a greater Grand Rapids Superfund site within 0.25 mile is 1.16E-04.

The Box-Cox coefficient estimates yield slightly different estimates of the marginal willingness to pay for attributes. The marginal willingness to pay for an additional mile from the closest site is $627. The marginal willingness to pay for one fewer non-NPL CERCLA site, RCRA site, or PCS site within 0.25 mile of the house is $1,982. An additional printed word about any of the sites decreases the price by $0.16. A house sold before the release of the EPA's Remedial Investigation for the closest site sold for $520 more than one sold after the Remedial Investigation was made public.

Our estimates indicate that removing a hazardous-waste site that is not a Superfund site yields a benefit between $1,486 and $1,982 for a household within 0.25 mile of the site. Using the other estimated coefficients for the *Sites* variables, we find that the average benefit of removing a site (to a resident within one mile of the site) ranges from $385 to $714. These estimates are similar to those found in Stock (1991), who estimated the benefit to an average household in suburban Boston from removing the Nyanza hazardous-waste site (located in Ashland, MA). His unrestricted OLS model found a benefit ranging from $487 to $885, and his nonparametric model found a benefit ranging from $155 to $161. (All estimates are converted to 1996 dollars.)[27]

[25] The marginal value of a house sold after the release of the Remedial Investigation is computed as the change in price with respect to a change in the dummy variable, and is evaluated at the mean level of risk. This net impact of the dummy variable differs from the analysis of the change in the impact of risk on prices after the release of the Remedial Investigation, which is represented by the interaction term.

[26] This estimate was determined by taking the mean willingness to pay for removal of a non-NPL CERCLA, RCRA, or PCS site and calculating the Superfund cancer risk that yields the same mean willingness to pay.

[27] Stock (1991) estimated that the total value of a cleanup of the Ashland site ranged from $7 million to $42 million (in 1996 dollars).

VI. Conclusion

Assessing the cost effectiveness of the EPA's Superfund program requires comparing the costs of the program with the benefits accrued from the reduction in the health risk. Previous studies have suggested that people overreact to the threats from hazardous wastes, resulting in an inefficient outcome in which the EPA spends too much on remediation. Pressures for public spending or safety, however, may be quite different from private willingness to pay amounts. Our results suggest that residents have heightened perceptions of the risks from Superfund sites before they receive the information provided in the Remedial Investigation. When the residents are informed of the risks through the EPA's Remedial Investigation, and when they must spend their own funds to avoid the Superfund risks, their willingness to pay is similar to tradeoffs made in other encounters with risk, such as those made in labor market decisions.

Before the EPA releases the Remedial Investigation, the estimated willingness to pay for a risk reduction implies an upper-bound benefit of cleaning up the six sites ranging between $9.1 million and $10.1 million for a reduction of the mean level of cancer risk. For comparison, the total present value cost of the EPA's remediation plans for the six neighborhood Superfund sites is $56.8 million. Had the EPA undertaken only institutional controls for the remediation, the total present value cost would be $5.4 million, a figure more consistent with values implied by residents' willingness to pay to avoid Superfund risk.

The housing choices in the greater Grand Rapids housing market provide evidence on private valuation of Superfund risk reduction. The findings indicate that, after the EPA releases its Remedial Investigation, the tradeoff between cancer risk and housing prices is similar in magnitude to the tradeoff between mortality risk and wages found in previous labor market studies. This similarity suggests that there appears to be no evidence that people substantially overestimate the risk of cancer when making informed decisions for which they must pay for greater safety.

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