# The Market Value of Reducing Cancer Risk: Hedonic Housing Prices with Changing Information

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In this paper, we use housing price changes occurring after the release of a regulatory agency's environmental risk information to estimate the value people place on cancer risk reduction. Using a large original data set on the repeat sales of houses, matched with detailed data on hazardous waste cancer risk and newspaper publicity, we find that housing prices respond in a rational manner to changes in information about risk. Since the new information indicated that the sites in our sample pose relatively low cancer risk, the informational release led residents to lower their risk beliefs, resulting in an average housing price increase of $56 to $87. This price change implies a statistical value per case of cancer of $4.3 million to $8.3 million, which is similar to the estimates obtained in labor market studies of the value of a statistical life. Newspaper publicity about the local sites increased housing prices, suggesting that residents perceived the news as good.

## 1. Introduction

Market evidence on the value of a statistical life invariably consists of cross-sectional evidence on risks and prices or wages at a point in time. If information about the level of risk changes over time and people incorporate this information in a rational manner, there will be a corresponding price response. On the basis of these temporal changes, one can estimate the market price-risk tradeoff, eliminating many confounding time-invariant effects that cannot be controlled for using cross-sectional data. This paper examines the market response to the release of government information about the level of risk at hazardous waste sites and provides insight into the rationality of this response.

Studies based on experimental evidence and survey data often find that individual beliefs may deviate from objective risk levels.[1] People often overestimate highly publicized risks and mortality risks. In the case of hazardous waste risks, bias in risk beliefs often leads to considerable public reaction and pressure for site cleanups, which may be an inefficient outcome. By using market data,

[1] Contributions to this literature include Lichtenstein et al. (1978), Combs and Slovic (1979), Kahneman and Tversky (1979), and Arrow (1982). Kahneman, Slovic, and Tversky (1982) provide a summary of such studies, and Viscusi (1998) also reviews this literature.

one can examine whether this intense public reaction carries over to contexts in which private money is at stake.

Government agencies frequently use information provision as a regulatory device, particularly since the advent of the right-to-know movement of the 1980s. Examples of information provision efforts include the Food and Drug Administration's requirement that many prescription drugs include information inserts, the Department of Housing and Urban Development's requirement that sellers of houses built before 1950 inform buyers about the presence of lead-based paints, and the Environmental Protection Agency's (EPA) requirement that manufacturing facilities report their annual releases of chemicals above a threshold amount for a list of over 600 substances. Such regulations imply a belief that citizens can learn from information about risk and rationally adjust their prior beliefs towards the objective risk level in light of the information. This article provides market evidence to bolster the results of some survey studies of information transfer that suggest that individuals revise their risk beliefs in response to new information.[2]

The U.S. federal policy dealing with hazardous waste sites is known as the Superfund program. The most hazardous sites are targeted for cleanup and placed on a government priority roster called the National Priorities List (NPL). Extension of the classic theory of compensating differentials to the housing market implies that environmental disamenities (such as hazardous waste sites) will reduce housing prices (Rosen 1974). The negative impact of hazardous waste sites on the housing prices of nearby residences is well documented. For example, in a previous study (Gayer, Hamilton, and Viscusi 2000), we used an analysis that focused on the sale of 16,928 houses from 1988 to 1993 that surround Superfund sites in Greater Grand Rapids, Michigan. We found that before the EPA released its risk report, a reduction in the cancer risk from neighborhood Superfund sites by the mean level of risk would increase the average value of a house by $238 (in 1996 dollars).[3] To estimate this willingness of residents to pay to avoid cancer risks before the release of the EPA's risk report, we assumed that residents' prior beliefs were equal to the objectively measured risks suggested by the report. Thus, this analysis was based on the very strong informational assumption that residents could, in effect, predict the results of the EPA's site-specific risk assessments. Before the release of the report, the price-risk tradeoff implied a value of a statistical cancer case of $51 million. Once the EPA released its risk information, the implied value of a statistical cancer case was $4 million. These results suggest that after the release of the EPA's risk report, revealed preferences for avoiding Superfund risks were consistent with surveys of the value of a statistical life in the labor market.

In this paper, we examine how residents respond to information about Superfund risks by explicitly formulating how risk beliefs may change with the release of the EPA's site-specific information about risk levels. We do not assume that people know the site-specific risks before the release of the EPA's studies providing estimates of the cancer risk levels. Rather, we make the more realistic assumption that people base their estimates of site risks on their general knowledge

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of Superfund sites. The two reference points we use involve equating residents' prior beliefs about site risks with estimates of the average cancer risk level at Superfund sites nationwide and across the state. Once the EPA's information about the site-specific risk level is released, our model incorporates this objectively estimated risk level into residents' posterior risk beliefs.

Because our focus is on changes in risk over time, we focus on the subsample of houses sold more than once in the Greater Grand Rapids area from 1988 to 1993. This repeat sales methodology allows us to avoid some econometric problems, such as omitted-variable bias, because all time-invariant effects drop out of the analysis. The estimates consequently isolate whether price effects vary over time as risk beliefs change.

The average cancer risk for Superfund sites throughout the country and throughout the state is greater than the average risk for the Greater Grand Rapids sites. Consequently, if residents are basing their priors on their general knowledge of Superfund sites, and if they update their beliefs after the site-specific EPA risk data are released, then their risk beliefs will decline after the informational release. We would then expect housing prices to increase. If news stories about sites convey information that also causes a reduction in risk beliefs, then we would expect housing prices to rise with newspaper coverage. We find both of these effects in the analysis of our repeat sales sample. When other factors are controlled for, prices for housing sales after the release of the EPA site-specific risk data are higher. The implied value of a statistical case of cancer is between $4.3 and $8.3 million, depending on whether one assumes prior risk beliefs were based on national average risk levels or statewide average risk levels. The similarity between these values and the estimates of the value of a statistical life from other market contexts, such as that of the labor market, suggests that the residents react to risks from hazardous waste sites in ways that closely parallel their reaction to other risks. The finding that newspaper coverage increases housing values further suggests that the circulation of information from private sources about sites can cause people to lower their estimates of risk.

Some other hedonic studies examine whether the price-distance (rather than the price-risk) gradient changes over time, as information changes. In contrast to our finding, Kiel (1995) found that the price-distance tradeoff did not diminish either after the announcement of the cleanup or after the beginning of the cleanup of two Superfund sites in Woburn, Massachusetts. This is not necessarily inconsistent with our results, since for these sites it may be the case that the new information conveyed by the cleanup announcement and action indicated that the risks from the sites were higher than the baseline perception. Michaels and Smith (1990) found a price-distance effect after the announcement of hazardous waste risks at a site, although their results vary by housing submarkets.[4]

This paper improves upon our earlier study of hazardous waste risks in at least three ways: In the present study, we (i) explicitly model how risk beliefs may change by positing that prior beliefs are based on general knowledge of hazardous waste sites rather than assuming that risk beliefs do not change, (ii) use a repeat sales methodology that helps avoid omitted-variable biases in the hedonic analysis, and (iii) estimate the value of a statistical cancer case given various assumptions of discount rates and latency periods.

Discussions of risk policy often assume that individuals cannot accurately perceive risks or that they fail to update their beliefs in the face of new information. This paper provides evidence that individuals can reassess their beliefs of the risks at hazardous waste sites and do spend their

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[4] For a thorough review of property hedonic studies involving environmental disamenities, see Farber (1998) and Boyle and Kiel (2000).

own resources to avoid these risks, reflecting tradeoffs that are similar to choices about safety and risk in other markets. In section 2, we describe the repeat sales model specification, which we then link to a risk-learning model in section 3. Our data are described in section 4, and results and conclusions are provided in sections 5 and 6, respectively.

## 2. The Repeat Sales Estimation Model

### The Hedonic Price Function

The empirical framework we use to assess the effect of changes in risk levels is the hedonic property model, which postulates that housing prices are a function of structural, neighborhood, and environmental characteristics.[5] The environmental characteristics of a house are the perceived environmental risks associated with living in the house. The price of house $i$ sold at time $t$ is given by

$$\text{Price}_{it} = f(\text{Structural}_i, \text{Neighborhood}_i, \text{Environment}_{it}, t), \qquad (1)$$

where $\text{Structural}_i$ is a vector containing the structural characteristics, $\text{Neighborhood}_i$ is a vector of the neighborhood characteristics, $\text{Environment}_{it}$ is the perceived environmental risk to the household, and $t$ indicates the year of the sale. Notice that the environmental risk belief variable is subscripted with $t$, indicating that it varies over time. The model assumes that the structural and neighborhood characteristics are unchanged for each house across sales.[6] Residents have a learning function in which they update their prior beliefs of hazardous waste cancer risk after receiving information about risk levels from the EPA. We describe this learning model in section 3.

The use of the repeat sales housing method first advanced by Bailey, Muth, and Nourse (1963) eliminates the time-invariant house-specific effects and focuses on the time-specific effects. All that is required for the analysis is the time of the housing sale, the price for which the house was sold, and measures of the environmental risk level known at the time of each sale. As a result, the model focuses on the relationship between changes in risk levels and changes in housing price.[7]

### Model Specification

The households in our sample are exposed to cancer risks arising from potential soil and groundwater contamination at nearby Superfund hazardous waste sites. Under the U.S. EPA's Superfund program, hazardous waste sites that pose the greatest risks to human health or the environment may be cleaned up with a combination of private and public funds (Sigman 1998). The

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[5] The estimated price change given a change in a housing characteristic is likely to yield an approximate measure of the welfare effects (Bartik 1988; Palmquist 1992).

[6] The assumption of the repeat sales model is that the structural and neighborhood characteristics are time-invariant. This is a reasonable assumption for our analysis, since there were no major changes in infrastructure for the housing market examined. We dropped the observations for which there was a change in the structural characteristics (bedrooms, bathrooms, and lot size) between sales. If there were other changes to the houses in the sample, then there will be omitted variables. Even if this were the case, the estimated coefficients of the variables of interest would be unbiased if these variables were uncorrelated with the omitted variables.

[7] Our analysis is similar to that of Palmquist (1982), who used a repeat sales method to estimate the price effects of highway noise.

EPA has placed these sites in the Greater Grand Rapids area on its National Priority List (NPL), thus qualifying them 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 (ROD). The RI/FS, as well as the ROD, are made available to the public for examination. Note that the EPA's information about risk levels can influence those who have not read the agency's study, since the information may be disseminated through such avenues as resident discussions, realtor interactions, and media coverage.

Figure 1 presents a timeline of Superfund events in the Greater Grand Rapids area. Each of the seven Superfund sites was placed on the NPL in the early 1980s. As shown in Figure 1, the RI/FS for each site was released at various dates between mid-1990 and late 1992. These release dates occurred within the six-year period of our housing sales.[8] Our goal, then, is to use sales data for those houses sold more than once to estimate the effects on housing prices of the risk levels stemming from the RI/FS.

We use two variables to measure the information derived from the EPA. The first, $RI_{it}$, is a dummy variable indicating whether the house was sold after the release of the EPA's RI/FS for the closest Superfund site. The second information variable, $Risk_{it}$, is a measure of the cancer risk level derived from the EPA risk information available to the public. That is, for a house sold after the release of the RI/FS for the closest site, $Risk_{it}$ is a measure of the objective cancer risk level stemming from the site (as derived from the EPA assessment released to the public). For a house sold before the release of the RI/FS for the closest site, $Risk_{it}$ is a measure of the average on-site risk level over all national or statewide Superfund sites, weighted by pathway dilution estimates corresponding to the house's proximity to the closest site. Thus, we assume that risk beliefs are based on the information about risk levels available at the time of the house's sale. The $Risk_{it}$ variable will serve as the mechanism for exploring the character of individuals' risk beliefs and learning, which we will discuss in the next section.

It is useful to compare this formulation with that in our earlier study (Gayer, Hamilton, and Viscusi 2000), in which we assumed that respondents' prior risk beliefs coincided with actual risk levels both before and after the EPA study release. Using this assumption in a repeat sales analysis, the change in risk beliefs would be zero over time. Thus, in the previous paper, the price-risk gradient was estimated from the cross-sectional differences in risk levels, not the temporal differences. The present study permits risk beliefs to vary over time and in fact generates results consistent with there being an updating of risk beliefs as characterized in rational learning models.

We use the variable $News_t$ to measure the site information provided by local publicity. This variable is the total number of words about the neighborhood Superfund sites printed in the local newspaper from 1985 until the sale of the house. We also estimate various specifications to test whether the newspaper publicity serves as a mechanism of dissemination of the EPA risk information. We describe the information measures in greater detail in section 4.

Equation 1 is a longitudinal model of housing prices that incorporates fixed and time-specific effects. Two problems arise when one tries to estimate this hedonic price function. The first prob-

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[8] Within our repeat sales data set, 767 housing sales occurred after the last RI/FS was issued on November 15, 1992.
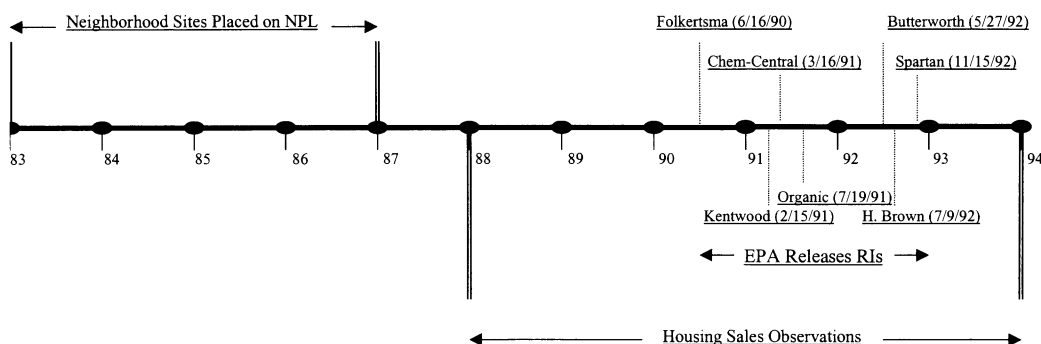
**Figure 1.** Timeline of Superfund Events in Greater Grand Rapids, Michigan

lem is that the collection of the relevant structural, neighborhood, and environmental data is extremely burdensome, often resulting in omitted-variable bias. The second problem arises in the choice of functional form. Hedonic theory does not provide guidance concerning which parametric model to estimate. If the parametric model is misspecified, the corresponding benefits estimator will be inconsistent. Most hedonic studies assume a semilog specification or a Box-Cox transformation (Harrison and Stock 1984; Bartik and Smith 1987; Cropper, Deck, and McConnell 1988; Michaels and Smith 1990; Kiel and McClain 1995; Gayer, Hamilton, and Viscusi 2000).[9]

By focusing on repeat sales of houses, we eliminate the problem of omitted-variables with respect to time-invariant characteristics of the house. We assume that changes in the housing price are in percentage terms. Because risk beliefs are based on the risk information, we can rewrite Equation 1 as follows:

$$\text{Price}_{it} = B_t g(\text{Structural}_i) h(\text{Neighborhood}_j) e^{\alpha_1 \text{RI}_{it}} e^{\alpha_2 \text{Risk}_{it}} e^{\alpha_3 \text{News}_t} e^{\varepsilon_{it}}, \tag{2}$$

where $B_t$ is a true but unknown real estate price index at the time of the sale; $\alpha_1$, $\alpha_2$, and $\alpha_3$ are the parameters that give the relative changes in price given changes in the variables of interest; and $\varepsilon_{it}$ is the error term.[10] We assume that $E(\varepsilon_{it}) = 0$ and $\text{Var}(\varepsilon_{it}) = \sigma^2$.

For the same house sold at time $t'$, the price function is the same as Equation 2, except that it is subscripted with $t'$ instead of $t$. When the ratio of the two prices is taken, the functions $g$ and $h$ cancel out, yielding

$$\frac{\text{Price}_{it'}}{\text{Price}_{it}} = \frac{B_{t'}}{B_t} e^{\alpha_1 (\text{RI}_{it'} - \text{RI}_{it})} e^{\alpha_2 (\text{Risk}_{it'} - \text{Risk}_{it})} e^{\alpha_3 (\text{News}_{t'} - \text{News}_t)} e^{(\varepsilon_{it'} - \varepsilon_{it})}. \tag{3}$$

Taking the natural logarithm of each side of Equation (3) yields

$$\ln \frac{\text{Price}_{it'}}{\text{Price}_{it}} = b_{t'} - b_t + \alpha_1 (\text{RI}_{it'} - \text{RI}_{it}) + \alpha_2 (\text{Risk}_{it'} - \text{Risk}_{it}) + \alpha_3 (\text{News}_{t'} - \text{News}_t) + u_{itt'}, \tag{4}$$

where $b_{t'} = \ln B_{t'}$, $b_t = \ln B_t$, and $u_{itt'} = \varepsilon_{it'} - \varepsilon_{it}$. Thus, the log of the price ratio over time is a simple linear regression in which the explanatory variables are the changes in RI/FS status, risk

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[9] In order to avoid the complications associated with choosing an inappropriate functional form, Stock (1989, 1991) proposes a nonparametric kernel regression for estimating the mean price effect of an environmental price change.

[10] The real estate price index is conflated with depreciation. Palmquist (1979) suggests a technique for distinguishing between price trends and depreciation. However, the estimation adjustment affects only the price index estimates, not the coefficients of the variables of interest.

level, and newspaper publicity. When there are only two sales of a house, one ratio is formed and $E(u_{itt'}) = 0$, $\text{Var}(u_{itt'}) = \sigma^2$. When a house is sold three times, two ratios are formed. While the means of the error terms are still zero, their covariance is equal to $\sigma^2$. We therefore have a problem of error correlation among observations.[11]

The coefficients of interest in Equation 4 correspond to the effects of RI/FS status, risk level, and newspaper publicity on housing prices in the original hedonic equation (Eqn. 2). In addition to eliminating the time-invariant effects, the repeat sales method allows for the estimation of real estate price trends even though the sales frequently do not occur in subsequent years and the years of the sales may vary by house. Bailey, Muth, and Nourse (1963) show that estimation of the price indexes can be treated as a regression problem by letting $x_j$ be a dummy variable that takes the value of $+1$ if period $j$ is the period of the final sale, $-1$ if period $j$ is the period of the initial sale, and $0$ otherwise for each pair of transactions. The index is normalized by letting $b_0 = 0$. Equation (4) becomes

$$r_{itt'} = \sum_{j=1}^{T} b_j x_j + \alpha_1 \text{RI}_{itt'} + \alpha_2 \text{Risk}_{itt'} + \alpha_3 \text{News}_{tt'} + u_{itt'}, \tag{5}$$

where $r_{itt'} = \ln(\text{Price}_{it'}/\text{Price}_{it})$, $\text{RI}_{itt'} = \text{RI}_{it'} - \text{RI}_{it}$, $\text{Risk}_{itt'} = \text{Risk}_{it'} - \text{Risk}_{it}$, $\text{News}_{tt'} = \text{News}_{t'} - \text{News}_t$, and the other variables are as described before.[12]

We estimate both an ordinary least-squares (OLS) regression of Equation 5 and a generalized least-squares (GLS) regression that address the problem of error correlation across repeat sales observations.[13] However, in section 5 we report only the OLS results, since the point estimates and the standard errors are virtually identical to the GLS results.

## 3. Prior Beliefs and Risk Learning

To capture residents' perceptions of Superfund risks, we assume a learning model in which posterior risk beliefs are a linearly-weighted average of the risk levels obtained from the informational sources.[14] The amount of learning that takes place given the new information will depend on the magnitude of the prior and updated risk levels, as well as the informational weight placed on both of these sources of information.

An individual's prior risk beliefs (before the release of the RI/FS for the closest site) are denoted by $p$, which has associated informational content $\varphi_0$. The information weight, $\varphi_0$, is equivalent to observing $\varphi_0$ draws from a Bernoulli urn. People update their risk beliefs taking into account the probability $q$, which is implied by the new site-specific information about risk levels

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[11] We also relax the assumption of constant variance across repeat sales by computing standard errors under the assumption of heteroskedasticity.

[12] The dummy variables control for the annual price trends. The time components of RI, Risk, and News vary by day, not by year. The News$_t$ variable varies only by time, since it measures the amount of publicity on Superfund sites up to the day of the sale. Two houses sold on the exact same day will have the same value for News$_t$ (although the change in publicity in the repeat sales observation will be different unless the two houses were sold twice on the same day).

[13] The GLS estimation yields efficient estimators. The variance-covariance matrix is equal to $\sigma^2\Omega$, where $\Omega$ is a known, symmetric, positive definite matrix with twos on the diagonal and ones where the error terms are correlated. The GLS method is to find a matrix $P$ such that $P'P = \Omega^{-1}$. The matrix $P$ is multiplied on both sides of the equation, and least-squares then yields efficient estimates.

[14] This approach is used in Viscusi's (1989) prospective reference theory model to structure biases in risk beliefs. This formulation is consistent with a rational Bayesian learning model, although other learning models may also be consistent with such a linear formulation.

obtained from the EPA's RI/FS. Other information (such as information provided by the local newspaper) would enter the model similarly. The risk level implied by this updating of information has informational content $\xi_0$. Posterior cancer risk beliefs, $\pi$, are of the form

$$\pi(p, q) = \frac{\varphi_0 p + \xi_0 q}{\varphi_0 + \xi_0}. \tag{6}$$

With the fraction of the total informational content associated with each information source denoted by $\varphi = \varphi_0/(\varphi_0 + \xi_0)$, $\xi = \xi_0/(\varphi_0 + \xi_0)$, the risk belief function is rewritten as

$$\pi(p, q) = \varphi p + \xi q = \varphi p + (1 - \varphi)q. \tag{7}$$

Therefore, given the release of the EPA's information about risk levels between the two sales of a house, a resident changes beliefs by posterior minus prior, which is equal to

$$\pi - p = (\varphi - 1)p + (1 - \varphi)q. \tag{8}$$

If residents place full weight on the updating information (i.e., $\varphi = 0$), then the change in beliefs is equal to the change in risk levels $(q - p)$. For the other extreme, residents would place no weight on the updating information (i.e., $\varphi = 1$), in which case the change in beliefs would equal zero (since the new information provided by the EPA is ignored).

The repeat sales regression equation discussed in the previous section tests the effect of the change in risk levels on housing prices without specifying the weights on the informational sources. Housing value changes in response to these changes would provide evidence that residents do place some weight on the site-specific information about risk levels provided by the EPA. In other words, if residents were ignoring the site-specific information provided by the EPA, then the change in risk levels would not affect beliefs, and thus there would be no effect on housing prices. The corresponding coefficient estimate would not be statistically different from zero.

We cannot explicitly estimate the informational weights placed on prior and updated risk levels. However, in order to compute the tradeoff between prices and risk beliefs, we assume that full weight is placed on the new site-specific information, and thus the change in risk levels is equal to the change in risk beliefs (i.e., $\pi - p = q - p$).

In order to test the effect of changes in risk levels, we first must postulate how rational individuals form their priors. In our earlier study (Gayer, Hamilton, and Viscusi 2000), we assumed that priors were equal to the objective risk measure derived from the EPA's risk report, even if the priors were formulated before the report. We based this assumption on the strong correlation between the objective risk measure and the known characteristics of the sites (such as the size and type of the site). In this study, we base our assumption of priors on the informational environment at the time of the house sale. Before the release of the RI/FS for the closest site, we assume that residents base their priors on the available general Superfund risk information. That is, we assume that unbiased priors $(p)$ are equal to the average on-site risk of sites on EPA's NPL, weighted by the house-specific dilution estimates.[15] Therefore, our assumption is that the residents' prior beliefs with regard to the on-site risks are equal to the average risk levels for all nationwide (or statewide) Superfund sites, since these residents have not yet received information on the specific risk levels of their local sites.[16]

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[15] When the house-specific dilution estimates are used, it is assumed that before the release of RI/FS, people are aware of their proximity to the site (since the site is on the NPL) but are not aware of the on-site risk (since the EPA has yet to do a risk assessment).

[16] Although we do not report it in our results, we also estimate repeat sales equations using priors in which the average on-site risks are weighted uniformly (using average dilution estimates) across the population of the houses.

If the average national (or state) Superfund site is less risky than the Greater Grand Rapids sites, then the residents' priors will be below the actual risk (i.e., $p < q$). If the average national (or state) Superfund site is riskier than the Greater Grand Rapids sites, then the residents' priors will be too high ($p > q$). In each case, according to the rational learning models, once information on the actual risk is released, people should revise their risk beliefs toward the true risk level (given that the new information is not ignored, i.e., that $\xi \neq 0$). However, the degree to which residents update their beliefs depends on the informational weight they place on the prior and the updated assessments. By assuming that residents place full weight on the new information, we can compute the marginal willingness to pay for reductions in risk beliefs.

We use a standardized measure of cancer risk for both the prior risk level based on a sample of 150 nationwide Superfund sites and that based on a sample of 19 statewide Superfund sites, as well as the updated risk level for the local sites.[17] These risk levels represent the additional probability of getting cancer (relative to a baseline cancer risk) for a person living *on* the Superfund site. We convert these on-site estimates to house-specific estimates by using dilution factors that vary with the location of the house. We then sum over media (groundwater and soil) and exposure routes (dermal, ingestion, and inhalation). In this way we obtain estimates of house-specific prior and updated risk levels. We discuss the computation of these risk levels more fully in the next section.

The average on-site lifetime cancer risk to adults from groundwater exposure for the 150 national sites is 0.042. The average on-site cancer risk to adults from 150 sites is 0.005 from dermal soil exposure, 0.002 from ingestion of soil contaminants and $6.2 \times 10^{-5}$ from inhalation of soil contaminants. Using the subsample of 19 sites in Michigan, we find that the average on-site lifetime cancer risk to adults from groundwater exposure is 0.041. The average on-site cancer risk to adults from the 19 sites is $9.5 \times 10^{-4}$ from dermal soil exposure, $1.2 \times 10^{-4}$ from ingestion of soil contaminants and $1.8 \times 10^{-4}$ from inhalation of soil contaminants. By contrast, the average on-site cancer risk to adults from groundwater exposure for the sites in Greater Grand Rapids is 0.014, and the average on-site cancer risk to adults from soil exposure is $9.6 \times 10^{-5}$ for dermal exposure, $6.0 \times 10^{-5}$ for ingestion exposure, and $4.7 \times 10^{-5}$ for inhalation exposure. Since the average national (and state) risk level is much higher than the average risk level from the Greater Grand Rapids sites, we expect that once the EPA releases the site-specific risk information, housing prices will increase, since residents will lower their risk beliefs.

Using the repeat sales method, we test whether housing prices react to the changes in risk levels. A negative coefficient estimate for $\alpha_1$ from Equation 5 would suggest that housing prices decline as a result of the release of an RI/FS for the closest site. On the other hand, if residents view the RI/FS as a sign that the site will soon be cleaned up, then one would expect a positive coefficient estimate for $\alpha_1$. One would expect a negative coefficient estimate for $\alpha_2$, suggesting that housing prices decline with increases in risk levels. In interpreting this coefficient estimate, one should keep in mind that the changes in risk levels could be confounded with changes in residents' perceptions about the likelihood that the site will be cleaned up soon, although the inclusion of the RI/FS dummy variable partially controls for this possibility. Given that, on average, the updated risk level is smaller than the priors based on the national (or state) average, a negative coefficient

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[17] The 150 sites were selected from the complete population of 267 nonfederal Superfund sites for which RODs were signed in 1991 or 1992. A subset of sites was chosen because of the cost of assembling the data and because of incomplete risk assessments at some sites. See appendix B of Hamilton and Viscusi (1999) for an analysis that suggests that this subsample is representative.

estimate for $\alpha_2$ would suggest that housing prices increased on average for this housing market because of the release of information about risk levels. The coefficient estimate for $\alpha_3$ could be positive or negative, depending on whether the residents perceive the local newspaper reports as good or bad news.

## 4. 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. Of the 16,928 house sales, 3702 were for houses that sold more than once. There were 1755 houses that were sold in two different years and 64 houses that were sold in three different years. The resulting repeat sales data set consists of 1883 observations.[18] Thus, even when the sample is restricted to repeat sales, a large sample of observations is obtained.

The Greater Grand Rapids area consists of the cities of Grand Rapids, Walker, Wyoming, Kentwood, and Grandville. This local market contains seven Superfund sites, and there were quantitative EPA risk data for all but one of these sites.[19] A local housing market with numerous Superfund sites enhances the analysis because there is heterogeneity of risk among the households.

We obtained data on the dates of the house sales, the house characteristics, the sale prices, and the addresses from the Multiple Listing Service of the Grand Rapids Society of Realtors. We also used a geographic information system (GIS) to compute the longitude and latitude coordinates of each house and of the neighborhood Superfund sites. With the GIS, we computed the distance of each house to each of the neighborhood Superfund sites. These distance values were used in the computation of the risk levels described below, since we weighted the on-site risk assessments for soil exposure by EPA standards on dilution estimates that vary by distance to the site. Application of this distance dilution estimate to the on-site risk assessments yields house-specific risk levels of soil exposure.

We use two variables to measure the risk information that households derive from the EPA. The first is a dummy variable, $RI_{it}$, which has a value of 1 if the day of the house's sale was after the release of the EPA's RI/FS for the closest Superfund site and has a value of 0 otherwise. The other risk information variable, $Risk_{it}$, measures the risk levels on the basis of information available to the residents. If a house was sold before the release of the RI/FS for the closest site, then $Risk_{it}$ is equal to the national (or state) on-site average risk level of Superfund sites, weighted by the house's dilution estimates. If the house was sold after the release of the RI/FS of the closest site, then $Risk_{it}$ is equal to the on-site risk level derived from the EPA's site-specific assessment, also weighted by the house's dilution estimates.

The EPA computes the on-site risk level for a chemical as the product of chemical concentration, ingestion rate, exposure duration, exposure frequency, the inverse of body weight, the inverse of the averaging time, and the chemical's slope factor. The slope factor is an upper-bound estimate of the probability of the development of cancer per unit intake of the chemical over a lifetime. We weight both the on-site national (or state) average risk level and the local site-specific risk level by soil and groundwater dilution estimates in order to estimate the impact of the known risk level on

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[18] Houses sold twice count as one observation, and houses sold three times count as two observations. Thus, the total number of observations for the repeat sales model is 1755 + (64 × 2) = 1883.

[19] The NPL sites used in this study are all of those for which RI/FSs were released during the relevant sample period. For the Spartan site there was only a qualitative analysis, which does not include residential risk estimates.

residents at different locations.[20] We draw on EPA guidelines for the soil dilution estimates, which are a function of the distances to the sites (which were measured using the GIS). To estimate groundwater dilution, we use the GIS to map the groundwater plumes (natural underground reservoirs) and to compute the proportion of houses in the Census block group residing above these plumes. For each block group, we use data from the U.S. Bureau of Census to determine the proportion of households that draw their water from groundwater, thus potentially exposing them to the cancer risk. These modifications mean that our risk level variable will not correspond exactly to a particular figure in the EPA reports, even though this level is based on the underlying EPA report data. Since the risk level depends on the location of the house and the timing of the sale with respect to the release of the information, $Risk_{it}$ varies over time and with each house.

We compute our publicity measure, $News_t$, on the basis of press coverage in the *Grand Rapids Press*, which serves the entire Greater Grand Rapids area. We compute the $News_t$ variable by first determining the exact publication date of each Superfund-related article and then computing the number of words in each article. The variable measures the exact number of words in the articles up until the day of the sale.[21] Therefore, the change in publicity between sales is gauged as the number of words printed in articles between the day of the initial sale and the day of the next sale. This change in publicity has a unique value for each repeat sales observation unless two houses were twice sold on the same day.[22]

Table 1 contains some descriptive statistics for the data set. The mean price of a house was approximately $70,500. On average, a house's price increased by about $7200 between sales. The mean number of words printed in the *Grand Rapids Press* about the Superfund sites at the time of the sale was approximately 13,000 (about 23 articles). Given priors based on the national on-site average weighted by the house's dilution estimates, the mean cancer risk level at the time of the initial sale was $1.23 \times 10^{-5}$, and the mean change between updated risk levels and prior risk levels was $-7.80 \times 10^{-6}$. Given priors based on the state on-site average weighted by the house's dilution estimates, the mean cancer risk level at the time of the initial sale was $4.93 \times 10^{-6}$, and the mean change between updated risk levels and prior risk levels was $-2.60 \times 10^{-6}$.

To examine the nature of the price and risk changes underlying the regression analysis, Table 2 presents information on those houses in the data set that were sold in 1989 and then again in 1992 (the modal repeat sales pair). The top rows indicate the changes in price, risk level, and news; the remaining rows indicate the houses' structural characteristics (which do not change between sales). It is important to keep in mind that throughout this paper, changes in risk level refer to changes in risk *known* to the residents, not actual changes in risk exposure. Thus, when the EPA releases its risk information, the residents become aware of a different level of risk, even though the risk itself has not changed. As can be seen in the first column of Table 2, these houses increased in price by $6252 between sales and also experienced a drop in risk levels and an increase in news publicity. The second column of Table 2 shows data on the subset of houses that

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[20] This methodology is similar to that used in Hamilton and Viscusi (1999) and Gayer, Hamilton, and Viscusi (2000).

[21] The articles in our newspaper data set begin in 1985. Since the repeat sales analysis uses changes in publicity from the first sale to the next sale, the starting date for the newspaper coverage is irrelevant as long as it begins by the date of the first house sale in the data set.

[22] To the extent that the local media disseminates the risk information provided by the EPA, the publicity measure could be correlated with the risk level. Almost all of the newspaper articles discuss, at least in part, both the risks and the costs associated with the site. However, most of the articles (approximately 69%) emphasize the risk for the sites instead of the cost information. In our analysis, we ran separate specifications in order to test whether the coefficient estimates changed when the publicity measure was omitted.

**Table 1.** Descriptive Statistics for the Sample of Repeat Sale Houses

| Variable | Mean | Standard Deviation |
|---|---|---|
| Price at time of initial sale ($) | 70,520 | 22,938 |
| Change in price between repeat sales ($) | 7172 | 6774 |
| Cancer risk level at time of initial sale × 1 million (prior = national average) | 12.30 | 38.60 |
| Change in cancer risk level between repeat sales × 1 million (prior = national average) | −7.80 | 28.52 |
| Cancer risk level at time of initial sale × 1 million (prior = state average) | 4.93 | 22.30 |
| Change in cancer risk level between repeat sales × 1 million (prior = state average) | −2.60 | 13.92 |
| Dummy variable indicating if house was sold after the EPA's Remedial Investigation for the closest site (0/1) | 0.31 | 0.46 |
| Change in Remedial Investigation status between repeat sales (0/1) | 0.63 | 0.48 |
| No. of words printed in newspaper at time of the initial sale | 12,939 | 8301 |
| No. of words printed in newspaper between repeated sales | 12,667 | 5859 |

had a RI/FS released between the two sale dates, while the third column shows data on the subset of houses that did not have a RI/FS released between the two sale dates. Those houses that did experience a RI/FS had a greater reduction in risk levels based on the new information and a greater increase in news publicity. To the extent that the RI/FS presents good news, that risk is perceived as an economic bad, and that the news publicity is favorable, one would expect the houses for which an RI/FS was released to have experienced a greater price increase than the houses for which no RI/FS was released. Of course, unlike the regression analysis conducted in the next section, this analysis does not attempt to separate out the various information effects. Comparing the structural characteristics of the houses for which an RI/FS was released to those of the houses for which no RI/FS was released indicates that there is no statistically significant difference between them except with regard to the number of fireplaces.

## 5. Empirical Results

### Estimation of the OLS Equations

As mentioned earlier, the repeat sales model eliminates the time-invariant effects. In order to test whether controlling for time-invariant characteristics affects the results, we first estimate cross-sectional equations for the 3702 house sales that we later use in the repeat sales analysis. The dependent variable in this cross-sectional analysis is the log of price. Tables 3 and 4 present the cross-sectional results when risk beliefs prior to the RI/FS are based on the national average and when risk beliefs prior to the RI/FS are based on the state average, respectively. Data are presented for different specifications that vary with regard to their inclusion of housing characteristics, neighborhood characteristics, county fixed-effects dummy variables, and annual fixed-effects dummy variables.

The cross-sectional results indicate that housing prices do respond to the level of risk. The coefficient estimates for the risk level variable are negative and significant at the 1% level for 4 of the

**Table 2.** Descriptive Statistics for Houses Sold in 1989 and Sold Again in 1992

| | Mean Change for All Houses Sold in Both 1989 and 1992 ($N = 196$) | Mean Changes for Houses for which RI/FS Was Released between Sales ($N = 151$) | Mean Changes for Houses for which RI/FS Was Not Released between Sales ($N = 45$) |
|---|---|---|---|
| Change in price ($) | 6252 | 6559 | 5232 |
| | (5950) | (4828) | (8721) |
| Change in cancer risk | −9.52 | −12.36 | — |
| level × 1 million | (29.15) | (32.71) | — |
| (prior = national | | | |
| average) | | | |
| Change in cancer risk | −2.87 | −3.73 | — |
| level × 1 million | (11.61) | (13.12) | — |
| (prior = state | | | |
| average) | | | |
| Change in news | 14,093 | 14,505 | 12,712 |
| (no. of words) | (2836) | (2873) | (2231) |
| Housing characteristics | | | |
| No. of bedrooms | 2.93 | 2.95 | 2.89 |
| | (0.73) | (0.74) | (0.71) |
| No. of bathrooms | 1.5 | 1.53 | 1.40 |
| | (0.56) | (0.57) | (0.52) |
| No. of fireplaces | 0.38 | 0.44 | 0.18 |
| | (0.66) | (0.70) | (0.49) |
| Basement | 0.84 | 0.82 | 0.89 |
| | (0.37) | (0.38) | (0.32) |
| Lot size (square feet) | 9176 | 9471 | 8186 |
| | (6481) | (6892) | (4792) |
| Garage | 0.91 | 0.93 | 0.87 |
| | (0.28) | (0.26) | (0.34) |

Standard deviations are in parentheses. The data are for the modal years of repeat sales. The difference in means of the last two columns (which represents a difference-in-difference approach) is significant at the 1% level for the change in risk using the state average (where the difference in risk for houses that did not have an RI/FS released is zero) and for the change in news, and it is significant at the 10% level for the change in risk using the national average (where the difference in risk for houses that did not have an RI/FS released is zero). Comparison of the housing characteristics for the last two columns suggests that the third column is an adequate control group, since the means are not significantly different between the two columns except for the number of fireplaces.

12 specifications and are negative and significant at the 5% level for 7 specifications.[23] For the mean housing price, the change in price given a mean change in the risk level ranges between $109 and $334 for the estimates in Table 3 and between $46 and $126 for the estimates in Table 4. The coefficient estimates for newspaper publicity and for the release of an RI/FS suggest that these forms of information do not significantly affect prices. We now turn to the repeat sales model in order to control for the time-invariant characteristics.

Table 5 contains the repeat sales results for the OLS equations.[24] The first column contains results based on the assumption that risk beliefs prior to the release of the RI/FS are based on the average national risk level of Superfund sites. The second column contains results based on the assumption that risk beliefs before the release of the RI/FS are based on the average state risk level

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[23] All tests of significance reported in this paper are two-sided tests.

[24] As mentioned earlier, we do not report the GLS results, since they are virtually identical to the OLS results.

**Table 3.** Cross-Sectional Regression Results for Six Specifications (I–VI) (Prior = National Average Superfund Risk)

| | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| Cancer risk level | −473.183*** | −465.826*** | −607.810*** | −197.522** | −234.482** | −236.230** |
| | (110.514) | (110.447) | (106.637) | (97.035) | (97.688) | (97.676) |
| Newspaper information | $-2.37 \times 10^{-6}$*** | $-1.30 \times 10^{-6}$ | $8.10 \times 10^{-7}$ | $1.87 \times 10^{-6}$ | $2.10 \times 10^{-6}$ | |
| | $(7.90 \times 10^{-7})$ | $(2.39 \times 10^{-6})$ | $(2.28 \times 10^{-6})$ | $(1.95 \times 10^{-6})$ | $(1.95 \times 10^{-6})$ | |
| Remedial investigation | 0.009 | 0.028** | −0.005 | −0.012 | −0.014 | −0.011 |
| | (0.013) | (0.014) | (0.014) | (0.012) | (0.012) | (0.012) |
| Housing characteristics | Yes | Yes | Yes | Yes | Yes | Yes |
| Neighborhood characteristics | No | No | No | Yes | Yes | Yes |
| County fixed effects | No | No | Yes | No | Yes | Yes |
| Annual fixed effects | Yes | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.492 | 0.494 | 0.543 | 0.668 | 0.670 | 0.667 |

Corrected standard errors are in parentheses. The number of observations for each specification is 3702, which represents 1755 houses sold twice plus 64 houses sold three times. The housing characteristics are the number of bedrooms, the number of bathrooms, the number of fireplaces, whether the house has a basement, the lot size, and whether the house has a garage. The neighborhood characteristics are the proportion of the block group that are Black, the median household income in the block group, the proportion of the block group that are high school educated, the city tax rate, the distance to the central business district, the seventh grade reading test scores in the school district, the proportion of the block group under 19 years old, and the city crime rate.

** Significant at the 5% level.

*** Significant at the 1% level.

**Table 4.** Cross-Sectional Regression Resuls for Six Specifications (I–VI) (Prior = State Average Superfund Risks)

| | I | II | III | IV | V | VI |
|---|---|---|---|---|---|---|
| Cancer risk level | -437.889** | -423.983** | -685.408*** | -252.211 | -332.460** | -333.050** |
| | 183.307) | (183.211) | (177.850) | (163.580) | (165.838) | (165.842) |
| Newspaper information | $-2.32 \times 10^{-6}$*** | $-1.17 \times 10^{-6}$ | $9.90 \times 10^{-7}$ | $1.93 \times 10^{-6}$ | $2.17 \times 10^{-6}$ | |
| | $(7.90 \times 10^{-7})$ | $(2.40 \times 10^{-6})$ | $(2.29 \times 10^{-6})$ | $(1.95 \times 10^{-6})$ | $(1.95 \times 10^{-6})$ | |
| Remedial investigation | 0.011 | 0.031** | -0.001 | -0.012 | -0.013 | -0.010 |
| | (0.013) | (0.014) | (0.014) | (0.012) | (0.012) | (0.012) |
| Housing characteristics | Yes | Yes | Yes | Yes | Yes | Yes |
| Neighborhood characteristics | No | No | No | Yes | Yes | Yes |
| County fixed effects | No | No | Yes | No | Yes | Yes |
| Annual fixed effects | No | Yes | Yes | Yes | Yes | Yes |
| $R^2$ | 0.490 | 0.492 | 0.541 | 0.668 | 0.667 | 0.669 |

Corrected standard errors are in parentheses. The number of observations for each specification is 3702, which represents 1755 houses sold twice plus 64 houses sold three times. The housing characteristics are the number of bedrooms, the number of bathrooms, the number of fireplaces, whether the house has a basement, the lot size, and whether the house has a garage. The neighborhood characteristics are the proportion of the block group that are Black, the median household income in the block group, the proportion of the block group that are high school educated, the city tax rate, the distance to the central business district, the seventh grade reading test scores in the school district, the proportion of the block group under 19 years old, and the city crime rate.

** Significant at the 5% level.

*** Significant at the 1% level.

**Table 5.** Repeat Sales Regression Results

| Variable | Prior = National Average Superfund Risk | Prior = State Average Superfund Risk |
|---|---|---|
| Intercept | 0.059*** | 0.059*** |
| | (0.006) | (0.006) |
| Year 1989 | 0.055*** | 0.055*** |
| | (0.006) | (0.006) |
| Year 1990 | 0.088*** | 0.087*** |
| | (0.009) | (0.009) |
| Year 1991 | 0.090*** | 0.090*** |
| | (0.014) | (0.005) |
| Year 1992 | 0.077*** | 0.077*** |
| | (0.020) | (0.020) |
| Year 1993 | 0.077*** | 0.076*** |
| | (0.025) | (0.025) |
| Change in cancer risk level | −158.234** | |
| (prior = national average) | (78.330) | |
| Change in cancer risk level | | −302.915* |
| (prior = state average) | | (166.022) |
| Change in no. of words | $2.297 \times 10^{-6}$** | $2.328 \times 10^{-6}$** |
| printed about sites in newspaper | $(1.080 \times 10^{-6})$ | $(1.078 \times 10^{-6})$ |
| Change in whether Remedial | −0.009 | −0.009 |
| Investigation has been conducted | (0.007) | (0.007) |

Corrected standard errors are in parentheses. Each observation represents a repeat sale of a house, and the dependent variable is the log of the price ratio of the scales. $N = 1883$.
* Significant at the 10% level.
** Significant at the 5% level.
*** Significant at the 1% level.

of Superfund sites. The standard errors reported in the regression tables are corrected for the possible existence of heteroskedasticity.

Sale prices rise with inflation, as expected. The annual price index estimates are positive and significant at the 1% level for both equations for each year.[25] Our goal is to test whether the EPA's RI/FS and the site-specific risk levels affect residents' beliefs with regard to the hazardous waste risks and result in a price change. We also examine whether the local newspaper serves as a mechanism to disseminate information about the Superfund sites.

The coefficient estimates indicate that housing prices respond to EPA information about risk levels in the expected direction. Given priors based on the national average, the mean change in risk levels (which involves a decrease in risk, since the updated risk level is lower than the prior risk level) results in a housing price increase of $87. Given priors based on the state average, the mean change in risk levels results in a housing price increase of approximately $56. This effect is significantly different from zero at the 5% level for the first specification and at the 10% level for the second specification, for which each test is a two-tailed test.[26]

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[25] Note that the base year is 1988. Also note that the annual dummy variables could capture effects other than inflation, such as depreciation.

[26] As mentioned previously, we also estimated repeat sales equations using priors in which the average on-site risks are weighted uniformly (using average dilution estimates) across the population of the houses. The coefficient estimates for these equations also show a negative effect of risk levels on housing prices, although this effect is not statistically significant. This finding could indicate that people base their priors on their understanding of the distance of their houses to the closest site, or it could be due to the lack of heterogeneity of the independent variable of interest.

These coefficient estimates provide evidence that housing prices are responding to changes in risk. It is important to emphasize that this conclusion assumes that the risk level is not confounded with other effects. For example, the release of the information about risk levels could also be interpreted by the residents as a sign that the EPA will soon clean up the site, and these future benefits of a cleanup will thus be capitalized into the housing price. The RI/FS dummy variable is included in an attempt to control for these confounding effects.

If one assumes that residents fully update their beliefs with the new risk information, then the change in risk levels is equivalent to the change in risk beliefs (i.e., if $\varphi = 0$, then Eqn. 8 equals $q - p$). Under this assumption, one can estimate the value of a statistical cancer case by multiplying the coefficient estimates for the Risk variable by the housing price.[27] The value must then be adjusted by dividing by the average number of people per household, since the housing price reflects the willingness to pay for risk reductions for each household member.[28] Thus, using the results for priors based on the national average risks, the value of a statistical cancer case is estimated at \$4.3 million. Using the results for priors based on the state average risks, the value of a statistical cancer case is estimated at \$8.3 million. These estimates are similar to the estimates of the value of a statistical life found in many labor market and product market studies.[29] These estimates are also similar to the \$4 million postinformation estimate found in our earlier study (Gayer, Hamilton, and Viscusi 2000) based on cross-sectional evidence for the Grand Rapids sample, thus suggesting consistency between the two studies.

We derive the estimates of the value of a statistical cancer case by using the estimated risk coefficients of the repeat sales analysis. It should be noted that we obtained the coefficient estimates using the objective cancer risk levels discussed earlier as our independent variables. These risk levels are based on EPA information, which assumes that residents are exposed to the risk for 30 years, that future risks are not discounted, and that there is no latency period before the onset of cancer. One can relax these assumptions, computing a new estimate of the value of a statistical cancer case given different exposure periods, discount rates, and latency periods. That is, for a given annual risk ($\text{Risk}^A$), the measure used in our empirical analysis is $30 \times \text{Risk}^A$ (i.e., 30 years of the annual risk). If, instead, one assumed an infinite stream of annual risk with a discount rate $r$ and a latency period of $n$ years, then the total risk would be

$$\frac{\text{Risk}^A}{(1+r)^n} + \frac{\text{Risk}^A}{(1+r)^{n+1}} + \cdots = \text{Risk}^A \frac{(1+r)^{1-n}}{r}. \tag{9}$$

Thus, if this annual stream is the accurate risk measure, then the 30-year assumption (with no discount rate and no latency period) yields estimates that are off by a factor of $(1 + r)^{1 - n}/30r$.[30] One must divide the estimates for the value of a statistical cancer by this amount in order to obtain an estimate under the assumption of an infinite stream of risks with the given discount rate and latency period. In other words, the transformation equation is as follows:

$$\text{VOC}' = \text{VOC} \times 30r(1 + r)^{n-1}, \tag{10}$$

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[27] The value of a statistical case of cancer is computed by dividing the point estimate of the marginal willingness to pay for risk reduction by the level of risk reduction. For inframarginal changes, the hedonic price gradient is an upper bound of the willingness to pay for risk reduction.

[28] The average number of people per household in the relevant block groups is 2.573.

[29] See Viscusi (1993) for a review of labor market findings and for survey evidence on cancer valuation.

[30] Note, for example, that a 30-year stream of risks with no discount rate and no latency period is equivalent to an infinite stream of risks at a 3.4% discount rate with no latency period.

where $r$ is the discount rate, $n$ is the latency period, and VOC is \$4.3 million given priors based on the nationwide average and \$8.3 million given priors based on the statewide average. For example, the estimated value of a statistical cancer case given a 3% discount rate and a 10-year latency period is approximately \$5.1 million based on the nationwide priors and \$9.7 million based on the statewide priors.

Although the results are not reported in the tables, we also estimated repeat sales equations with either the change in estimated soil risk levels or the change in groundwater risk levels replacing the change in overall risk levels. Distinguishing these component risks allows us to test whether people are willing to pay more or less for soil risk reduction with respect to groundwater risk reduction. The coefficient estimates for the change in risk levels by medium were significantly different from zero at the 10% level when priors based on the national average risks were assumed, but these estimates were not significantly different from zero when priors based on the state average were assumed. When priors based on the national average are used, the estimated price-risk tradeoff implies statistical cancer case values of \$4.5 million for soil risk and \$8.7 million for groundwater risk. This finding suggests that people value groundwater risk reduction more than they do soil risk reduction (or that they place greater informational weight on new information about groundwater risk than they do on new information about soil risk).

The estimates obtained indicate that an increase in the mean number of words printed in the *Grand Rapids Press* about the Superfund sites causes housing values to increase. Housing prices increase by 3% in both equations, and estimates are significant at the 5% level for both equations. The dollar change for the mean housing price given this change in publicity is \$2052 for the first equation and \$2080 for the second equation. This amounts to a price increase of approximately \$89 for every article pertaining to a neighborhood Superfund site. This price increase suggests that residents perceive local newspaper articles about the sites as good news.[31] In the cross-sectional results reported in Tables 3 and 4, the effect of publicity on housing prices was mixed. The positive correlation found for the repeat sales equations implies that some time-invariant unobservable characteristics apparently are correlated with publicity, thus biasing the cross-sectional results.

The coefficient estimates indicate a negative effect of the release of an RI/FS for the closest site on prices. Holding all else constant, if an RI/FS is released for the closest site, the price of a house decreases by 1%. However, this effect is not significantly different from zero for either specification.

Experimental studies sometimes indicate that people do not accurately assess technical risk information (Slovic, Fischhoff, and Lichtenstein 1982) and that individuals either overreact to or ignore new risk information.[32] Contrary to these claims, our repeat sales regressions based on market data indicate that residents respond to the information about risk levels provided by the EPA and to information provided by the local newspaper. Residents lower their risk beliefs for neighborhood Superfund sites, resulting in an increase in housing prices.

## Estimation of Alternative Specifications

For robustness, we estimate equations with each of the time-variant variables of interest, as well as pairs of these variables, omitted from the repeat sales equation. To the extent that the local

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[31] We also estimated a model that includes the interaction of risk and news, and we found a nonstatistically significant effect with this model. This finding suggests that the price-news gradient does not vary given different values of risk.

[32] See, for example, Slovic (1986). Viscusi, Magat, and Huber (1987) first identified such reference risk effects. Hartman, Doane, and Woo (1991) also found evidence of status quo bias in consumer valuation of the reliability of residential electrical service.

newspaper reports on the information provided by the EPA, the News variable may be correlated with the Risk variable, resulting in a biased estimate of the effect of the risk levels when the News variable is excluded. Similarly, the release of an RI/FS could be correlated with the Risk variable. The alternative estimates capture both the direct effect of the included variable(s) of interest and the effect of the omitted variable(s). Table 6 contains the regression results of the variables of interest when the priors are based on the national Superfund average, and Table 7 contains the regression results of the variables of interest when the priors are based on the state Superfund average.

Although the results are not reported in the tables, the estimates for the annual indexes are positive and significant at the 1% level for each equation. The coefficient estimates for the change in the risk level are negative and significant for all of the pertinent specifications. The coefficient estimate for the change in News is significant at the 5% or the 10% level when a measure of the change in the risk level is not included in the regression, and it is significant at the 10% level when the change in the risk level is included in the regression. The slight change in the News coefficient estimate when the change in risk is removed from the equation suggests that there is a small correlation between newspaper coverage and risk. Nonetheless, overall, the estimation results are stable across specifications. As shown in Table 5, the coefficient estimate for the change in RI/FS status is not significantly different from zero for any of the specifications, suggesting that the exclusion of this variable does not bias the results of the effect of risk information on price. These results thus offer further evidence that people lower their risk beliefs after the EPA releases site-specific risk information, resulting in increased housing prices.

We also conducted a test of whether the repeat sales results of this paper are consistent with the full-sample results obtained in our earlier study (Gayer, Hamilton, and Viscusi 2000). In the previous paper, we assumed that the log of prices was a function of (among other things) the RI/FS status, the objective risk level, and an interaction of the risk and the RI/FS status. However, since we did not explicitly formulate prior and updated risk levels (as we do in this paper), the objective risk level was the same whether or not the RI/FS had been released yet. As a check on the repeat sales model, we reestimated Equation 5, adapting the specification of our previous paper to the repeat sales framework and using the assumption of equal prior and updated risk levels. As in our earlier study (Gayer, Hamilton, and Viscusi 2000), the risk measure we use for this equation is the aggregate of all of the risks from the local sites. The new equation is as follows:

$$
\begin{aligned}
r_{itt'} &= \sum_{j=1}^{T} b_j x_j + \alpha_1 RI_{itt'} + \alpha_2 (Risk_i - Risk_i) + \alpha_3 [(RI_{it'} \times Risk_i) - (RI_{it} \times Risk_i)] \\
&\quad + \alpha_4 News_{tt'} + u_{itt'} \\
&= \sum_{j=1}^{T} b_j x_j + \alpha_1 RI_{itt'} + \alpha_3 Risk_i (RI_{it'} - RI_{it}) + \alpha_4 News_{tt'} + u_{itt'}.
\end{aligned} \tag{5'}
$$

Since taking differences in the repeat sales method eliminates time-invariant effects, the risk variable drops out, and the equation cannot estimate the price-risk tradeoff before and after the release of the RI/FS. Nevertheless, the equation does test whether the change in price resulting from the release of the RI/FS varies with respect to the level of risk. Table 8 shows the results of this robustness check. These results suggest that the release of the RI/FS does reduce price (though not significantly), and that the price reduction is smaller for higher-risk houses. When evaluations are carried out for the mean risk level and the mean housing price, the results suggest that the release of the RI/FS decreases a house's price by $612. In our earlier study (Gayer, Hamilton, and

**Table 6.** Alternative Specifications (Prior = National Average)

| Variable | I(b) | I(c) | I(d) | I(e) | I(f) | I(g) |
|---|---|---|---|---|---|---|
| Change in cancer risk level | | −146.998* (77.864) | | | −158.793** (78.576) | −140.846* (77.532) |
| Change in no. of words printed about sites in newspaper | | | $2.005 \times 10^{-6}$* $(1.096 \times 10^{-6})$ | $2.304 \times 10^{-6}$** $(1.083 \times 10^{-6})$ | | $1.927 \times 10^{-6}$* $(1.078 \times 10^{-6})$ |
| Change in whether Remedial Investigation has been conducted | −0.004 (0.007) | | | −0.007 (0.007) | −0.006 (0.007) | |

Corrected standard errors are in parentheses. Each observation represents a repeat sale of a house, and the dependent variable is the log of the price ratio of the sales. Each column represents an alternative specification of the repeat sales model. Although not reported in this table, these equations include the other variables listed in Table 4. $N = 1883$.
* Significant at the 10% level.
** Significant at the 5% level.

**Table 7.** Alternative Specifications (Prior = State Average)

| Variable | II(b) | II(c) | II(d) | II(e) | II(f) | II(g) |
|---|---|---|---|---|---|---|
| Change in cancer risk level | | −282.857* (163.965) | | | −298.695* (168.355) | −274.613* (160.091) |
| Change in no. of words printed about sites in newspaper | | | $2.005 \times 10^{-6}$* $(1.081 \times 10^{-6})$ | $2.304 \times 10^{-6}$** $(1.083 \times 10^{-6})$ | | $1.974 \times 10^{-6}$* $(1.077 \times 10^{-6})$ |
| Change in whether Remedial Investigation has been conducted | −0.004 (0.007) | | | −0.007 (0.007) | −0.005 (0.007) | |

Corrected standard errors are in parentheses. Each observation represents a repeat sale of a house, and the dependent variable is the log of the price ratio of the sales. Each column represents an alternative specification of the repeat sales model. Although not reported in this table, these equations include the other variables listed in Table 4. $N = 1883$.
* Significant at the 10% level.
** Significant at the 5% level.

**Table 8.** Robustness Check of Repeat Sales Regression Results

| Variable | I |
|---|---|
| Intercept | 0.059*** |
| | (0.006) |
| Year 1989 | 0.055*** |
| | (0.006) |
| Year 1990 | 0.087*** |
| | (0.009) |
| Year 1991 | 0.090*** |
| | (0.014) |
| Year 1992 | 0.077*** |
| | (0.020) |
| Year 1993 | 0.076*** |
| | (0.025) |
| Change in whether Remedial Investigation has been conducted | −0.009 |
| | (0.007) |
| Risk × change in whether Remedial Investigation has been conducted | 15.792** |
| | (8.065) |
| Change in no. of words printed about sites in newspaper | $2.345 \times 10^{-6}$** |
| | $(1.078 \times 10^{-6})$ |

Corrected standard errors are in parentheses. Each observation represents a repeat sale of a house, and the dependent variable is the log of the price ratio of the sales. The risk measure used in the interaction independent variable is constant over time (as in Gayer, Hamilton, and Viscusi 2000). $N = 1883$.
** Statistically significant at the 5% level.
*** Statistically significant at the 1% level.

Viscusi 2000) the price reduction was estimated at $670.[33] The similarity between these two results suggests that these two papers are consistent with each other.

We offer one final comparison with our previous paper as a consistency test. For this test, we estimated the cross-sectional equation of the previous paper using the full sample of 16,928 observations and substituting in the explicitly formulated prior and updated risk levels used in the current paper. Given priors based on the national average, the estimated postinformation price-risk gradient was −151. Evaluated at the mean price, this implies a value for a statistical case of cancer of $4.3 million. Given priors based on the state average, the estimated postinformation price-risk gradient was −149. Evaluated at the mean price, this implies a value for a statistical case of cancer of $4.3 million. These estimates are very similar to the $4 million estimate obtained in our earlier study (Gayer, Hamilton, and Viscusi 2000), again suggesting consistency between the two papers.

## 6. Conclusion

The emergence of right-to-know legislation (such as the Emergency Planning and Community Right-To-Know Act of 1986, the Pollution Prevention Act of 1990, and the Food and Drug

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[33] The mean risk in the sample used in Gayer, Hamilton, and Viscusi (2000) was almost an order of magnitude smaller than the mean risk used in the repeat sales sample for this paper. This may suggest that high-risk houses are more likely to sell repeatedly during a given period.

Administration Modernization Act of 1997) suggests an increased reliance on the ability of people to assess publicly provided information on health risks. These right-to-know policies have raised the issue of how much confidence policy makers should place on people's ability to think clearly about the risks they face. If individuals accurately process the risk information provided by the government, such information transfers can foster sounder risk decisions. Our analysis of the housing price effects of EPA risk information examines risk learning based on housing market behavior, without relying on experimental or survey data.

In order to test whether individuals respond to information about hazardous waste risk levels, we make plausible assumptions on how people form their beliefs before receiving site-specific risk information. We assume that before receiving the site-specific information from the EPA, residents base their initial beliefs about the cancer risk from the local Superfund sites on their general knowledge of the risks posed by nationwide (or statewide) Superfund sites. We further assume that changes in price due to information result from changes in risk beliefs and not from other confounding factors. Controlling for the time-invariant housing characteristics, we find that housing prices do indeed respond to the level of risk. Since risk levels for the sites in Grand Rapids are, on average, lower than the nationwide (or statewide) average risk level, residents lower their risk beliefs and housing prices increase.

Regulatory agencies such as the EPA must frequently evaluate programs that address cancer risks. In order to enact efficient regulations, an agency must obtain estimates of the value of such risk reductions. Typically, labor market studies are the source of such estimates because of the relatively greater availability of labor market risk measures. However, estimates of the value of a statistical life obtained from a certain population of workers may not be appropriate for another population, such as one that includes nonworkers or children. Moreover, most labor market studies focus on mortality risk and must rely on survey data to evaluate willingness to pay for cancer risk reductions.

In this paper, we use housing market evidence to find that residents learn from the cancer risk information provided by the EPA and that their reduction in risk beliefs leads to an increase in housing prices. The estimated price-risk tradeoff implies a value of a statistical cancer case of $4.3 million to $8.3 million. If one assumes a 3% discount rate with a 10-year latency period for acquiring cancer, the tradeoff implies a value of a statistical cancer case of $5.1 million to $9.7 million. Thus, by developing measures of house-specific cancer risk beliefs before and after the EPA's risk report, we provide housing market estimates of the value of a statistical cancer case that are highly consistent with estimates of mortality tradeoffs found in other domains (such as the labor market or the automobile market). Our results also suggest that residents perceive the newspaper coverage of the Superfund sites as good news and that this perception results in an increase in individual housing prices of approximately $89 per article.

Our analysis suggests that EPA information leads residents to adjust their initial estimates of the risks from hazardous waste sites, resulting in a change in housing prices. These results contradict previous studies that suggest that people have either alarmist reactions or no reaction at all to risk information.[34] We provide evidence that residents exhibit the ability to learn from information presented by the EPA on the specific local risks and that large gains from learning can take place once the public receives expert risk information.

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[34] See, for example, Nisbett and Ross (1980) and Morgan et al. (1985).

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