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Valuing Risk-Reducing Interventions with Hedonic Models: The Case of Erosion Protection

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This article extends the literature on economic valuation of public interventions that reduce environmental risk. We consider the case where risk-reducing interventions have different characteristics than the risk proxies used in hedonic regressions. We then demonstrate the importance of these considerations by reexamining an existing analysis of shoreline protection where we estimate risk using a latent variables model. The results show substantially different and arguably more plausible results.

Key words: hedonics, risk, valuation

Introduction

Economic valuation of environmental risks is a theoretically important and, yet, empirically elusive concept. Adverse health outcomes, property damage, and other undesired outcomes of environmental phenomena can rarely be predicted with certainty by individuals. Important contributions to understanding how individuals value these risks have been made with expected utility models that have valued changes in the risk of unfavorable outcomes such as the probability of being in an earthquake or the risk of danger from a toxic dump. Because risk is not directly observable, researchers have used hedonic models to measure the value of changes in observable variables (proxies) closely correlated with the underlying risk being studied. The option price of a change in risk has been estimated as the change in the value of an asset ascribed to marginal changes in the proxy variable. The results of the hedonic equations have then been used to infer the value of interventions that may change the probability of less preferred outcomes or mitigate the damaging effects (Brookshire et al.; Kriesel, Randall, and Lichtkoppler; MacDonald, Murdoch, and White).

This research has been carried out within a "timeless" framework in which the value of risk reduction is estimated through a single, one-period proxy of risk. For example, distance from a hazard has been used as a proxy of pipeline explosion (Kask and Maani), earthquakes (Brookshire et al.), and flooding (MacDonald, Murdoch, and White). Such approaches have been useful in determining the value of risk-mitigation when there is a single measurable factor which is clearly related to the risk of a bad outcome. We suggest that expanding the usefulness of these hedonic techniques to the evaluation of policies that impact risk levels in complex ways will require models in which multiple factors affect risk and, more important, models in which these factors change over time.

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Closer attention to measuring risk is necessary for three reasons. First, the hedonic analysis will be more useful if it can effectively value policies that work in ways not directly related to the variables currently used as risk proxies. For instance, a flood control project changes the probability of flooding in a manner fundamentally different from a shift in location relative to a floodplain. Man-made environmental mitigation changes the probability of good and bad states over which utility is defined (cancer, property destruction, quality of air and water) in a way that has a different time profile than most risk proxies used in past hedonic analyses. Second, risk is often the result of a number of different characteristics. In the example of flooding, the risk of damage is influenced by mean height relative to the floodplain, existing dams and flood control procedures, construction techniques, and landscaping. Individuals assign probabilities to different states of nature based on combination of these factors, which may vary over time. Third, when the time profile of risk is considered, then the analysis must also consider repeated risks and how one bad outcome affects the probability of subsequent bad outcomes.

In this article we discuss the above points in reference to the timeless model used to date in the literature. We address our criticisms by formulating a model to measure the value of reducing the risk of property damage from shoreline erosion on Lake Erie. This case presents an interesting comparison because an existing analysis (Kriesel, Randall, and Lichtkoppler) uses a risk proxy in a timeless framework to analyze the same problem. However, the risk of flood damage is influenced both by the setback distance and the age of existing private protective devices, and both of these change over time. The cooperative intervention we value reduces risk to a relatively low level which is invariant during the useful life of the device. We find an option price of the intervention that is substantially higher for almost all households than do Kriesel, Randall, and Lichtkoppler; this option price is a plausible function of the risks households face without intervention. We also find that the estimated option prices are sensitive to small changes in the probability of damage associated with the risk-reducing intervention.

Considerable literature exists on the relationship between option price and the appropriate ex ante welfare measure. Recent contributions by Meier and Randall and Ready have done much to establish the conditions under which option price provides a valid welfare measure. Our aim in this study is limited to improving the way option price is calculated using hedonic approaches, but we believe that the dynamic considerations we address will be useful in improving more robust measures like Ready's maximum agreeable payment. For the empirical problem in this article, however, we argue that option price meets the conditions of an appropriate ex ante benefit measure.

The "Timeless" Model

Here we develop the timeless model as it has been used in the existing literature, using shoreline protection as a concrete example. This presentation closely follows that of Smith. Let $r = r(\text{a})$ be the value of a property near the shore as a function of some vector of characteristics, a. Consumers maximize a utility function $U(x, a)$ where x is a numeraire Hicksian composite good, subject to the budget constraint $x + r(a) = Y$. This utility function takes the Lancasterian view that utility received from the property is a function of the services derived from the characteristics of the property (Lancaster). The first-order condition for utility maximization is $U_a / U_x = r_a$, where subscripts represent partial differentiation with respect to the subscripted variable. The risk of environmental damage is introduced through the assignment of probabilities to good and bad outcomes. Let p be the probability of the favorable state (no loss) and $(1-p)$ be the probability of a loss through erosion damage; let L be the size of the loss in the bad state. Then, defining U_1 as the utility function in the favorable state and U_2 as the utility function in the unfavorable state, expected utility (EU) is given by:

$$EU = pU(Y - r(a), a) + (1-p)U_2(Y - r(a) - L, a). \tag{1}$$

Brookshire et al. used location inside or outside of designated earthquake risk zones as a proxy for the probability p in (1). Smith related the hedonic analysis of valuing risk characteristics to the literature on option price. He posited that the value of changes in levels of environmental risk can be expressed as a willingness to pay for (accept) a lower (higher) level of risk and can be measured by an option price, OP.[1] Let the probability of erosion damage be subject to change through some policy instrument or choice variable and let the change in the probability be captured by σ. Then option price of a change in the probability of damage can be defined implicitly by

$$\begin{aligned}(p+\sigma)U_1(Y - r(a) - OP, a) + (1-p-\sigma)U_2(Y - r(a) - L - OP, a) \\ = pU(Y - r(a), a) + (1-p)U_2(Y - r(a) - L, a).\end{aligned} \tag{2}$$

A marginal change in the probability of damage can be measured by totally differentiating the above equation with respect to OP and σ:

$$\frac{dOP}{d\sigma} = OP_\sigma = \frac{U_1 - U_2}{(p+\sigma)\frac{\partial U_1}{\partial x} + (1-p-\sigma)\frac{\partial U_2}{\partial x}}, \tag{3}$$

where the above term can be interpreted as the slope of the option price—risk schedule. This is the basic theoretical result of this literature, and it has an important consequence for empirical research (Smith). If a measure of the probabilities associated with various states of nature exists, then this information and the utility attached to those states can be used to estimate the value (or implicit price) of marginal changes in the probability of the good and bad outcomes. MacDonald, Murdoch, and White, demonstrate how (3) can be used to provide a point estimate of the marginal rate of substitution between an argument of $U(\cdot)$ and a change in the probability of the bad state occurring with expected utility held constant. They used this formulation to value the variations in risk of flooding as measured by dummy variables related to one of three flood-zone designations, and Kask and Maani used a proximity-re-

[1]Smith notes that his formulation of option price as measuring the value of changes in risk differs slightly from existing definitions of option price as the payment that is equivalent to resolving the uncertainty regarding good and bad states. He argues that his formulation is appropriate for studying the value of changes in the probabilities underlying uncertain environmental outcomes. We concur and discuss option price in this article entirely in the context of the value of changes in underlying probabilities.

lated, high-risk/low-risk dummy variable to measure the value of changes in the risk of pipeline explosions.[2]

Our point of departure is to examine how this information can be used to value risk-reducing policies. We agree with MacDonald, Murdoch, and White that a main purpose of this technique is "to develop benefit/cost studies which attempt to assess the economic merits of policies that change the likelihood or magnitude" of an uncertain environmental hazard. However, the studies discussed above do not actually use p in specifying their empirical models; instead, they use a location-based proxy for probability. Smith points out that this should not be a problem when the proxy is a good one for risk. This is only true when the intervention in question changes risk in the same way that the proxy does. For example, suppose that the distance from a hazardous waste incinerator is used as a proxy for how residents negatively value the environmental risk of the facility and that the risk that concerns them is a catastrophic event. Such a proxy will work well to measure the value of reduction in the risk of major airborne contamination but would be much less successful in valuing more stringent standards which reduce the risk of worker illnesses. Further, risk may be a function of several attributes. In the shoreline protection case at least three important determinants could be used as proxies: setback distance, condition of existing private protective devices, and historical erosion rate.

Risk-reducing policies do not necessarily imply the same mechanism as the risk-reducing characteristics valued in a hedonic option price analysis. For this reason, they do not have the same time profile. The timeless model implicitly assumes that consumers (*a*) estimate probabilities of damage over time, (*b*) discount those probabilities and expected losses back to the present, and (*c*) reveal that information in the bundle of risk-affecting attributes they purchase. Assuming that individuals can form a coherent set of subjective probabilities of the risk-mitigating properties of these characteristics, they will correctly incorporate this information in the way they value the stream of hedonic attributes $r(a)$, the stream of risks p, and the risk mitigations σ.

However, a hedonic regression that indicates the value of reducing some environmental risk provides an unbiased estimate only when the regression model accounts for the time profile of its risk reduction. For example, suppose that distance from the tide line and mean height above sea level are used as proxies for the risk of losing property to beach erosion, and that this information is required to value the construction of seawalls to protect property. If building these devices decreases the probability of property loss significantly in year one but increases that probability in later years (the typical ocean shoreline protection case), using the hedonic information from location measures to value the risk reduction provided by the seawall must take account of the varying probabilities over time.

The final point is that individual's determinations of the risk of loss are dependent on previous probabilities. These risk determinations are conditioned by the fact that you cannot lose the same house in an earthquake or flood twice; you cannot die twice of kidney cancer; and so forth. If the loss is of this type, then a multiple-period model is necessary to properly capture the dynamics inherent in the probabilities of incurring a loss and the discounting of future loss relative to a loss incurred today.

[2]Both of these articles made important theoretical contributions to the literature. MacDonald, Murdoch, and White explored the value of risk reduction when insurance is an option; Kask and Maani examined the consequences of consistent ex ante biases in property owners' probability assessments. Our citation here refers only to the specification of their hedonic analysis and is not meant to capture, or dismiss, the significance of their research. Other proxies in the literature include Kriesel, Randall, and Lichtkoppler's use of the expected years until erosion would reduce setback to zero as a proxy for risk of erosion damage and Harrison and Stock's use of distance from a hazardous waste facility as a proxy for the risk of damage from exposure to those wastes.

Valuing Erosion Protection

In this section we use the considerations developed above to value risk-reducing interventions for shoreline erosion on Lake Erie. We have chosen this empirical problem because existing research has considered the same situation in the timeless framework (Kriesel, Randall, and Lichtkoppler). Our refinements of the hedonic model allow a different interpretation of homeowner behavior and, more important, valuation of an available cooperative intervention.

Loss of and damage to property due to shoreline erosion is a constant threat to many Great Lakes residents. Wave and wind action, drainage patterns, and cyclical changes in lake levels all affect erosion. If left unchecked long enough, houses will eventually fall into the lake. Two property characteristics determine the risk of damage. The setback is the distance from the shore; larger distances reduce risk of damage for obvious reasons. The erosion rate determines how fast setback is lost to natural processes and also captures information about the stability of a property's geological makeup. As setback diminishes, it is more likely that a sudden major event will occur resulting in a significant loss of setback above the historical erosion rate and/or changes in the property that increase the likelihood of future damage. Such events are held to be more likely for a given setback level when the erosion rate is higher. In practice, homeowners will respond to events before they actually lose their homes. However, responding to these events is expensive and can be interpreted as a bad outcome for the homeowner. Private interventions, in the form of protective devices, have been constructed at various times and have provided decreasing protection as they age and degrade. Thus, we have a situation where ordinary erosion reduces setback and existing protective devices age, increasing the risk of failure over time without further intervention.

There is an alternative form of erosion protection that affects erosion risk in a different way: a "Great Lakes module" (Kriesel and Randall). These devices are precast of concrete in the shape of an "M" and held together by steel cables to form a continuous wall about 25 feet offshore. Economies of scale in the construction of Great Lakes modules mean that they are much more economical when provided cooperatively. During their useful life they reduce the risk of damage to a low and fairly uniform level over time.

The first step in valuing the Great Lake module is to determine the probability that a property buyer would have erosion damage in a given year. Although the ultimate threat was complete loss if the property fell into Lake Erie, in practice, remedial measures are taken before such a catastrophic loss occurs. Typically, a household waits as setback diminishes and protective devices age until some discrete event signals a dramatically increased risk of greater losses (for example, an overnight loss of twenty feet of setback). At this point the household ordinarily incurs expenditures to reduce that risk, either by adding setback with fill dirt, by building a new protective device, or both. In this study, the need to undergo such an expenditure defines the bad state whose probability households wish to reduce.

Probabilities for the two states of nature will be estimated with a logit model. The probability of a bad state occurring is specified as a function of the property's setback distance (hypothesized to have a negative effect on probability), the number of years that the property was observed (a positive effect), the annual erosion rate (a positive effect), and the inverse of the protective device's age (a negative effect). The logit model allows the generation of expected probabilities of a bad state for each household and for different setbacks, erosion rates, and protective device ages.

The next step is to use these results to determine the homeowner's expected probabilities of the bad state occurring in each year for a set of T years into the future. To calculate these expected probabilities for future years, the distribution of potential states of nature must be constructed for each year. Consider the probability of a bad state occurring in year t as being the value of a function $p_t = R(S_t)$ where S_t is the vector of measurable characteristics which are used to model the risk of erosion damage (setback, erosion rate, protection device age). Since S_t is observable for the first year, estimating p_t is straightforward and is accomplished with the logit model outlined above. We generate per year probabilities by multiplying setback, age, erosion rate, and the value 1 (for years of observation) by the corresponding estimated coefficients. This creates a predicted probability for one year. For future years, a probability tree must be constructed representing possible values for S_{t+k} and their associated probabilities. If the bad state of nature does not occur in year t, then the values in S_{t+1} must be adjusted to reflect reduced setback (based on each property's observed erosion rate) and the aging of the protective device. If the bad state does occur in year t, the construction of a new protective device means that S_{t+1} will reflect a protection device age of 1 and a return to the property's original setback distance. Given such a probability tree, the estimated probability of a bad state occurring in year $t + k$ is constructed by summing the products of each node's risk $R(S_{t+k,i})$ and the probability of being at that node, $\omega_{t+k,i}$ (where I indexes the possible states for the vector of observable characteristics). That is, the estimated probability of in year $t + k$ is

$$p_{t+k} = \sum_{i=1}^{r} \omega_{t+k,i} R(S_{t+k,i}). \tag{4}$$

The final result of these calculations is a set of expected probabilities of the bad state into the future which fully incorporates the dynamics of erosion, setback, and protection device depreciation.

The information developed on dynamic risk is now available for use in estimating the hedonic equation for housing price. Ideally the entire vector of risks could be included, allowing the hedonic model to estimate the discount rate applied to future risks. However, the risks were so collinear that the hedonic regression presented below performed very poorly with each element of the twenty-year vector included as a regressor. A single variable for dynamic probability was developed by discounting risks twenty years into the future at a rate of 5% per year. Denoting this single variable, discounted risk proxy by P, it can be calculated according to

$$p_t = \sum_{k=1}^{20} (1.05)^{-k} p_{t+k}. \tag{5}$$

This discounted risk was adopted as a second-best procedure. Thus, our risk measure is also a single-variable proxy, but one which incorporates a measure of actual risk and at least some information about the time profile of that risk.

The offshore protection devices proposed for cooperative shoreline protection are said by engineers to effectively reduce the probability of damage or significant setback loss to zero for at least twenty years. After that, the devices degrade and the risk of damage increases. Intending no professional disrespect to engineers, we find the idea of zero risk difficult to believe. We therefore determine the value of the intervention for two scenarios: an annual risk level of zero and an alternative estimate of 0.05 (a level significantly lower than the mean risk of undergoing significant expenditure in our sample). This was done by creating values of P_t for the two constant risk streams (0 and 0.05) according to equation (5). An hedonic model of housing prices is then used to compare predicted prices for each house given the expected risks under current conditions and the expected risks with the cooperative shoreline protective device in place. The difference in predicted prices represents the option price of the intervention for that household.

Empirical Results

The data used to value this potential cooperative, risk-reducing intervention are from a sample of 226 households located along the 160-mile Ohio portion of Lake Erie running from Pennsylvania to Cedar Point, Ohio (about forty miles east of Toledo). Households were included in the study if (*a*) they had purchased their property between January of 1984 and June of 1988, and (*b*) they subsequently responded to a mail survey. In addition to demographic and housing characteristics, information about the existence and age of private protective devices was collected, along with information about expenditures made to prevent erosion damage. Data on property values and attributes and on protective devices were obtained from a search of county courthouse property records and a mail survey of property owners.[3] Information on site-specific erosion rates was obtained from Ohio Geological Survey reports of shore recession between 1876 and 1973. For further details, see Kriesel.

Before estimating the logit model for the probability of a bad state, two preliminary steps are necessary to prepare the data. Some households spent minor amounts on maintenance for existing protective devices. Therefore, we defined the occurrence of a bad state as expenditures of more than $1,000, a circumstance reported by 30.5% of the observations in the data set.[4] Because some properties had no protective device and the variable enters the logit model as (1/age of device), these observations must be adjusted to avoid infinite values. Properties with no device at purchase time were assigned an age of 60 years, an age at which any existing device would certainly be fully depreciated. This adjustment was applied to 153 of the 226 properties in the data set. The coefficient estimates of the logit model are reported in table 1. All four coefficients have the correct sign and three are significantly different from zero at the 10% significance level. The model correctly predicts the states of nature for 73.5% of the observations. Probabilities are generated for each household for twenty years into the future using the estimated logit model and the procedure outlined in (4) and are then used to compute the discounted risk proxy described in (5).

The hedonic price model includes nine property characteristic variables, two neighborhood variables, three dummy variables that indicate the year in which the property was sold, and the risk proxy variable generated from the logit model results. These variables are common to many other hedonic price studies.[5] A consideration of insurance to compensate

[3]The mail survey of 459 shoreline property owners yielded a response rate of 67.4%. Eighty-three of the 309 returned surveys were removed because of missing responses, leaving 226 complete observations in the final data set. Examination of the characteristics of respondents versus nonrespondents showed that the usable sample is representative. The survey instrument inquired about property characteristics, including erosion and protective devices, as they existed at the time of purchase. It also asked about subsequent protective action taken by the purchaser. The data on purchase price and date were from courthouse records. Further details may be found in Kriesel.

[4]We wish to limit the bad state to occurrences when large, unplanned expenditures were necessary to rebuild protective devices. Small routine expenditures, in contrast, were typically made for routine maintenance. The $1,000 figure is an arbitrary cutoff made by examining the data and consulting with people familiar with shoreline protection on the Lake Erie shore.

[5]The hedonic model does not contain a variable to describe recreational and scenic amenities. This is because all properties in the data set are on the lakefront, with the result that all observations have equal access to these amenities. Since a variable for these amenities would have zero variance across the data set, it can not be included in the model.

erosion damage is not appropriate because insurance companies routinely cancel homeowner policies when the property becomes endangered, and the collapse of homes into the lake is not covered by federal flood insurance. Following Anderson and Edwards and Smith, the regression model was estimated with a double-log functional form using ordinary least squares (OLS). All variables have their expected signs except the number of fireplaces, but this effect is not significant (table 2). The model has an R^2 of 0.76. The statistical significance of the coefficient on the dynamic probability variable confirms that buyers do, in fact, value lower risks of erosion damage.

For OLS estimation to be valid for the hedonic model containing the estimated risk variable, the two-equation system must be recursive. A system of equations is recursive if the endogenous variables have only one-way causation and the errors in the different equations are independently distributed. The one-way causation is easy to establish: risk affects house values, but house values do not affect the risk of erosion damage. If the models presented are correctly specified in the sense that home buyers compute risk and house valuations according to the functional forms displayed, then the errors in the two equations should be independent. Thus, conditional on the model specification, the OLS estimates from the hedonic model for house prices are unbiased and efficient.[6]

The results indicate that homeowners would be willing to pay a mean of $16,261 to reduce their annual probability of the bad state occurring to a constant 0.05. There was a wide range of values, with houses at low risk showing very low values for the intervention.[7] The highest option price was $71,057 for a house with a very high erosion rate. If the intervention actually reduced the probability of a bad state to zero, our results indicate an option price distribution with a mean of $37,826. The lowest predicted valuation of the cooperative intervention is $1,038 and the highest is $135,336. For comparison, the average selling price of the homes in the sample is $127,800.

Discussion

There are two aspects of these results which are worth noting. One is the way that these results contrast with the results of Kriesel, Randall, and Lichtkoppler, who analyzed the same data. They used a proxy defined as the number of years until a property would be expected to fall into the lake, given the setback distance, erosion rate, the age of protective devices, and no further mitigation measures. They then computed an option price for an intervention which added an additional twenty years to a home's expected life. They found that only homeowners with very limited time left would be willing to pay substantial amounts for protective devices. The mean willingness to pay for a protective device which would significantly reduce risk was $2,328, while the median willingness to pay was $1,399.[8] This

[6]If the risk model is misspecified, the errors of the two equations will likely be correlated, and the inclusion of the risk variable will introduce a generated regressor problem (a type of simultaneous equation bias). Because the estimated risk variable is already "purged" of stochastics due to its generation process as a predicted value, the OLS estimation of the hedonic model is essentially instrumental variables in this case. The coefficient estimates will now be biased but consistent, while the standard errors presented in table 2 are biased and inconsistent. Because the true risk is a latent variable, an exact correction to the standard errors cannot be computed for the data in this application; however, an upper bound was constructed. The maximum correction for the generated regressor would inflate the presented standard errors by a factor of 2.48.

[7]Four of the houses in the sample were at such low risk that their discounted sum of expected probabilities was less than that of a constant 0.05 intervention. These four properties showed a negative valuation for the 0.05 intervention, although they still had positive option prices for the complete elimination of risk. These option prices were set to zero in computing the sample average for the 0.05 intervention.

[8]This average value was obtained by using Kriesel, Randall, and Lichtkoppler's preferred model (Model 2) to generate predicted willingness-to-pay amounts for a 20-year increase in *GEOTIME* (the variable reflecting time remaining until expected setback is zero) for each household and then taking the mean and median of these generated values.

Table 1. Logit Model Coefficient Estimates

Independent Variable	Beta Coefficient	Standard Error
Intercept	–0.808	0.871
Natural log of setback distance	–0.356	0.193*
Inverse of protective device's age	–0.627	1.121
Annual erosion rate	0.006	0.002*
Years of observation	0.450	0.132*

Note: The dependent variable is 1 for bad state and 0 for good state. The sample includes 226 observations. The log likelihood is –253.86. The correct prediction rate is 73.5%. An asterisk indicates significance at the 0.10 level.

Table 2. Hedonic Model Coefficient Estimates

Independent Variable	Beta Coefficient	Standard Error
Intercept	–0.052	1.293
Log of distance to Cleveland	–0.082*	0.043
Log of lot square footage	0.123*	0.026
Log of number of fireplaces	–0.017	0.080
Log of house square footage	0.332*	0.079
Log of mean income in neighborhood	0.693*	0.1032
Log of house age	–0.043	0.037
Log of number of rooms	0.138*	0.080
Log of number of bathrooms	0.135*	0.077
Dummy for air conditioning	0.131*	0.071
Dummy for stone or brick exterior	0.116*	0.053
Dummy for 1985 purchase	0.095	0.079
Dummy for 1986 purchase	0.103	0.075
Dummy for 1987 purchase	0.087	0.070
Dummy for garage	0.385*	0.074
Dynamic probability	–0.205*	0.070

Note: The dependent variable is the natural logarithm of house selling price. The sample includes 226 observations.
The R^2 was .76. An asterisk indicates significance at the 0.10 level

contrasts with the numerous occurrences in the data of households with greater than average setbacks making investments of a thousand dollars or more in erosion protection. This contradiction is due to the inability of the Kriesel, Randall, and Lichtkoppler proxy to measure the true risk to homeowners—the possibility of having to spend money to fix devices and restore setback before the house is lost, and of having to do so in an unpredictable pattern over time. The finding in this study is much more in line with the observed behavior—unpredictable but significant expenditures on risk reduction even when considerable setback from the lake remains. Our results imply a substantially higher value for the Great Lakes module than would the estimates resulting from a timeless framework.[9]

The second aspect which is worth noting is that the option price is quite sensitive to variations in fairly low risk levels. The difference between an annual risk level of 0 and 0.05 averages $21,565. The valuation of the Great Lakes module considered here depends very much on just how close to zero the risk of significant erosion damage is driven.

The use of this technique provides an improved estimate of option price. In this particular example, special circumstances allow us to interpret the option price as an ex ante welfare measure of the cooperative intervention. First, the Great Lakes module affects only the probabilities faced by households and not the payment streams which result from each state. Second, there is no scope for risk reallocation (Ready) since all households put a positive value on risk reduction. We also avoid the identification problem faced by other researchers in attempting to recover a willingness-to-pay schedule from estimates of marginal willingness to pay (Anderson and Bishop; Diamond and Smith). This is because we are valuing only the changes to erosion protection that individuals can make on their own property in the hedonic regression, and these small changes cannot affect the OP-risk schedule that has been estimated. In addition, the household is able to observe indicators of risk to its members and furnishings, so potential loss is limited to the property's reduction as a real property asset, that is, a lump-sum reduction in wealth. If the household seeks to protect its asset value, then the hedonic price equation provides a valid basis for estimating the household-level benefit from protection and it is not necessary to estimate the entire demand curve for erosion protection (Palmquist).

Conclusion

In this article we have argued that improved risk measures are required to make progress in using hedonic estimation of option price to value public interventions which reduce environmental risk. First, actual risks instead of proxies must be developed wherever possible. Second, the time profile of these risks and the time profile of the intervention must be considered to accurately gauge the option price of the intervention. We use a model that includes an estimated risk variable to value a cooperative intervention that reduces the risk of erosion damage for lakefront properties on Lake Erie's Ohio shore. Our results give a more plausible explanation of behavior than previous research using a timeless proxy and

[9]If the hedonic model is estimated with the proxy used by Kriesel, Randall, and Lichtkoppler (*GEOTIME*), the R^2 is statistically equivalent to that of our model with the discounted risk proxy (they are almost identical). Thus, the two approaches do an equal job of fitting the data statistically, although the economic implications that result are quite distinct.

indicate that the value of the Great Lake module is economically significant for most property owners and the magnitude is sensitive to small variations at very low risk levels.

Our analysis suggests, that valuing public interventions would ideally be done in a fully dynamic framework. Conceptually, the theoretical model is a straightforward extension of the timeless model into a set of discrete, discounted periods. The data demanded to fully implement this model have thus far been elusive because of multicollinearity between temporal risks. Possible alleviations of this problem might be specifying time periods which are as long as are credible, using techniques such as ridge regression, or imposing a "lag" structure on the regression coefficients of the time series of probability values. Thus while implementing a fully dynamic option price model will be challenging, the problems are not insurmountable. Another interesting extension made possible by direct measures of risk is a test of market rationality: do homeowners' valuations of risk match the observed costs of risk reduction? This information could make a valuable contribution to the debate over the objectivity of the public's perceptions of environmental risk.

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