Estimation of Perceived Risk and Its Effect on Property Values

Jill J. McCluskey and Gordon C. Rausser*

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Abstract: A dynamic discrete time model is estimated in order to analyze the evolution of perceived risk around a hazardous waste site and its effect on property values. Residential property values are modeled as a function of housing attributes and perceived risk to health from a nearby hazardous waste site using an hedonic price framework. Perceived risk enters the model as a state equation, which includes a media coverage variable. An aggregate measure of perceived risk is estimated and weighted by the distance to the hazardous waste site in order to individualize risk to each location. Using a data set that spans seventeen years of property values around a hazardous waste site, the results indicate that media coverage and high prior risk perception increase current perceived risk. Increased perceived risk surrounding the hazardous waste site, in turn, lowers property values. Implications for compensation for property value diminution caused by environmental contamination are discussed.

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*McCluskey: Assistant Professor, Department of Agricultural Economics, PO Box 646210, Washington State University, Pullman, WA 99164-6210; Rausser: Dean and Robert Gordon Sproul Distinguished Professor, College of Natural Resources, University of California, Berkeley, CA 94720 and member, Giannini Foundation of Agricultural Economics. The authors wish to thank without implicating Amos Golan, Michael Hanemann, Ron Mittelhammer, Zhihua Shen, and Eric Schuck for helpful insights and computer programming expertise. They also wish to thank Anupama Jain for her assistance with data collection. This work was supported by an EPA-NSF grant. Jill McCluskey gratefully acknowledges financial support she received from the Fisher Center for Real Estate and Urban Economics at U.C. Berkeley's Haas School of Business.

1 Introduction

The impact of perceived risk on property values has important economic and legal implications because polluters are often sued under nuisance law by their neighbors for losses in property values. Compensation for property value diminution caused by perceived risk is not straightforward because of the unobservable nature of public risk perceptions. Should firms be held responsible for the entire amount of real property values losses caused by risk perceptions that are inflated by the media? This topic has both distributional and efficiency implications. Firms can be required to pay compensation when their actions created no scientific risk. In terms of efficiency, compensation requirements for perceived risk may distort real estate markets.

There is a distinction between scientifically assessed risk and perceived risk. The public's beliefs about environmental risk are often very different from the experts (Jenkins-Smith and Bassett, 1994; Lindell and Earle, 1983; McClelland *et al.*, 1990). Studies such as McClelland *et al.* (1990) suggest that the public perception of health risk in close proximity to a hazardous waste site is higher than the assessments of experts.

There are significant public policy implications that come from evolving risk perceptions and the distinction between scientifically assessed risk and perceived risk. The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) required that the EPA establish criteria to prioritize sites based on risks to health, environment, and welfare. Welfare was interpreted to mean impacts associated with health and the environment, not economic and social impacts. If risk perceptions cause real losses in property values, then a more efficient outcome may result when perceived risk is included in the resource allocation decision.

From an empirical perspective, these issues cannot be resolved without a method for measuring perceived risk. Accordingly, in this paper we use property value data to estimate perceived risk as it evolves over time, including the effect of the media on risk perceptions. The estimates of perceived risk are simultaneously used to analyze the effect of perceived risk on property values.

1.1 Literature Review

It is worthwhile to briefly consider the literature on valuing environmental amenities in order to re-think how to estimate perceived risk. Methods for valuing environmental amenities have traditionally been categorized as indirect and direct. Indirect methods, like the hedonic price technique and the travel cost model, use actual consumer decisions to model consumer preferences. Consumer decisions form revealed preferences over goods, both market and non-market. Direct methods, such as contingent valuation, ask people what they would be willing to pay or accept for a change in an environmental amenity. Direct methods are examples of stated preference techniques in which individuals do not actually make any behavioral changes. Direct methods are commonly criticized because of the hypothetical nature of the questions and the fact that actual behavior is not observed (Cummings *et al*., 1986; Mitchell and Carson, 1989). Adamowicz *et al*. (1994) criticizes indirect methods on the basis that the models of behavior developed constitute a maintained hypothesis about the structure of preferences that may or may not be testable. They also point out that indirect methods can suffer from collinearity among attributes. Collinearity typically precludes the isolation of factors that affect choice.

Perceived risk has been estimated primarily with direct methods. Approaches to estimating perceived risk include the use of surveys (Bord and O'Connor, 1992; Gegax *et al*, 1991; Lindell and Earle, 1983; McClelland *et al*, 1990; Rogers, 1997; Slovic *et al*, 1991), the use of surveys within Bayesian learning framework (Smith and Johnson, 1988; Viscusi, 1985; Viscusi, 1991; Viscusi and O'Connor, 1984), and the use of measures of concern (Loewenstein and Mather, 1990). Gayer *et al* (1997) starts with an objective cancer risk measure and uses a Bayesian learning framework to update risk. In contrast to these studies, our analysis uses an indirect approach to estimate perceived risk. Obviously the use of property value data, rather than survey data, is less costly to implement. Both approaches attempt to capture revealed preferences over attributes, including perceived risk.

Other researchers have analyzed the effect of media on risk. Gayer *et al's* (1997) analysis of risk tradeoffs at Superfund sites includes a news variable, which is based on Superfund coverage in a regional newspaper. They find that their news variable has a negative and significant effect on property values. Johnson (1988) quantifies the disruption in the market for grain products that resulted from media coverage of product contamination by the pesticide ethylene dibromide (EDB). Burns *et al* (1990) find that extensive media coverage of an event can contribute to heightened perception of risk and amplified impacts. In contrast to previous work, this study uses individual transaction property value data to analyze the effect of media on estimated perceived risk.

2 Model and Design of the Analysis

The price of housing and land reflects consumers' valuations of all the characteristics that are associated with housing, including the level of perceived health risk from living near a hazardous waste site. The level of perceived risk can be considered to be a qualitative characteristic of a differentiated good market. Consumers can choose the level of perceived risk through their choice of a house. Housing prices may include discounts for locations in areas with high levels of perceived risk. If so, the price differentials may be viewed as implicit prices for different levels of perceived risk.

Following the standard hedonic price model, the price of housing, P, is assumed to be described by a hedonic price function, $P = P(x)$, where x is a vector of housing attributes. The hedonic price of an additional unit of a particular attribute is determined as the partial derivative of the hedonic price function with respect to that particular attribute. Each consumer chooses an optimal bundle of housing attributes and all other goods in order to maximize utility subject to a budget constraint. The chosen bundle will place the consumer so that his indifference curve is tangent to the price gradient, P_x. The marginal willingness to pay for a change in a housing attribute is then equal to the coefficient of the attribute (Rosen, 1974).

In order to analyze the evolution of perceived risk and its effect on property values, we estimated a system of two equations, which includes the following hedonic price equation:

$$P_{ti} = \beta_{11} + \sum_{k=2}^{n} \beta_{1k} x_{kit} + \beta_{1n+1} \frac{R_t}{d_i^{\alpha}} + \varepsilon_{1t} \,. \qquad (1)$$

Where the scalar P_{it} is the hedonic price of the house of the i^{th} observation at time t, adjusted for inflation, $\mathbf{x}_{it}$ is the vector of housing attributes of the i^{th} observation at time t, R_t is the scalar, unobserved variable, perceived risk, at time t, d_i^{α} is distance of the i^{th} observation from the hazardous waste site raised to the power α, and ε_{1t} is a random variable error term. The distance from the hazardous waste site is used to individualize risk to a particular property. This variable is always greater than zero, so there is no division by zero problem in Equation 1.

Equation 1 is a hedonic representation of property values. Many authors have used property value data to value environmental attributes and, more specifically, study the impact of hazardous waste sites. Researchers, such as Smith and Desvousges (1986) and Thayer *et al* (1992), have consistently found that proximity to hazardous waste sites and other locally undesirable land uses (LULUs) has a negative impact on property values.

Numerous previous studies, including those already cited suggest that distance between a house and a hazardous waste site can serve as a proxy for two effects--heightened perceived risk and/or general disamenities such as odor and visual disamenities. In this analysis, we include the estimated perceived risk in the hedonic equation weighted by distance to the hazardous waste site in order to individualize the perceived risk to each particular house. However, we follow McClelland *et al* (1990) and do not include distance separately in the hedonic regression because of potential problems resulting from multicollinearity with perceived risk. The functional form of the distance weighting is allowed to be flexible in a limited way. The distance is raised to the power α, which is chosen with a grid search based on minimizing the sum of squared errors.

For the hedonic price technique to result in an equilibrium of implicit markets with demand and supply functions for each attribute, households must have full information on all housing prices and attributes, transaction and moving costs must be zero, and the price vector must adjust instantaneously to changes in either demand or supply (Freeman, 1993). Obviously, these conditions are not perfectly met, and consequently, the idealized hedonic price model is not an accurate representation of real-world real estate markets. When housing prices change so that the marginal implicit price schedule for an attribute moves consistently in one direction, households will consistently lag in their adjustment to that change resulting in a systematic bias. This may be the case in our analysis of the RSR hazardous waste site, since the information about environmental quality did change rapidly. However, as Freeman (1993) points out, it is possible to determine the direction of the bias. Consequently, even if bias is present, the estimates of marginal willingness to pay are still very important for applied welfare analysis because they can be labeled as an upper bound or lower bound on the basis of that analysis.

An alternative to our chosen hedonic setup is that the causation is reversed, and homebuyers actually use the price of homes in an area as proxies for the risks associated with proximity to the RSR smelter site. A situation such as this could possibly be analyzed with techniques used in the literature on prices as signals of product quality (Wolinsky, 1983). The presence of the unobservable variable perceived risk would complicate any attempts to model the problem using this approach.

To complete our model, we will add an equation describing the evolution of perceived risk. As Smith and Johnson (1988) argue, a complete behavioral model of how people form risk perceptions would incorporate the importance of the events at risk; the role of prior beliefs concerning the process that generates the risk; the implications of new information about that process; and the costs of acquiring that information.[1] As with Smith and Johnson (1988), our model is best interpreted as a reduced form approximation of the outcomes from such a behavioral model.

Cognitive and behavioral studies, such as Slovic (1987), suggest that the formation of perceived risk is more complicated than the traditional expected utility approach that is taken in the field of economics. He suggests that risk appears to be influenced by two major factors: dread risk and unknown risk. Environmental contamination is high on both counts because an individual property owner experiences a lack of control in the remediation process, possible fatal consequences, and the contamination is often unobservable with delayed harmful consequences. We do not explicitly account for these factors in our model of the evolution of perceived risk.

Following a modified Bayesian learning approach, we assume that people update their prior risk beliefs in response to new information. To complete our model, we add a state equation that describes the evolution of perceived risk over time. Equation 2 below describes this process:

$$R_t = \beta_{21} R_{t-1} + \beta_{22} media_t + \varepsilon_{2t} . \tag{2}$$

Where R_{t-1} is lagged perceived risk, media is the weighted number of newspaper articles about the RSR hazardous waste site, and ε_{2t} is a random variable error term. Using generalized maximum entropy techniques allows us to avoid making any assumptions about the distributions of the two error terms, ε_{1t} and ε_{1t}; and specifically, they are not required to have identical distributions.

Perceived risk is unobservable and changes over time. Current posterior beliefs about risk are a function of prior beliefs about risk and current information obtained from the media. In Equation 2, people update their perception of risk with the information they receive from the media. If the media affects the public perception of risk, then media coverage of environmental damage should be a significant factor in determining property values.

Koné and Mullet (1994) find that the media is the dominant force in determining public risk perception. Media coverage can affect risk perception through its informational content. It can also affect risk perceptions through changing the salience of a particular risk to an individual. Wildavsky (1995) argues that people usually first encounter claims of chemical harm to health and the environment from the media. Slovic *et al* (1991) discuss a process labeled "social amplification of risk." The media is one of the major mechanisms for this process. Flynn *et al* (1998) write, "News coverage of an event…may produce stigma impact by (1) initiating awareness of a danger, (2) increasing perceptions of a known danger, (3) stimulating recall for people with latent negative reactions that have atrophied with time, and (4) increasing the number and geographical locations of people with knowledge of the danger."[2]

Potential homebuyers come from both within and outside the area studied. Although there was locally intense media coverage of the RSR hazardous waste site, a concern is whether this coverage affects the perceived risk of buyers from outside the area. The outside buyer's awareness of the extent and content of past media coverage of environmental contamination is likely to be high because the vast majority of buyers use realtors.[3] For a realtor that is representing a buyer, it is his or her job to be aware and inform the client of market conditions and factors, such as media coverage of a hazardous waste site, that may affect the market for a particular property.

In this study the problem is, given the observable variables (price, housing attributes, the distance to the smelter, and the media variable) to estimate the unobserved variable (perceived risk) and the model parameters. As with Golan, Judge, and Karp (1996), we apply generalized maximum entropy techniques to recover unknown parameters and an unobservable state variable. Golan, Judge, and Karp (1996) offer the problem of "counting the fish in the sea." They estimate a system of equations in which the dependent variable in their observable equation is fish harvest, which is a function of fishing inputs and the unobservable fish biomass in the sea. The system is completed with a state equation that describes the evolution of the fish biomass, which like perceived risk is an unobservable variable.

An alternative approach for a problem such as this is using Kalman filter-maximum likelihood methodology. Burmeister *et al*. (1986) use a Kalman filter to estimate unobserved expected monthly inflation. Other procedures to recover the unknown parameters in Equations (1) and (2) exist, but they all are based on a large set of assumptions that are necessary to convert an illposed inverse problem into a well-posed one. For example, Chow (1981) suggests a two-stage least squares method to estimate the parameters of the state equation and feedback rule from a linear-quadratic inverse control problem. He uses a set of equations that defines the parameters of the optimal control rule to recover those parameters while imposing a large set of zero restrictions.

3. Data

The data set used to quantify Equations (1) and (2) includes variables describing price and attributes of single-family, detached homes sold within three miles of the hazardous waste site over the period 1979 to 1995 in Dallas County, Texas.[4] In order to make this dynamic estimation problem computationally feasible, a random sample, which was limited to forty observations per year for each of the seventeen years for a total of 680 observations. Each observation includes information about the sale price[5] of the homes and different variables which affect the sale price, including house attributes and proximity to the RSR lead smelter.[6] The square footage of living space, number of bathrooms, and lot size describe housing quality.

The data set in this analysis includes a media variable, which was created from a random sample of two issues per month of the *Dallas Morning News* in the years 1979-1995 for a total of 408 issues sampled.[7] In this analysis, newspaper coverage serves as a proxy for media coverage. We acknowledge that in recent decades television coverage as a source of news has grown in importance relative to newspaper coverage. However, we justify our use of newspaper coverage because its content tends to be correlated with television coverage. A variable representing television coverage would be extremely difficult to obtain. In the period before EPA identification of the RSR site, there was no newspaper coverage in the sample. The bulk of the coverage occurred in the period in which identification of the site and cleanup occurred (1981-1986).

As Johnson (1988) points out, the impact of the media coverage depends on how prominently it is displayed. Johnson uses column inches of coverage to account for the differing impact of articles. Gayer *et al* (1997) uses the number of words on coverage to account for different impacts. In this analysis, we constructed a media variable by weighting each article by the inverse of the page number of the start of the article. The number of article plus the weighted sum of articles during a given year is the media variable for that year. Mathematically, the media variable for year *t* is can then be expressed as the following

$$media_t = \sum_i article_{\mathrm{i}} \left(1 + {}^{1}\!/\!_{\text{page number}_{\mathrm{i}}}\right) \tag{3}$$

where $article_i$ is any article about the RSR hazardous waste site found in the sample issues in year t, and $page\ number_i$ refers to the page number at the start of $article_i$. These three methods of weighting articles should be correlated. Front-page articles tend to be longer, while shorter articles are often buried in the back of the newspaper.

A potential criticism of this media variable is that stories that provide positive information on the site are forced to affect the price of homes in the same way as stories that provide negative information. A justification for this is that any publicity about a hazardous waste site and a limited residential area strengthens the identification that people make between that particular residential area and environmental contamination. Using this argument, any publicity is bad publicity. It only reminds the public about the contamination or the history of contamination. There are examples of property values actually falling after a hazardous waste site has been remediated. (For example, see *DeSario v. Industrial Excess Landfill, Inc.*[8]) In this perverse scenario, if there is excessive publicity surrounding the cleanup, property values may decline.

The RSR lead smelter site is located within the geographic area contained in this data set. The RSR lead smelter can be found in the central portion of Dallas County, approximately six miles west of the central business district of Dallas. The smelter operated from 1934 to 1984 and was purchased in 1971 by the RSR Corporation. The smelter emitted airborne lead, which contaminated the soil in the surrounding areas. Lead debris created by the smelter was used in the yards and driveways of some West Dallas residences. In 1981, the EPA found health risks, and RSR agreed to remove any contaminated soil in the neighborhoods surrounding the RSR site using standards that were considered protective of human health at the time. In 1983 and 1984, additional controls were imposed by the City of Dallas and the State of Texas. In 1984, the smelter was sold to the Murmur Corporation who shut the smelter down permanently. In 1986, a court ruled that the cleanup was complete. In the period before EPA identification of the RSR site, there was no newspaper coverage in the sample. The bulk of the coverage occurred in the period in which identification of the site and cleanup occurred (1981-1986). Media coverage again increased in the period of new concern after cleanup (1991-1995).

In 1991, the Center for Disease Control (CDC) lowered the blood level of concern for children from thirty to ten micrograms of lead per deciliter of blood. Low-level lead exposure in childhood may cause reductions in intellectual capacity and attention span, reading and learning disabilities, hyperactivity, impaired growth, or hearing loss (Kraft and Scheberle, 1995). Also in 1991, the State of Texas found hazardous waste violations at the smelter. In 1993, the RSR smelter was placed on the Superfund National Priorities List (NPL). For a summary, see the Event History in Figure 1.

Using a Geographic Information Systems (GIS) database, Dallas County was set up as a grid of *X* and *Y* coordinates. Coordinates were assigned to each house and the RSR hazardous waste site. Distance could then be calculated between any two points. A description of the variables used in the analysis is provided in Table 1, and descriptive statistics are presented in Table 2.

Functional Form

This study follows Thayer *et al* (1992) and considers only the linear and semi-log (natural logarithm of the dependent variable) functional forms for the hedonic price equation (1). A linear specification has the obvious interpretation that a unit increase in an attribute causes the price to rise by an amount equal to the coefficient; while with a semi-log specification, the coefficients can be interpreted as a percent of the average house price. The following Box-Cox transformation of the dependent variable was used on the entire data set to choose between the linear or natural logarithmic forms for the dependent variable only.

$$(4) \qquad p(\lambda) = \begin{cases} \dfrac{P^{\lambda} - 1}{\lambda}, \lambda \neq 0 \\ \\ \ln \lambda, \quad \lambda = 0 \end{cases}$$

Using Box-Cox maximum likelihood analysis λ was estimated for each year. The yearly estimates of λ range from -0.09 to 0.21. A value of $\lambda = 0$ implies that a semi-log specification is best, and $\lambda = 1$ indicates a linear form is best. Confidence intervals for λ were also estimated. The hypothesis that $\lambda = 1$ could be rejected for every year. Although the hypothesis that $\lambda = 0$ could be rejected for most years, the estimates of λ are always close to zero. Given this limited analysis of functional form, the semi-log specification of the hedonic price equation is used in our analysis.

Previous studies, such as McClelland, *et al*. (1990), have found that the impact of the waste site on property values dissipates rapidly with distance. Therefore, the distance from the hazardous waste site is used to individualize risk to a particular property in the hedonic price equation (2). The functional form of the distance weighting on perceived risk depends on the value of α. Possible values of α were selected from the set {1, 2, 3} using a grid search. We found that setting α equal to one results in the lowest sum of squared errors from among this limited choice set. Therefore, α is set equal to one in the estimation problem.

We also tested for serial correlation with the approach proposed by Burmeister et al. (1986). The residuals from both the hedonic price equation (1) and the state equation for perceived risk (2) were regressed on their lagged values up to the seventh lag. We found that the estimated coefficients on all lagged residuals are insignificant at the five-percent level. One can thus conclude that the residuals are uncorrelated with their lagged values, and that an assumed AR(1) process describing the evolution of perceived risk is appropriate.

4 The Dynamic Estimation Problem.

The formulation in Golan, Judge, and Miller (1996) is used to convert the system of equations (1) and (2) to a form that is consistent with the maximum entropy principle. The system of equations in 1 and 2 is transformed so that each β_{1k} and β_{2k} is represented by proper probabilities $p_k^{\beta_1}$ and $p_k^{\beta_2}$, indexed by *m*, for *m* = 1, …, *M*. The support spaces for $p_k^{\beta_1}$ and $p_k^{\beta_2}$ are $z_k^{\beta_1}$ and $z_k^{\beta_2}$, respectively, also indexed by *m*. The β_{ik} coefficients (*i* = 1, 2) can be expressed as

$$\beta_{ik} = \sum_m p_{mk}^{\beta_i} z_{mk}^{\beta_i}\text{, for } k = 1, 2, \ldots, \tau_{\mathrm{i}}\ (i = 1, 2) \tag{5}$$

The matrix β_i (*i* = 1, 2) can then be written as

$$\beta_i = \mathbf{Z}^{\beta_i}\mathbf{p}^{\beta_i} = \begin{bmatrix} \mathbf{z}_1^{\beta_i\prime} & \mathbf{0} & \cdot & \mathbf{0} \\ \mathbf{0} & \mathbf{z}_2^{\beta_i\prime} & \cdot & \mathbf{0} \\ \cdot & \cdot & \cdot & \cdot \\ \mathbf{0} & \mathbf{0} & \cdot & \mathbf{z}_k^{\beta_i\prime} \end{bmatrix} \begin{bmatrix} \mathbf{p}_1^{\beta_i} \\ \mathbf{p}_2^{\beta_i} \\ \cdot \\ \mathbf{p}_K^{\beta_i} \end{bmatrix}. \tag{6}$$

Here, $\mathbf{Z}^{\beta_i}$ is a (K x KM) matrix, and $\mathbf{p}^{\beta_i} >> \mathbf{0}$ is a KM-dimensional vector of weights. Similarly, ε_{it} (i = 1, 2) is represented by the discrete probabilities $w_t^{\varepsilon_i}$,(i = 1, 2) indexed by j, for j = 1 ,…, J. The support space for $w_t^{\varepsilon_i}$ is $v_t^{\varepsilon_i}$. The random variable error terms can then be expressed as

(7)
$$\varepsilon_{\mathrm{it}} = \sum_j w_{tj}^{\varepsilon_1} v_{tj}^{\varepsilon_1}$$

The two sets of T unknown disturbances may be written in matrix form as

(8)
$$\varepsilon_i = \mathbf{V}^{\varepsilon_i}\mathbf{w}^{\varepsilon_i} = \begin{bmatrix} \mathbf{v}_1^{\varepsilon_i\prime} & \mathbf{0} & \cdot & \mathbf{0} \\ \mathbf{0} & \mathbf{v}_2^{\varepsilon_i\prime} & \cdot & \mathbf{0} \\ \cdot & \cdot & \cdot & \cdot \\ \mathbf{0} & \mathbf{0} & \cdot & \mathbf{v}_T^{\varepsilon_i\prime} \end{bmatrix} \begin{bmatrix} \mathbf{w}_1^{\varepsilon_i} \\ \mathbf{w}_2^{\varepsilon_i} \\ \cdot \\ \mathbf{w}_T^{\varepsilon_i} \end{bmatrix}$$

where $\mathbf{V}^{\varepsilon_\iota}$ is a (T x TJ) matrices, and $\mathbf{w}^{\varepsilon_\iota}$ is a TJ-dimensional vector of weights.

The support spaces for the coefficients on the explanatory variables are chosen so that they contain all reasonable possible parameter values and are symmetric around zero. By making these supports symmetric around zero, one is assuming that there is no prior information about these coefficients. The support space range needs to be large enough so that the optimization problem is feasible given the other parameters. In this estimation, the support spaces, $z_k^{\beta_1}$ and $z_k^{\beta_2}$, have three points (M = 3) and are an equal distance from each other. Specifically, $z_k^{\beta_i}{}' = (-100, \quad 0, \quad 100)$, ($i$ = 1, 2). To calculate the width of the error support space, v_i, a three-standarddeviations rule around zero is used. The error supports range from -3σ_y to 3σ_y, where σ_y is the standard deviation of the dependent variable. In this estimation, the support spaces, $v_t^{\varepsilon_1}$ and $v_t^{\varepsilon_2}$, have three points (J = 3) and are symmetric around zero. For example, $v_t^{\varepsilon_1}{}'$=(-3σ_y, 0, 3σ_y). Finally, in order to simplify the statement of the GME optimization problem, the independent variable R_t/d is defined as x_{n+1t}.

The entropy estimation then solves the following optimization problem with a state equation restriction:

$$\max_{\mathbf{p},\mathbf{w},R_t} H(\boldsymbol{p},\boldsymbol{w}) = \{-\boldsymbol{p}'\ln\boldsymbol{p} - \boldsymbol{w}'\ln\boldsymbol{w}\} \tag{9}$$

subject to

$$P_t = \boldsymbol{x}_t'\boldsymbol{z}^{\beta_1\prime}\boldsymbol{p}^{\beta_1} + v_t^{\varepsilon_1\prime} w_t^{\varepsilon_1} \qquad for \quad t = 1,\ldots,T$$

$$\begin{cases} R_t = 1 & for \quad t = 1 \\ R_t = z^{\beta_{21}} p^{\beta_{21}} R_{t-1} + z^{\beta_{22}\prime} p^{\beta_{22}} media_t + v_t^{\varepsilon_2\prime} w_t^{\varepsilon_2} & for \quad t = 2,3,\ldots T \end{cases}$$

$$\mathbf{1}_K = (\boldsymbol{I_K} \otimes \mathbf{1}_M')\boldsymbol{p}$$

$$\mathbf{1}_T = (\boldsymbol{I_T} \otimes \mathbf{1}_J')\boldsymbol{w}$$

$$x_{n+1t} = R_t/d$$

Under this framework, the unobserved perceived risk variables and the unknown model parameters are simultaneously recovered.

5 Results

The GME estimation results of Equations 1 and 2 are presented in Table 3. All of the explanatory variables in the hedonic price equation (Equation 1) have the expected relationship with housing price and are statistically significant at the five-percent level. The variable of the most interest for this study, perceived risk weighted by distance, has the expected negative relationship with housing price. If the price vector is not adjusting rapidly to the changes in information about environmental quality as required for an equilibrium (Freeman, 1993), then the magnitude of coefficient on weighted perceived risk should be interpreted as an upper bound. The explanatory variables in the state equation describing the evolution of perceived risk (Equation 2) also have the expected relationship with perceived risk and are statistically significant at the five-percent level. The coefficient on lagged perceived risk is positive and less than one, which means that perceived risk is a stationary time series process. Finally, the media coefficient is positive, which means that, as hypothesized, media coverage increases perceived risk.

Specification of the model was evaluated by following Mittelhammer and Cardell (1997) and analyzing the marginal values of the data constraints in the dynamic estimation problem. The values of LaGrange multipliers on the data constraints are non-zero, which means that the data constraints are binding. The implications are similar to rejecting an F-test to test that all the coefficients are zero.

The estimates of the unobserved variable perceived risk are shown below in Figure 2. Initial perceived risk is normalized to one. In the period before EPA identification of the RSR site, there was no newspaper coverage in the sample. The intense media coverage that coincided with the identification and remediation of the RSR smelter site (1981-1986) increased perceived risk, which then decayed over time. There was a dip in perceived risk in 1985, which coincides with a lull in media coverage. In 1985, remediation had been progressing normally for a few years, and the RSR smelter was no longer fresh news. In 1986, when a court ruled that the cleanup was complete, the newspaper coverage and estimated perceived risk increased. After 1987, the estimated perceived risk falls and remains relatively low. This is despite a 1991 CDC announcement about concern over lower levels of lead in the blood and additional concerns about the safety of the site. One possible explanation that before identification, houses were sold as close as 0.17 miles from the RSR site. In the period after cleanup (1987-1990), no houses within a mile of the RSR site were sold. Therefore, in the years 1987-1990, the houses within one mile of the smelter, which are the most affected by the smelter, no longer affect estimated perceived risk.

Finally, in order to evaluate whether perceived risk changes over time, we tested whether the coefficient of the lagged risk is equal to one and whether the media coefficient is equal to zero. The generalized maximum entropy estimated coefficient less the hypothesized value divided by the standard error of the coefficient is asymptotically distributed as a t-distribution (Mittelhammer and Cardell, 1997). The hypotheses that the lagged perceived risk coefficient is equal to one and that the media coefficient is equal to zero can both be rejected at the five percent level. We conclude that perceived risk does evolve over time and is affected by media coverage.

6 Conclusions

Given observable variables (price, housing attributes, distance to the hazardous waste site, and a media coverage variable), we applied generalized maximum entropy techniques to estimate the unknown parameters from the statistical model and an unobservable state variable, perceived risk. Using a data set of property values around a hazardous waste site that covers the years 1979 to 1995, our results indicate that media coverage and high prior risk perceptions increase perceived risk. Increased perceived risk surrounding the site, in turn, lowers property value.

As demonstrated above, risk perceptions change over time and can be influenced by the media. The empirical results that perceived risk both affects property values and can be manipulated has implications for compensation for losses in property values. With these findings, we have shown that contaminated properties are not strategy proof. Property owners can affect outcomes with their actions. Plaintiffs can introduce the media to contamination problems. The ensuing media coverage in turn increases public perceived risk and lowers property values. One solution to this dilemma is to not hold defendants responsible to pay for scientifically baseless increases in public risk perception. The classic example of scientifically baseless perceived risk is electromagnetic fields (EMFs) created by high voltage lines.[9] Following this argument, one should not use property value observations for compensation without adjusting for scientifically baseless risk.

Scientifically assessed risk rather than perceived risk, which can be manipulated, should be the basis of the compensation from the polluter. A compensation methodology that filters out scientifically baseless risk by substituting scientifically assessed risk for perceived risk is ideal. Note that the plaintiffs can still seek to recover the scientifically baseless portion of their loss in property values. However, they must recover it from the responsible party, such as particular media sources. An alternative approach is that the plaintiff could seek to recover the entire amount of the property value loss from the polluter, who could in turn seek to recover the scientifically baseless portion from the responsible parties.

In terms of efficient public policy, our findings that increased risk perceptions affect property values, which are a real loss, could be used to argue that the EPA should consider risk perceptions in their cost-benefit analysis for purposes of resource allocation for remediation of contaminated sites. Ignoring perceived risk, scientists at the United States Environmental Protection Agency (EPA) currently use dose-response relationships to calculate risk in their decisions about how to allocate resources for remediation of environmental contamination. Consequently, the real effect of hazardous waste sites on property values has been neglected in cost-benefit analyses. Based on our findings, incorporating losses in property values in the analyses could yield a different conclusion about the effectiveness of remedial actions.

Finally, McClelland et al (1990) have argued that there may be a policy role for government in mitigating losses from the overestimation of risk in the area of environmental contamination. Our findings that risk perceptions evolve over time and are affected by new information supports the argument that the government could take a more active role in risk communication.

However, more research is needed in the area of risk communication. Lopes (1992) writes, "[A]lthough risk experts understand that they cannot impose their views on people in a democratic society, they do tend to define their problem as one of developing techniques for communicating correct assessments to an inexpert public."[10]

Table 1. Variable Definitions

Variable	Description
Dprice	Deflated sales price of the home
Livarea	Square feet of living area
Baths	Number of bathrooms
Landarea	Lot size in square feet
Distance	Miles to the RSR facility
Media	Weighted number of articles in the *Dallas Morning News* about the RSR site

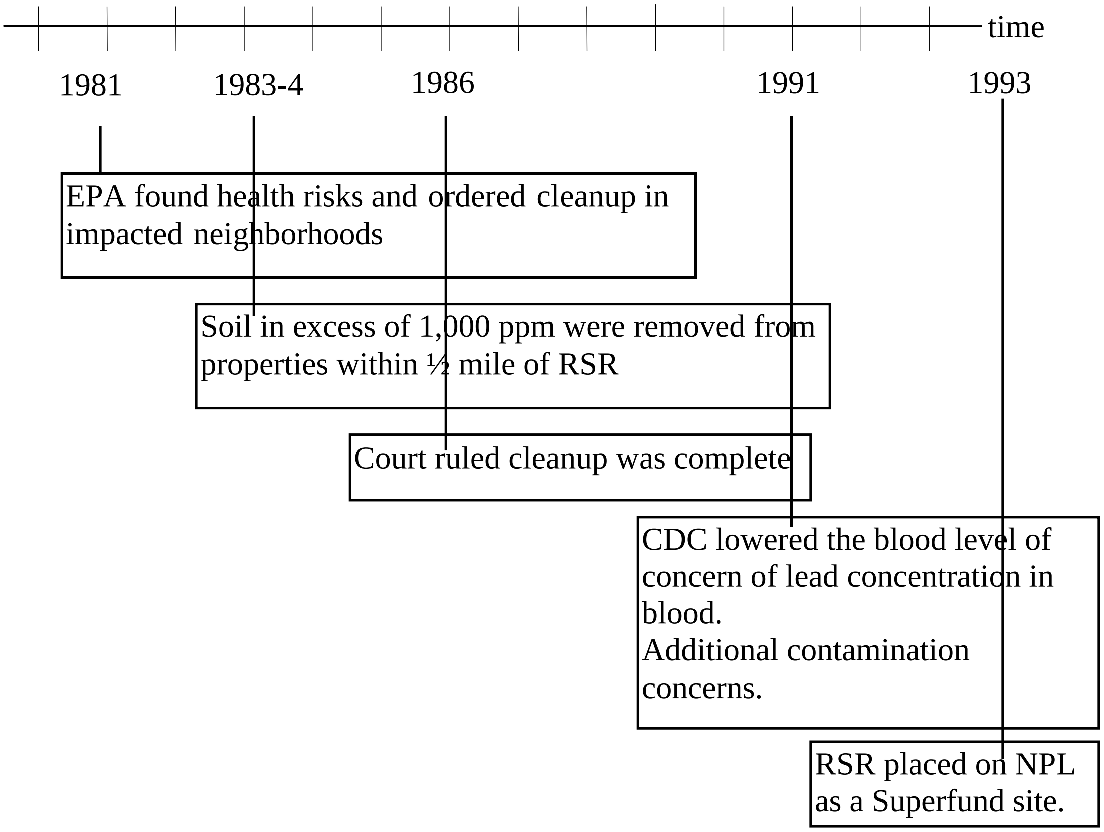
Table 2. Descriptive Statistics

Variable	Mean	Standard Deviation
Dprice	41306.18	4760.11
Livarea	1496.68	641.13
Baths	1.41	0.74
Landarea	8932.41	4306.29
Distance	2.32	0.49
Media	2.33	14.04

Table 3. Perceived Risk, Generalized Maximum Entropy Results

Variable	Estimated Coefficients	Standard Errors
Intercept	9.231	0.017
Living Area	5.609E-4	1.02E-5
Bathrooms	0.052	0.0107
Land Area	2.751E-5	1.68E-6
Weighted Risk	-0.787	0.0316
Lagged Risk	0.785	0.105
Media	0.053	0.0244

Figure 1
Event History of RSR Site



EPA found health risks and ordered cleanup in impacted neighborhoods

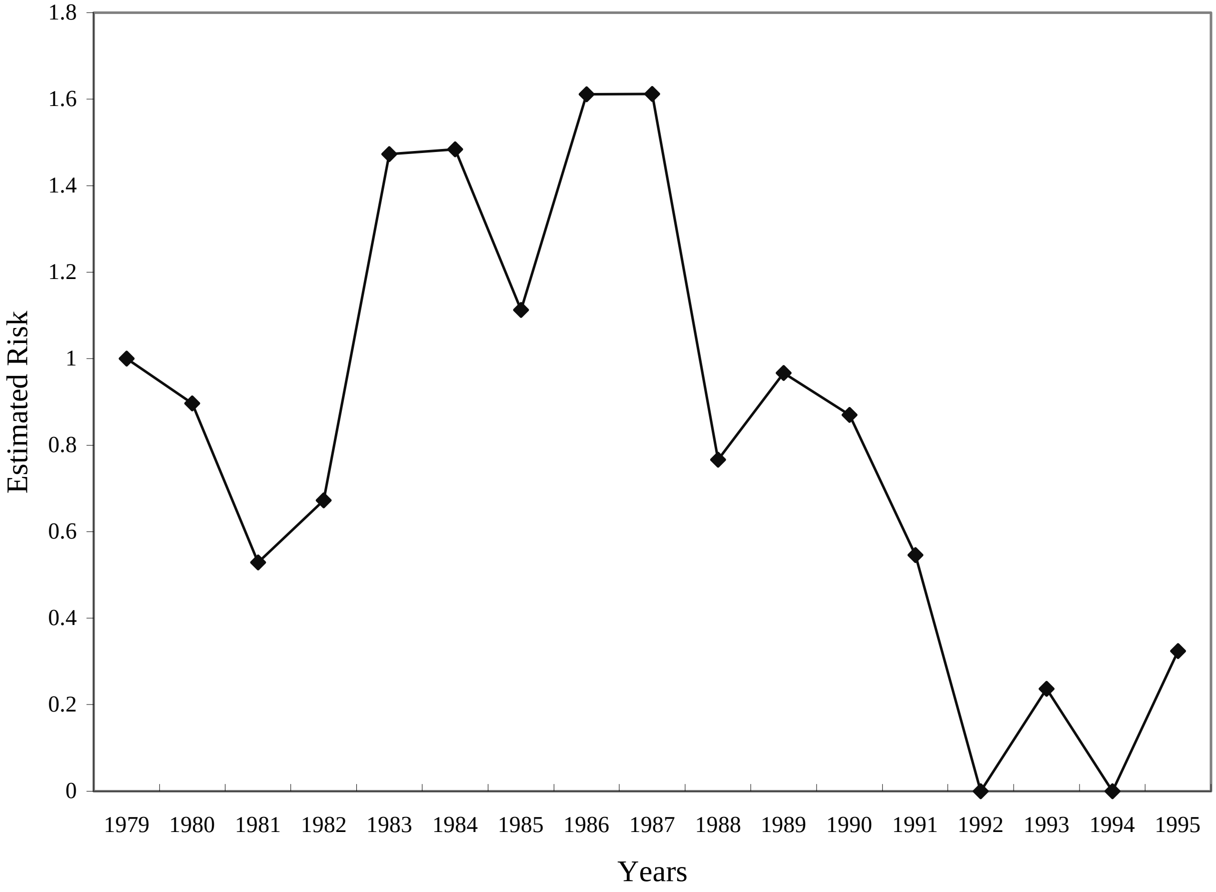
Soil in excess of 1,000 ppm were removed from properties within ½ mile of RSR

Court ruled cleanup was complete

CDC lowered the blood level of concern of lead concentration in blood.
Additional contamination concerns.

RSR placed on NPL as a Superfund site.

Figure 2: Estimated Perceived Risk



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Endnotes

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[1] Smith and Johnson, (1988), p. 2.

[2] Flynn *et al* (1998), p. 717.

[3] For example, according to the National Association of Realtors, 82% of buyers used realtors in 1982.

[4] Dallas County Appraisal District.

[5] Prices are deflated using the shelter housing price index (1982-84=100) from the *Economic Report of the President*.

[6] Other environmental indicators, e.g., air and water quality, do not vary by location and were not included in this study.

[7] The *Dallas Morning News* is not indexed over the entire period of the data set (1979-1995), so the data was obtained by going through microfiche. Consequently, only a random sample of issues was used to construct the media variable.

[8] 587 N.E. 2d 454 (Ohio 1991)

[9] Note that high voltage lines can also lower property values because they are aesthetically unappealing.

[10] Lopes (1992), p. 67.