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12 The Valuation of Environmental Risks Using Hedonic Wage Models

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12.1 Introduction

Whenever benefit-cost analysis is applied to evaluate policies intended to reduce the risks to life experienced by members of a community, the valuation of these risk changes is inevitable. This process has been a continuing source of controversy in areas with these types of policy-making responsibilities. Indeed, for nearly twenty years economists have been criticized on ethical grounds for attempting to "value human life." While there is unlikely to be an end to this philosophical debate, it would appear that progress has been made in recognizing the importance of addressing explicitly these valuation decisions. This has been especially true for environmental policy, since William Ruckelshaus returned to EPA. Ruckelshaus identified risk management as one of the most important issues facing environmental policy-making. In discussing before the National Academy of Sciences the difficulties associated with the current regulatory process at EPA, he observed that

> Science and the law are thus partners at EPA, but uneasy partners. . . . The main reason for the uneasiness lies, I think, in the conflict between the way science really works and the public's thirst for certitude that is written into EPA's laws. . . . EPA's laws often assume, indeed demand, a certainty of protection greater than science can provide at the current state of knowledge. (Ruckelshaus 1983, pp. 3–4)

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The purpose of this chapter is to consider whether economic methods are currently capable of responding to the demands likely to be posed by an approach to environmental regulation that focuses on the changes in risk resulting from more stringent standards for one or more dimensions of environmental quality. It is reasonable to expect that there will be a corresponding demand for these risk changes to be valued.

Several methods exist for measuring an individual's valuations of nonmarketed goods or services, including changes in risks.[1] The specific focus of this chapter is on only one of these methodologies—the hedonic wage model. It has been the mainstay of most valuation estimates for the risk changes associated with life-threatening events, and plays an important role in the benefit estimates derived for the health effects associated with the primary national ambient air quality standards.[2]

To conduct our appraisal of this framework, consideration will be given to the strengths and the limitations of the conceptual model underlying the hedonic approach and to the most detailed set of empirical estimates for a hedonic wage model currently available. Finally, this evaluation will be used to interpret the range of estimates currently available for valuing a "statistical life." However, before turning to this evaluation, it is important to provide some perspective on what the policy-making needs are likely to be. Consequently, in section 12.2 we discuss the types of risk assessments that are a part of the standard-setting process for air pollutants, since they serve to define the nature of the valuation problems.

Section 12.3 develops the conventional conceptual framework for the hedonic model, focusing particular attention on the assumptions important to the use of empirical model estimates of an individual's willingness to pay for risk reduction.

Section 12.4 describes a detailed empirical analysis of real wages using the 1978 Current Population Survey, including both individual and site characteristics as determinants of wages, together with three types of risk variables: one of the conventional measures of on-the-job accidents, an air quality index as a measure of the risk of potential chronic and acute health effects resulting from exposure to these pollutants, and an index of

1. A variety of taxonomic frameworks are used in describing these methods (see, for example, Schulze, d'Arge, and Brookshire 1981, Desvousges, Smith, and McGivney 1983). The *indirect market methods* rely on market transactions to infer an individual's demand (and thereby willingness to pay) for a good or service. With nonmarketed goods, some linkage must be established between the marketed good and the nonmarketed commodity. This can be an a priori restriction to the utility function (as in weak complementarity), an assumption regarding how the marketed and nonmarketed goods are used in consumption (e.g., a restriction to the household production technology, see Bockstael and McConnell 1983), or a technical linkage caused by the physical delivery system for the nonmarket good (i.e., air pollution is "delivered" in different doses to different geographic locations).

The direct valuation methods rely on surveys to elicit individuals' willingness to pay for hypothetical changes in one or more dimensions of environmental quality.

2. See MathTech 1983 for the benefits analysis associated with the proposed new primary standards for particulate matter.

the prospects for exposure to carcinogenic substances in the workplace. Specific consideration is given to the sensitivity of the valuation estimates to decisions that cannot be resolved on an a priori basis using economic theory.

The last section summarizes the chapter and provides a prognosis for this method in valuing environmental risks.

12.2 The Nature of Policy Demands for Risk Valuation

It is common practice among economists to assume that the primary issue in valuing the risk changes associated with air and water pollution control policies involves selecting a value for a statistical life.[3] While there can be little doubt that this is an important component of these tasks, it is not the sole area where risk valuation is required. Indeed, this perspective can be misleading. It would seem to imply that estimates of individuals' valuations for risks to life in other contexts (such as industrial accidents) can be readily transferred to the valuation of environmental risks.

There is no a priori reason to accept this conclusion. Different types of activities that impose risks to an individual's life may well lead to quite disparate willingness-to-pay values for risk reductions. The correspondence between willingness-to-pay values across different types of risk is the result of an assumption in the economic model used to describe individual behavior, not a conclusion drawn from empirical analysis. Moreover, as we shall develop in the next section, analyses of individuals' risk-taking decisions suggest quite different conclusions.

A second reason for questioning this view of the valuation problem arises from the specific needs of environmental policy-making and the likely expansion in these needs under a regime of standard setting based on concepts of risk management.

In order to limit the scope of our summary of the policy-based needs for environmental risk valuation, we will consider only air quality regulations. Under section 109 of the Clean Air Act, EPA is required to establish ambient air quality standards for the criteria pollutants.[4] This section mandates that primary standards be set at a level necessary to protect public health with an adequate margin of safety. Based on the act and its legislative history, EPA has interpreted this mandate in defining primary ambient air quality standards to be based on protecting those individuals established to be most sensitive to each criteria pollutant (though not necessarily the most sensitive members of the group) against adverse health effects (see Richmond 1981, and Jordan, Richmond, and McCurdy 1983).

3. An explicit example of these practices can be found in EPA's guidelines for preparing the regulatory impact analyses required by Executive Order 12291. See especially U.S. Environmental Protection Agency 1982, Appendix A, pp. 10–12.

4. See Richmond 1981 and Jordan, Richmond, and McCurdy 1983 for further discussion.

In order to implement this approach, the activities associated with defining a standard for each pollutant must: (*a*) identify the types of health effects likely to result from alternative ambient concentrations of the pollutant under evaluation; (*b*) specify the groups within the population most likely to be susceptible to these health effects; and (*c*) judge the changes in likelihood of these health effects that would accompany changes in the ambient concentration of the relevant pollutant.

This process inevitably leads to a fairly detailed description of the health effects considered relevant to the standard-setting process. To illustrate the nature of these effects, we have considered a recent analysis of four criteria pollutants—carbon monoxide, sulfur dioxide, particulate matter, and lead. Table 12.1 describes the types of health effects considered in each case.[5] Three aspects of these risks are important from a valuation perspective.

The first arises in the definition of the group used to value statistical lives. A statistical life is an alternative measure of risk reduction. It is based on an ex ante welfare criterion and envisions the decision process as follows (see Hammond 1981 and Ulph 1982). The decision maker is confronted with a policy that will reduce the risk for a group of individuals by a certain amount, say Δr. Since this risk reduction is experienced equally by all individuals it is a type of public good. A common approach for reporting the valuations of risk reductions has been to form an aggregate by asking how large the group would need to be in order for the change of Δr to lead to a reduction of one in the expected number of deaths for the group (i.e., $N = 1/\Delta r$). If we have estimates of the willingness to pay for Δr for each member of the group, then their valuation of the risk change can be considered their collective willingness to pay ($AWTP$) for a statistical life (i.e., $AWTP = \Sigma\, w_i(\Delta r)$, where $w_i(.)$ is the ith individual's willingness to pay for risk reductions). This has been a common format used in reporting the valuations of risk reductions.

However, in interpreting these estimates it is important to recognize that the risks described in table 12.1 are not experienced by all members of society. Rather they are usually associated with specific groups (i.e., the sensitive members of the population). These groups will not, in general, correspond to the groups used in estimating (with hedonic wage models) the "representative" individual's willingness to pay for risk reductions.[6]

5. These health effects are not intended to provide an exhaustive summary of those identified in the criteria document for each pollutant. Rather, they are indicative of the level of detail required in specifying both the nature of the effects at risk.

6. See Smith 1979, Blomquist 1979, and Violette and Chestnut 1983 for reviews of the literature estimating the value of risk reductions using wage models. These analyses are confined to groups with available wage surveys and often to subsets of employed individuals involved in more hazardous work. This was the case for one of the first studies in the area by Thaler and Rosen 1975.

Table 12.1 Selected Criteria Pollutants and Health Effects at Risk

Pollutant	Health Effect	Threat to Life
Carbon monoxide[a]	aggravation of Angina[b]	no
	aggravation of peripheral vascular disease	no
	myocardial infarction	yes
	effects on fetuses (increases in late fetal and early neonatal mortality rates)	yes
Sulphur dioxide[c]	aggravation of asthma	no
	aggravation of emphysema	no (?)
	aggravation of chronic bronchitis	no
	aggravation of heart disease	yes
	aggravation of other forms of lung disease	yes (?)
Particulate matter[d]	aggravation of acute respiratory disease	no
	aggravation of chronic respiratory disease	yes
	aggravation of heart disease	yes
Lead[e]	impacts on the nervous system	no
	IQ detriment in children	no
	impacts on the circulatory system	yes (?)
	increased risks in childbirth	yes (?)
	aggravation of anemia	no

Notes: The judgments as to the threat to life resulting from the health effect are interpretations of discussions in the risk assessments used to develop this table. They are intended to convey an appraisal of whether the health effect noted would be the primary cause of death.

[a]The sources of this summary of health effects were Keeney et al. 1982, and Smith, McNomee, and Merkhofer, n.d.

[b]Some questions have been raised recently with respect to the statistical analysis undertaken to establish this effect. Therefore, it should be regarded as a potential impact but not as clearly established as the others.

[c]The health effects were not drawn directly from a risk assessment for sulphur dioxide. Rather they were taken from Merkhofer's 1981 summary of the principles involved in conducting such assessments.

[d]These health effects were not as specifically defined because the criteria document focused on epidemiological studies rather than clinical studies in defining the health risks. See MathTech 1983, vol. 2 for more details.

[e]These health effects are based on the preliminary work currently underway in the development of a primary standard for lead and are based on private correspondence with Allen Basala, Chief Methods Development Section, OAQPS, U.S. Environmental Protection Agency.

To the extent that members of these groups have specific characteristics that affect their performance in the labor market, we can expect differences between their "true" *AWTP* and that estimated using the results from conventional hedonic wage models.

A second issue arises with the type of events at risk. They are different from those providing the risk estimates in the hedonic wage models. The latter are based on accidents within the workplace and are likely to involve immediate physical consequences including physical impairment and, in some cases, fatalities. These differences are important because a growing body of research suggests that attributes of the events at risk and the risks themselves affect individuals' valuations of risk.[7] Violette and Chestnut (1983) in their recent summary of the relevance of these findings to the economic methods for valuing statistical lives noted that

> The evidence accumulated by the studies that have researched this topic indicates that society may place different values on different types of risks . . . it may be the case that individuals value the flexibility associated with the acceptance of voluntary risks. Voluntary risks are usually associated with activities that could be discontinued in the future if the individual's risk preference structure were to change. This is not the case with many involuntary risks. (Violette and Chestnut 1983, pp. 5-18 to 5-19)

Equally important, the character and quality of an individual's life (Zeckhauser and Shepard 1976) are clearly affected by the types of health effects leading to fatalities.

Finally, many of the risk changes involve health effects that do not represent immediate (or indeed any) threats to life. They are changes in the likelihood of either chronic or acute health effects. While a willingness-to-pay criterion would also offer the most appropriate basis for valuing these risk changes, there has been no empirical basis for developing these estimates.[8]

Thus, the policy demands for risk valuation require more detailed and discriminating estimates of individuals' willingness to pay, accounting for both the nature of the health effects and the character of the risk than is generally available with hedonic models. Of course, it should also be acknowledged that these limitations are largely the result of the constraints imposed by the available information used in constructing these models. Consequently, it seems reasonable to consider the behavioral assumptions made in describing individual actions that function as a "partial" substitute for the more discriminating information. A risk management policy may well require transferring the available risk valuation estimates based on experience within the workplace to a wider range of environmental risks. An examination of the implications of these assumptions should

7. See Violette and Chestnut 1983 for a review of the research in this area that is most directly related to the economic estimates of the value of risk. Other related work in psychology is discussed in Fischhoff et al. 1981, chap. 5.

8. See Freeman's 1979 summary of practices in this area. Several authors have attempted to distinguish separate effects for the risks of fatal and nonfatal accidents. Olson 1981 is one notable example. However, this practice is also imperfect because of the heterogeneity in the nonfatal accidents.

also provide some basis for judging the desirability of these transfers of the willingness-to-pay estimates.

12.3 The Application of Hedonic Models to Represent Risk-Taking Decisions

The application of the hedonic framework to explain transactions in labor markets has been described as a formal statement of the theory of equalizing differences (see Thaler and Rosen 1975; Smith 1979). Hedonic wage functions are thus considered to be equilibrium relationships, representing a double envelope—the lower boundary of the individual worker's wage acceptance functions and the upper frontier of firms' wage offer functions.[9] Consequently, the specifications necessarily reflect both the demand and supply determinants of these tied transactions in labor markets. By maintaining that these functions describe the market equilibrium, it is possible to use them to estimate the representative individual's marginal willingness to pay for any attribute (or component) of the tied transaction. This conclusion follows from the nature of the equilibrium itself. Under ideal conditions, if the contribution made to the market-clearing price by an increment to any attribute was not simultaneously equal to the marginal willingness to pay and offer price for that attribute, then there would be scope for arbitrage behavior.

When this framework is applied to the analysis of job risks, these risks are treated in simplified terms. The events at risk are assumed identical and capable of being fully described by the probability of a homogeneous accident. Consequently, risk becomes similar to any other job attribute. To appreciate the implications of this framework, we need to consider, in specific terms, the model of individual behavior used to describe such choices.

Assume an individual seeks to maximize expected utility defined in terms of Von Neumann-Morgenstern utility functions over the states of nature. Each state has implications for the income stream an individual can expect to realize and therefore for the goods and services that can be consumed. The individual will be assumed to be risk averse (i.e., the utility function $\mu(x, y)$, is concave in x and y). For our purposes we maintain that there are two states—either the individual incurs an accident or he does not incur an accident. The accident is defined as equivalent to an income loss of L. An individual obtains income by working and can select jobs that deliver wages and some probability, r, of an accident. He also selects commodities x and y.

9. See Rosen 1974 for a general discussion of the hedonic framework and Thaler and Rosen 1975 for a derivation of the framework with job risks. Triplett 1983 has recently provided an overview of this literature, appraising the implications of recent theoretical developments for the practical use of hedonic models.

In this framework the individual's objective function can be written as equation (1):

$$\text{(1)} \qquad \text{Maximize } E = R \cdot \mu \left(\frac{w(r) - P_y y - L}{P_x}, y \right) + (1 - R)\mu \left(\frac{w(r) - P_y y}{P_x}, y \right),$$

where P_i = price of commodity i ($i = x, y$);
R = probability of state involving loss of L (in this example $R = r$);
$w(.)$ = wage function describing equilibrium locus of wages and risks, r.

If we assume that the individual cannot change jobs and, in the process, control the level of risk experienced (i.e., r is not a choice variable), then risk of the loss, L, is a given to the decision process. Under these circumstances the individual's marginal willingness to pay ($MWTP$) for risk reduction is given by equation (2).

$$\text{(2)} \quad MWTP = P_x MRS_{rx} = P_x \frac{\mu^* - \bar{\mu}}{r\bar{\mu}_x + (1 - r)\mu_x^*},$$

$$\text{where } \bar{\mu} = \mu \left(\frac{w(r) - P_y y - L}{P_x}, y \right),$$

$$\mu^* = \mu \left(\frac{w(r) - P_y y}{P_x}, y \right),$$

$\mu_i^*, \bar{\mu}_i$ = first derivative of μ^*, $\bar{\mu}$ with respect to i.

Since equation (2) defines the individual's inverse demand for risk reduction, it provides the accepted economic basis for valuing changes in risk.

Once we acknowledge an individual's ability to select a job and assume that those selections are based on the wage–job risk combinations available in the market, then the model must be adapted. If we assume, in addition, that an individual correctly perceives job risks (so that $R = r$), then there is some basis for using behavioral actions to estimate an individual's valuation of risk changes. That is, the existence of $w(.)$ allows us to observe one point on this inverse demand function corresponding to the individual's equilibrium selection of the terms of work. The first-order conditions for a maximum of equation (1) with r a choice variable imply that $P_x \times MRS_{rx}$ will equal the slope of the hedonic wage function at the equilibrium selection of r, as given in equation (3).

$$\text{(3)} \qquad \frac{dw}{dr} = P_x \frac{\mu^* - \bar{\mu}}{r\bar{\mu}_x + (1 - r)\mu_x^*}.$$

This framework can be seen as an adaptation to that presented by Thaler and Rosen (1975) (see also Freeman 1979).

Nonetheless, several points are worthy of specific attention. First, the loss, L, is assumed capable of being expressed in monetary terms. As Thaler and Rosen observed, this simplification implies that if individuals can insure against the loss at actuarially fair rates, then this specification would imply an equalization of incomes between the two states.

To the extent we believe that the events at risk do not readily translate into monetary terms, then the utility function for the loss state may include a reduction in income, L (and the corresponding decreased consumption of x and y), as well as changes in other variables that are assumed to be associated with characteristics of the loss state, which are not purchased in markets but are "delivered" with the events at risk. These variables might reflect the nonmonetary dimensions of the events at risk. This case can be treated as implying state-dependent utility functions. With this specification the equalization of marginal utilities under fair insurance would not imply equal incomes.[10] Indeed, in such cases even with fair insurance an individual will nonetheless prefer one of the states over another (see Cook and Graham 1977).

These two assumptions (i.e., state dependency of the utility function and existence of fair markets for diversifying risk) have direct implications for the interpretation of the hedonic wage model. For example, if we assume that there are fair insurance and state-independent utility functions, then we can write dw/dr in terms of the loss experienced, as in equation (4) below.[11]

$$\frac{dw}{dr} = L. \tag{4}$$

By contrast with state-dependent utility functions, or an absence of actuarial fair insurance, the form of dw/dr is altered as given for the former in equation (5).

10. This conclusion follows because the utility functions for each state are assumed to be different. Consequently, the income certainty and utility certainty loci will be distinct and also different from locus of equilibrium choices in a contingent claims framework.

11. This result can be established by respecifying the objective function as:

$$EU = r\mu \left(\frac{w(r) - P_y y - L + I}{P_x}, y\right) + (1 - r)\mu \left(\frac{w(r) - P_y y - (r/1 - r)I}{P_x}, y\right),$$

where I = level of insurance. Differentiating with respect to the selection of I yields equality of the marginal utilities for x in both states. Consequently the income levels assigned to each state will be equal and $I - L$ must equal $-(r/1 - r)I$. Thus $I = (1 - r)L$. Given this result, the specification of the utility function implies equal marginal utilities with respect to y.

$$\frac{dw}{dr} = P_x \left[\frac{\tilde{\mu} - \bar{\mu}}{\mu_x}\right] + \frac{I}{(1 - r)},$$

where $\tilde{\mu}$ = total utility in no accident state and $\bar{\mu}$ = total utility in accident state. However, equal income implies $\tilde{\mu} - \mu = 0$. Substituting for I we have equation (4).

(5) $$\frac{dw}{dr} = L + P_x\left(\frac{\tilde{\mu} - \hat{\mu}}{\tilde{\mu}_x}\right),$$

where $\tilde{\mu}$ = the total utility without the accident and $\hat{\mu}$ = the total utility with the accident. The existence of fair markets for insurance implies that $\tilde{\mu}_x = \hat{\mu}_x$.

Equation (5) implies that transferring the estimates of individuals' willingness to pay for risk reduction for one type of risk to the valuation of the incremental changes in another type of risk may not be possible. That is, even if the monetary losses at risk are identical, the nonmonetary may well be different, and therefore we can expect differences in the magnitude of $(\tilde{\mu} - \hat{\mu})$.

Thus, examining the behavior of a set of individuals facing one type of risk and using their behavioral responses to develop estimates of the same individuals' valuation of another type of risk will lead to incorrect estimates of the values of the risk change. The same conclusion can be drawn if there are differences in the extent to which individuals can diversify activities and reduce the impacts of each type of risk. In this case, dw/dr for the risks facing one individual would reflect that individual's risk distribution of income, which may not characterize the opportunities available to a second individual.[12]

It may be more reasonable to assume that the same individual faces risks from different activities and can select the risk level in each by either changing jobs or altering the mix of his activities. The conventional assumption for these models is to maintain that these risks lead to the same outcome (see Freeman 1979 as an example). The risk of death from any source has the same valuation. It is this assumption (i.e., R in equation (1) is simply $\sum_{j=1}^{n} r_j$, where n = the alternative mutually exclusive ways in which an individual might experience risks of fatalities) that assures that the marginal valuations of the alternative risks correspond.[13] However, if

12. See Cook and Graham 1977 for further discussion of this concept of inefficiency in the risk distribution of income.

13. In this case the objective function could be rewritten as

$$EU = (r + s)\mu\left(\frac{w(r) - P_y y(s) - L + I}{P_x}, y(s)\right)$$
$$+ (1 - (r + s))\mu\left(\frac{w(r) - P_y y(s) - \frac{(r + s)}{1 - (r + s)} I}{P_x}, y(s)\right),$$

where s = risk associated with consumption activity that is selected by the intensity of undertaking y (hence y is a function of s). Differentiating with respect to s we have a general expression for dy/ds that suggests the marginal valuations of risk are equated after adjustment to reflect their respective roles in consumption in relationship to relative prices. That is,

$$P_y\frac{dy}{ds} = \frac{1}{\left(\frac{P_x}{P_y} \cdot \frac{\mu_y}{\mu_x} - 1\right)}\left[P_x\left[\frac{\tilde{\mu} - \mu}{\mu_x}\right] + \frac{I}{1 - (r + s)}\right].$$

it is believed that the attributes of the events at risk are important to an individual's evaluation, then the model must be amended to include new states and corresponding distinct utility functions for each. These amendments imply that the transfer of marginal valuations estimated from decisions on one type of risk to those of another type would not be warranted. It seems reasonable, therefore, to consider the nature of the evidence available for differences in how individuals respond to different types of risk.

As we noted earlier Violette and Chestnut (1983) used this literature in their review of the available estimates of the willingness to pay for risk reductions. Clearly one can use the differences in risk valuations between workplace (i.e., hedonic wage) and consumer market studies to provide informal evidence that individuals value different types of risk differently.[14] In 1982 dollars, the range of estimates for the values of a statistical life derived from the consumer market studies was confined to the lower end of the valuations from wage hedonic models based on workplace risks.[15] Of course, it should be acknowledged that each type of study is subject to many assumptions that might also account for this discrepancy. Nonetheless, when considered together with the policy and psychological analyses of risk-taking behavior, this interpretation cannot be dismissed as irrelevant.

The policy analyses of risk-taking behavior begin with the assumption that individual (and indeed social) preferences toward risk are revealed through individuals' behavior in accepting different types of risk. Starr (1969) appears to have been the first to use this framework to compare risks in an effort to identify the characteristics of risks that influence individuals' willingness to accept them. All of the studies in this area have been crude in their methodologies and should therefore be regarded as suggestive of the important characteristics of risk. Nonetheless, the characteristics identified by the most recent of these studies of Litai (1980) conform in several respects with the features found to affect the performance of the expected utility model in experimental tests (see Hershey, Kunreuther, and Schoemaker 1982). They include: volition, severity, origin, effect manifestation, exposure pattern, controllability, familiarity, benefit, and necessity.

Both sets of research seem to suggest that a state-dependent framework that recognizes the influence of the attributes of risk may be necessary for modeling individuals' responses to different types of risk. Furthermore, this would imply that valuation estimates derived for risks in one context may not be relevant to comparable risk reductions in another setting.

14. The consumer market studies are more limited and refer to such decisions as wearing seatbelts or purchasing smoke detectors. See Violette and Chestnut 1983 for a review.

15. These estimates were quite close to Portney's 1981 implicit valuations of risk derived using the results of a hedonic property value model.

Unfortunately, it is not possible to directly investigate this issue. Data limitations prevent specific consideration of how individuals' value different types of risks. It is, however, possible to consider the sources of some of these risks (e.g., exposure to air pollution and to carcinogenic materials) in a hedonic wage model and to consider how robust the model and its estimates of willingness to pay for risk reductions in the workplace are to the role of these environmental variables in the model.

12.4 Estimates of a Hedonic Wage Model and the Valuation of Risk

Our reviews both of the policy requirements for estimates of individuals' valuation of risk reductions and of the theoretical basis for valuing risk changes endorse the need for distinguishing different types of risks. From the perspective of environmental policy (especially air pollution policies), such distinctions are important because they arise from the nature of the effects of different pollutants. The theoretical analysis also focuses on these differing effects, but emphasizes the possibility that individuals might value them differently. Consequently, even though two different activities might yield the same risk to life, an individual may well value reductions in the risk posed by one of these activities more highly than the other.

In order to evaluate the practical significance of these policy needs and theoretical arguments, empirical estimates of the willingness to pay for risk reductions across a range of activities are needed. Moreover, these estimates must be derived from a consistent description of individual behavior if they are to be compared in a meaningful way. As we noted earlier, the present analysis will fall short of this goal. Data limitations remain the primary culprit. While the analysis that can be undertaken is more limited, it is, nonetheless, suggestive of the importance of refining our empirical models for estimating individuals' valuation of risk.

Our empirical analysis will consider two aspects of hedonic wage models. First, using a detailed wage model developed with microdata, we estimate individuals' willingness to pay for two types of risks—life-threatening accidents in the workplace and risks of death through exposure to air pollutants (i.e., total suspended particulates). Our results indicate under reasonable assumptions that these two sources imply quite different implicit valuations for comparable risk changes.

The second aspect of our empirical analysis considers the variation in estimates of these marginal valuations that would arise from plausible variations in the specification of the hedonic wage model. The objective of this appraisal is to gauge whether the discrepancy in the estimates of the marginal valuation of different types of risk reductions would be attributed to the imprecision of the hedonic model.

12.4.1 The Basic Model

Since the hedonic wage function is an equilibrium relationship, the model should include both demand and supply determinants of wage rates. Moreover, to the extent that the sample used in estimating this relationship includes individual wage rates in different geographic locations, we can expect that the equilibrium locus will reflect the marginal valuations of site amenities (see Rosen 1979). Equation (6) provides a general statement for the hedonic wage function.

$$\left(\frac{w}{P}\right)_i = f(x_{I_i}, x_{J_i}, x_{S_i}) + \epsilon_i, \tag{6}$$

with ϵ_i a stochastic error. This specification maintains that the real wage rate (i.e., the nominal wage w divided by a cost-of-living index, P, for individual i) will be a function of individual characteristics (x_{I_i}), job characteristics (x_{J_i}), and geographic site characteristics (x_{S_i}).

Past hedonic models have tended to focus on a subset of these variables, with those arising from the wage differential literature emphasizing x_I and x_J (see Brown 1980, Lucas 1977, Thaler and Rosen 1975, and Viscusi 1978a as examples), while those from the environmental and urban applications focusing on x_I and x_S (see Hoch 1974, Cropper and Arriaga-Salinas 1980, and Rosen 1979 as examples). In order to avoid the possibility of specification errors, all three sets of variables must be included.

To meet this objective requires a merging of the information from conventional wage surveys with data on job and site characteristics. This task was undertaken using the individuals living in each of forty-four Standard Metropolitan Statistical Areas (SMSAs) for the May 1978 Current Population Survey. This locational attribute permitted the assignment of site characteristics to each sample respondent. In addition the available information on individuals' characteristics, including socioeconomic attributes, occupation, and industry, permitted the assignment of job characteristics.

Since the specific details of these assignments are discussed in Smith (1983), we will turn to a description of the variables included in the specification of the basic model used for the estimation of the marginal values for risk reductions from different sources. The sample after these assignments consisted of 16,199 observations.[16]

A wide array of variables describing site characteristics were considered. The final set of variables used in the model included: a crime rate measure (i.e., serious crimes per 100,000 inhabitants of the SMSA in 1975), *CRIME;* the average unemployment rate for the SMSA in 1978, *UN78;* the mean annual percentage of possible sunshine, *SUN;* and an air

16. For the specific details on the treatment of missing observations, consideration of alternative specifications and samples, and discussion of the implications of the selectivity bias for the model's results, see Smith 1983.

quality index, *TSP* (i.e., total suspended particulate matter in micrograms per cubic meter, measured as the annual geometric mean at sites with complete data).[17]

The job characteristics were confined to four variables that could be assigned based on translating the census identification of industries to the Standard Industrial Classification (SIC). They were as follows: the BLS occupational injury rate for 1975, *ACCIDENT RATE;* an index of exposures to carcinogens in the workplace,[18] *CANCER;* a measure of workers' knowledge of job hazards (defined as the number of workers in each industry covered by collective bargaining agreements with general provisions concerned with health and safety conditions relative to the total employment in that industry), *KNOW;* and a measure of the degree of price uncertainty in the product market for each industry, *OJT.*[19] Based on earlier theoretical research (i.e., Holtmann and Smith 1977, 1979), it was hypothesized that uncertain product market conditions would affect the availability of on-the-job training.

Finally, the individual characteristics provide the most extensive set of variables, including most of the factors mentioned in earlier studies of the determinants of wage rates including: education, *EDU;* experience (measured as age minus years of education minus six), *POTEXP;* race (white = 1); sex (male = 1); veteran status, *VET* (veteran = 1, and relevant only for males); union member (union = 1); head of household (head = 1), dual-job holder (if dual-job holder variable = 1); and qualitative variables for occupations (see table 12.2 for the specifics).

The wage rate measure was calculated as usual weekly earnings divided by usual hours worked. The local cost-of-living index was based on the 1977 BLS cost-of-living index for an intermediate budget (see Smith 1983).

The first columns in tables 12.2 and 12.3 report the ordinary least-squares estimates for the basic model with the full sample and a subsample composed only of males respectively. A semilog specification (with the log of real wages as the dependent variable) was used for these results. The overall estimates of the effects of individual characteristics are comparable to earlier studies. The site and job characteristics are also generally consistent with those earlier studies which included subsets of the set of variables included in this specification. Consequently, either model (i.e., that based on the full sample or that derived using only males) would be

17. A variety of other pollution measures were also considered. However, the measures are closely intercorrelated, suggesting that precise estimates for each one's effect on wages will be difficult to realize.

18. For more details and caveats with respect to these exposure estimates see Hickey and Kearney 1977.

19. See Smith 1983 for more details.

Table 12.2 Hedonic Wage Models: Full Sample with Alternative Environmental Quality Measures

Variable	Basic Model	*EQ* *A*	*EQ* *B*	*EQ* *C*
Intercept	.341	.767	.694	.668
	(6.15)	(9.13)	(8.72)	(8.69)
EDU	.024	.017	.018	.018
	(3.88)	(2.34)	(2.32)	(2.40)
EDU^2	.0013	.002	.0017	.0016
	(5.05)	(5.38)	(5.39)	(5.33)
POTEXP	.026	.026	.026	.026
	(32.44)	(26.94)	(27.05)	(26.88)
$POTEXP^2$	−.046	−.040	−.045	−.040
	(−26.62)	(−21.4)	(−21.54)	(−21.40)
Race	.056	.054	.056	.056
	(5.85)	(4.72)	(4.82)	(4.89)
Sex	.166	.163	.164	.163
	(17.59)	(14.51)	(14.56)	(14.48)
VET	.075	.083	.082	.083
	(7.80)	(7.20)	(7.17)	(7.20)
UN78	−.014	−0.014	−0.010	−0.014
	(−5.59)	(−4.39)	(−2.82)	(−4.61)
Professional	.347	.301	2.99	.300
	(16.67)	(11.86)	(11.80)	(11.81)
Manager	.374	.311	.311	.312
	(17.32)	(11.88)	(11.85)	(11.89)
Sales	.149	.099	.099	.100
	(6.52)	(3.54)	(3.55)	(3.56)
Clerical	.200	.147	.146	.147
	(10.15)	(6.09)	(6.05)	(6.07)
Craftsman	.265	.214	.214	.216
	(12.26)	(8.07)	(8.05)	(8.12)
Operative	.078	.023	.023	.025
	(3.62)	(.89)	(.85)	(.94)
Transport	.123	.081	.081	.083
equip. operator	(4.68)	(2.58)	(2.55)	(2.63)
Nonfarm labor	.078	.024	.023	.025
	(3.25)	(.81)	(.78)	(.84)
Service	−.0098	−.054	−.055	−.054
	(0.48)	(−2.16)	(−2.20)	(−2.13)
ACCIDENT RATE	.011	.010	.010	.010
	(12.87)	(9.71)	(9.67)	(9.89)
CANCER	.219	.105	.107	.096
	(2.757)	(1.03)	(1.05)	(.94)
TSP[a]	.0871	.175	.121	.201
	(3.88)	(5.92)	(4.62)	(5.85)
Household head	.157	.158	.157	.157
	(18.08)	(15.23)	(15.15)	(15.18)
SO_2 measure	—	−0.257	−0.118	−0.281
		(−5.33)	(−4.60)	(−4.56)

Table 12.2 (continued)

Variable	Basic Model	*EQ* *A*	*EQ* *B*	*EQ* *C*
Union member	.183	.184	.184	.185
	(22.32)	(19.131)	(19.103)	(19.159)
*OJT*POTEXP*	−.0012	−0.0016	−0.0017	−0.0017
	(−0.98)	(−1.12)	(−1.15)	(−1.16)
CRIME[b]	.094	−0.151	.262	.156
	(4.60)	(−0.40)	(.75)	(.43)
SUN	−.0015	−0.0056	−0.0049	−0.0052
	(−2.62)	(−6.12)	(−5.61)	(−5.66)
Dual job	−.0439	−0.0436	−0.042	−0.043
	(−2.28)	(−1.91)	(−1.86)	(−1.90)
*KNOW*CANCER*	4.303	4.374	4.347	4.589
	(6.01)	(5.19)	(5.16)	(5.46)
R^2	.460	0.463	0.426	0.463

Note: The numbers in parentheses below the estimated coefficients are the t-ratios for the null hypothesis of no association.

[a]Coefficient has been scaled by 100 (i.e., reported = estimated × 100).

[b]Coefficient has been scaled by 10,000.

Table 12.3 **Hedonic Wage Models: Male Sample with Alternative Environmental Quality Measures**

Variable	Basic Model	*EQ* *A*	*EQ* *B*	*EQ* *C*
Intercept	.651	1.031	1.006	0.847
	(8.98)	(9.68)	(9.91)	(8.69)
EDU	.031	0.035	0.035	0.035
	(4.06)	(3.94)	(3.92)	(3.90)
EDU^2	.0010	.0010	.0010	.0010
	(3.30)	(2.78)	(2.78)	(2.80)
POTEXP	.0309	0.0315	0.0316	0.0414
	(25.67)	(21.61)	(21.72)	(21.54)
POTEXP^2	−.053	−.053	−.053	−.053
	(−22.26)	(−18.20)	(−18.29)	(−18.15)
Race	.112	0.106	0.107	0.107
	(8.66)	(6.97)	(7.03)	(7.04)
VET	.036	0.042	0.041	0.042
	(3.60)	(3.56)	(3.51)	(3.56)
UN78	−.021	−0.020	−0.014	−0.023
	(−6.47)	(−5.028)	(−3.040)	(−5.73)
Professional	.087	0.044	0.041	0.043
	(2.79)	(1.17)	(1.11)	(1.13)
Manager	.141	0.077	0.074	0.077
	(4.45)	(2.02)	(1.94)	(2.02)
Sales	.0019	−0.0317	−0.0334	−0.0315
	(−0.05)	(−0.77)	(−0.81)	(−0.76)

Table 12.3 (continued)

Variable	Basic Model	*EQ A*	*EQ B*	*EQ C*
Clerical	−.101	−0.159	−0.162	−0.161
	(−3.06)	(−4.00)	(−4.08)	(−4.05)
Craftsman	.017	−0.026	−0.029	−0.025
	(0.54)	(−0.67)	(−0.74)	(−0.65)
Operative	−.147	−0.196	−0.200	−0.195
	(−4.40)	(−4.86)	(−4.96)	(−4.84)
Transport	−.118	−0.152	−0.155	−0.150
equip. operator	(−3.35)	(−3.60)	(−3.67)	(−3.55)
Nonfarm labor	−.129	−0.172	−0.175	−0.172
	(−3.81)	(−4.16)	(−4.23)	(−4.16)
Service	−.253	−0.285	−0.289	−0.286
	(−7.77)	(−7.24)	(−7.34)	(−7.24)
ACCIDENT RATE	.011	.00987	.00976	0.010
	(10.65)	(7.768)	(7.688)	(7.913)
CANCER	.028	0.0211	0.0211	0.0201
	(2.77)	(1.344)	(1.343)	(1.280)
TSP[a]	.112	.207	.155	.186
	(3.85)	(5.455)	(4.605)	(4.260)
Household head	.232	0.225	0.225	0.225
	(16.96)	(13.942)	(13.924)	(13.887)
SO_2 measure	—	−.00284	−.00160	−.00181
	—	(−4.603)	(−4.905)	(−2.319)
Union member	.173	0.177	0.176	0.177
	(17.09)	(14.956)	(14.896)	(14.916)
*OJT*POTEXP*	−.002	−.002	−.002	−.002
	(−1.60)	(−1.313)	(−1.301)	(−1.335)
CRIME[b]	.078	−.289	−.076	.490
	(2.94)	(−0.599)	(−0.170)	(1.0669)
SUN	−.0021	−.0067	−.0066	−.0050
	(−2.79)	(−5.813)	(−5.933)	(−4.401)
Dual job	−.041	−0.032	−0.031	−0.032
	(−1.71)	(−1.162)	(−1.119)	(−1.140)
*KNOW*CANCER*	3.879	3.261	3.148	3.560
	(4.70)	(3.294)	(3.175)	(3.601)
R^2	.462	0.481	0.481	0.479

Note: The numbers in parentheses below the estimated coefficients are the t-ratios for the null hypothesis of no association.

[a]Coefficient has been scaled by 100 (i.e., reported = estimated × 100).

[b]Coefficient has been scaled by 10,000.

regarded as a plausible framework for measuring the implicit valuation of job risk or the marginal willingness to pay for reductions in air pollution.

Equally important, these results indicate that it is possible to estimate separate, statistically significant effects on real wages for different sources of risk—accidents on the job, health risks that arise from exposure to air pollution, and the long-latency health risks associated with exposure to carcinogens in the workplace. It appears that the statistical significance and direction of these effects are stable for variations in sample composition (see Smith 1983). Consequently, at a general level these results confirm the earlier work of Hoch (1974), Rosen (1979), and Cropper and Arriaga-Salinas (1980).

What has not been undertaken, to date, is the development of a comparison of the implied valuations of risk changes. Unfortunately, we cannot include in this comparison the long-latency risks. Our index of carcinogenic exposures is based on a limited survey of experience with carcinogens in the workplace. The estimated exposures were extrapolated for each two-digit SIC code to the industry level. They do not take account of control methods that may be in place in each industry and should be treated as a crude measure of potential exposure, scaled by the estimated working hours from the BLS injury rate data. Given the limitations in the index, we have interpreted it as a proxy variable to account for this factor and not attempted to use it as an estimate of exposure risk. Consequently, in what follows we develop and compare the estimates of the willingness to pay for risk reductions implied by these models for two of the three sources of risk.

12.4.2 The Estimated Valuation of Risk Reductions

We have estimated two implicit valuations for risk changes from the hedonic wage models. The first follows directly from conventional practices. As we noted in section 12.2 above, the valuation estimates for "statistical lives" are simply transformations to the wage premiums required for small increments in the risk of fatal accidents. Rather than scale these estimates to correspond to the value implied by reducing the expected number of fatalities by one, we have simply reported the estimated marginal valuations for an incremental reduction in risk.

The second is derived by adapting an ingenious proposal by Portney (1981) to the wage-hedonic framework. Portney's suggestion was made using a hedonic property value model but is equally relevant for a wage model. It maintains that individuals seek to avoid exposure to air pollution because they recognize that such exposure increases mortality risks. Consequently, if we assume that individuals "know" the relationship between air pollution exposure and this increased risk, we can infer an implicit valuation for risk reductions using the wage premiums required to accept increased pollution.

For our particular application, both risk valuation estimates require some specific adjustments to the estimated parameters. The first valuation relates to the wage premiums for increased risk of fatal accidents, while the risk measure used in our hedonic wage model is for all accidents.[20] Consequently we must estimate the share of total accidents that are fatal. Following Viscusi (1978b) we maintain that fatalities are approximately .4 percent of all accidents. Our wage measure is the hourly rate. To convert our valuation estimate to an annual willingness to pay, we assume 2,000 hours are worked per year. Thus, the estimated marginal willingness to pay for a risk reduction is assumed to correspond to the acceptance wage in annual terms and is calculated by rescaling the estimated parameter for our risk measure to reflect the units of measure and proportion of fatal accidents. This coefficient is then multiplied by the relevant (depending on the sample) average hourly wage and by 2,000. Since our model corresponds to wages in 1978, the result is adjusted by the Consumer Price Index to provide the 1982 estimates of implicit marginal valuations of risk changes. The resulting estimate for our basic model is reported in the first column and row of table 12.4.

To translate the wage premium for incremental changes in TSP to a valuation of risk, we must postulate the mortality risk-*TSP* relationship that is assumed to be recognized by our sample respondents. This literature is fraught with problems and exhibits a diverse array of estimates (for discussion see Gerking and Schulze (1981), and Freeman (1982). Fortunately, as part of the benefit analysis conducted for its review of the current primary standard for particulate matter, the EPA sponsored research that attempted to provide consensus estimates of the total mortality risk-*TSP* relationship based on both micro- and macroepidemiological studies. We have selected three values, including the consensus point estimate from the macroepidemiological studies, for our analysis. The range of estimates was from 0 to .471 as the impact of a change of one microgram per cubic meter in *TSP* (measured as the annual geometric mean) on the total mortality rate (deaths per 100,000). Our three estimates span the range of possible impacts of particulates on mortality. Each has been considered in the calculations including what was judged to be the "best" estimate of .171 (see MathTech 1983, pp. 4-55–4-56). Using these estimates together with the wage premiums for increments to TSP we can impute values for fatality risks associated with air pollution exposures (i.e., $\partial w/\partial\beta = (\partial w/\partial TSP)/(\partial\beta/\partial TSP)$, where β = risk of death due to air pollution exposure). This scaling together with the use of the average hourly wage and assumption of 2,000 hours worked yields estimates for the implicit annual valuation of this risk. They are reported in 1982 dollars for the basic model in the second column (I) for the smallest impact, the intermediate value (II) in the third column, and the highest value (III) in the fourth. All estimates are for 1×10^{-5} increments in risk.

20. The BLS accident rate measure was scaled to a rate per hundred workers. Hence the parameter estimates must be adjusted to reflect this scaling.

Table 12.4 **Estimated Marginal Valuations for Risk Reductions**

	Source of Risk			
		Exposure to Air Pollution[a]		
Model	Workplace	I	II	III
1. *Basic model*				
Comparable treatment of fatal + nonfatal accidents	52.70	941.82	94.18	34.19
Proportional reduction in marginal valuation to reflect role of aesthetics[b]	—	659.27	65.93	23.94
2. *Alternative samples*				
Male[c]	61.02	2,419.45	241.95	51.36
3. *Alternative models/samples*				
Full sample, unrestricted[d]	51.78	508.22	50.82	18.45
Full sample, excluding air pollution	53.62	—	—	—
Male sample, unrestricted	59.41	871.67	87.17	31.92
4. *Expansions in air pollutants treated*				
SO_2 measured as annual arithmetic mean (A)	46.23	1,892.31	189.23	68.70
SO_2 measured as annual arithmetic mean of daily highs (B)	46.23	1,308.40	130.84	47.50
SO_2 measured as annual arithmetic mean of daily lows (C)	46.23	2,173.45	217.35	78.91

Note: These estimates are in 1982 dollars and were converted from 1978 dollars using the Consumer Price Index for December 1982.

[a]These estimates of the marginal willingness to pay for risk reduction relate to the increased risk of mortality based on exposure to total suspended particulates. I assumes a marginal effect of .017, II an effect of .171, and III an effect of .471.

[b]In a contingent valuation survey of individuals' willingness to pay for air quality improvements, Brookshire et al. 1979 asked respondents to allocate their total willingness to pay among aesthetic and health motivations. Their results indicated that 30 percent of the total willingness to pay was attributed to aesthetic motives. This estimate maintains that the same proportion can be applied to the willingness-to-pay estimates from the wage model.

[c]These estimates utilize the average wage for males of $7.22 rather than the overall sample average wage rate of $6.18.

[d]In the semilog specification of the hedonic wage model, the use of the log of the real wage is equivalent to a specification using the log of the nominal wage with the log of the cost of living as a determinant of wages whose coefficient is restricted to unity. The unrestricted form uses nominal wages and allows the parameter for the cost-of-living variable to be freely estimated.

Clearly these marginal valuations are quite different. The implicit valuation due to air pollution ranges from a value nearly twenty times to one that is about 60 percent of that associated with fatal accidents in the workplace. Since it might be argued that these estimates reflect other motives for valuing air quality, we have considered a variety of adjustments to this estimate.

The second row in the table uses the only available estimate of the portion of household's valuation of air quality due to health and aesthetics to adjust implicit risk valuation as a result of exposures to air pollution. The highest valuation (I) remains well outside the scope that might be attributed to random variation, while the intermediate case could well be considered within the range of estimates for risk valuations due to job risks. However, it is also fair to note that further adjustments are clearly warranted. Even after adjustment for aesthetics, this approach to valuation attributes all the wage premiums to mortality risk reductions. The wage differential may also reflect morbidity effects. Finally, within a simple general equilibrium description of household adjustment in the property and labor markets (i.e., selecting site amenities by changing location), we might also expect that these estimates of willingness to pay for air quality improvements would reflect the implications of these changes for all household members.

We have attempted two further adjustments to reflect these two considerations. Freeman's (1982) recent analysis of the benefits with the air quality improvements from 1970 to 1978 indicated that approximately 18 percent of the total benefits arose from morbidity effects. Using either this adjustment or the assumption of a three-person household, we can narrow the discrepancy between the valuation implied by the intermediate mortality/particulate association. For example, assuming the valuation is equal for all household members is below the workplace risks (i.e., \$31.39 versus \$52.50). Adjustment for morbidity effects alone reduces the valuation to \$77.23. This is not true for either of the extreme assumptions concerning mortality/particulate associations. In both cases, these adjustments and the implicit valuations remain substantially different. In case I, they remain substantially greater than the implicit valuation of workplace risk, while in case III they become much smaller. These distinctions serve to highlight the importance of the individual's perception of the relationship between exposure to particulate matter and the associated risk of death.

The balance of the table repeats the calculations presented in the first row with a variety of alternative model or sample specifications including: (*a*) confining the sample to males (as frequently has been the case in the literature on valuing job risks); (*b*) changing the treatment of the local cost-of-living variable; (*c*) excluding air pollution completely; and (*d*) expanding the types of pollutants included in the model to include another pollutant—sulphur dioxide. The complete results for the wage models associated with the last of these variations are also reported in tables 12.2 and 12.3. The equation designations—A, B, and C—correspond to the various measures of sulphur dioxide identified in table 12.4.

These results clearly indicate that the implicit value of risk associated with air pollution exposure is sensitive to model specification, while that due to job fatalities is not. However, these variations do not serve to narrow greatly the discrepancy in marginal valuations of risk associated with these two sources. Accordingly, if we accept the theoretical premises of the hedonic model itself, these results provide indirect and tentative support for the need to distinguish estimates of the willingness to pay for risk based on the types of risk and of the effects involved. At the same time, they also indicate the significant limitations of the hedonic wage model as a method for precisely estimating distinct valuations for risk reductions from different sources.

12.5 Implications

There is growing evidence that the hedonic wage model can provide an empirical basis for isolating the site and job characteristics that influence equilibrium wage rates. Our analysis with a large microdata set and more extensive definitions for site characteristics is also clearly consistent with this conclusion. Equally important, it provides some evidence that indicates individuals may well value comparable risk changes differently. That is, we have considered risk increments that are of equivalent size and lead to the same ultimate outcome (a fatality). Of course the initial probabilities of the fatality and the avenues available for adjustment can be expected to be different in these two cases.

It should also be acknowledged that access to information and the corresponding perception of these risks are likely to be different in these cases. Work-related risks are more tangible. Many union contracts require not only wage adjustments to reflect such hazards, but also disseminate information on the risks. By contrast, the extent of general knowledge of the risks of exposure to air pollution, especially pollution associated with one particular pollutant, is much more limited. Indeed, the available technical information of the health risk exhibits considerable diversity of opinion on the severity of the risks. It would therefore not be too surprising to find that these estimates were subject to large errors. Nonetheless, to attribute all of the difference between these estimates of individual willingness to pay for risk to random error requires that we regard the effects of air pollution on wages as essentially noninformative. This is certainly not the position that has been taken in benefit cost analyses of air quality changes. Consequently, we must attempt to explain the discrepancy. One of the most important explanations is the role of perceptions in the valuation of risk changes. Clearly the sensitivity of the implicit valuation of risk derived from the wage-risk relationships illustrates the importance of this explanation.

In his discussion of the failure of the expected utility model as a description of individual behavior under uncertainty, Schoemaker (1982) identifies five aspects of decision making that have been established from psychological research. They deal with limitations in the simple economic description of individual choice, noting that: (1) most decisions are made by decomposing the problem involved and using relative comparisons; (2) the strategies used for decisions vary with the complexity of the task to be undertaken; (3) choices on one problem are often made in isolation from other decisions; (4) selections involving gains and losses are made with individual reference points; and (5) subjective perceptions of probabilities may not relate linearly to objective estimates.

While these are all interesting and potentially important reasons for amending economic models of individual behavior, they have been derived largely in frameworks that are purely experimental and therefore outside the domain of actual economic choices.

In order to advance our understanding of individual behavior under uncertainty and the role of perceptions for it, research must be directed to how individuals conceive of risks that are part of their everyday economic choices. Slovic, Fischhoff, and Lichtenstein's (1979) work began in inquiry in this direction, but did not go far enough. Research must examine tangible choices involving risk, how they would be (and are) made, the information acquired to judge risk, and how prior beliefs are changed with the availability of new information. In conducting such research there is an inevitable trade-off between the controlled, but unrealistic, environment of the laboratory versus the realistic, but hypothetical, setting of survey research. For real-world economic choices we see little alternative to the survey approach. However, such surveys must be paired with behavioral models where actual choices can be observed and used to gain insight into individuals' trade-offs. For example, surveys can attempt to elicit wage-acceptance functions for job risk and investigate how they change with new information. These responses could be compared with respondents' actual choices and with the results derived from empirically estimated hedonic wage models.

Comparative analyses of the perceptions of environmental risks versus other types of risks also might serve to identify the factors that influence individuals' understanding of these risks and the sources used for information on them.

One of the most important distinctions between these research efforts and those undertaken in psychology is a willingness to use behavioral models in conjunction with survey research to frame the research questions and analyze the findings. This should not be misconstrued as a call for blind acceptance of the current economic framework for describing individual behavior under uncertainty. Rather, it is a suggestion that we need not dispense with it entirely. Indeed, there appears to be a framework that is capable of explaining contradictions to the expected utility framework, but requires empirical research to facilitate our understanding of its implications. That is, our theoretical analysis suggests that if, following Cook and Graham, the effects at risk cannot simply be converted into equivalent income streams, state-dependent utility functions may be the most appropriate way of modeling individuals' valuation of risk changes. Within these models, differences in the willingness to pay for comparable risk changes can be expected. This poses significant problems for the transfer of willingness-to-pay estimates for one type of risk change to value a comparable change in another.

Finally, our analysis also suggests that the wage-hedonic framework based on secondary data cannot be regarded as a precise instrument for estimating the value of risk changes. It is simply incompatible with the degree of resolution and detail expected in environmental risk assessment. This incompatibility poses significant problems for the economic valuation of the estimates of risk changes available from the current structure of risk assessment practices in environmental policy-making.

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Comment T. H. Tietenberg

Risk management used to be a private affair. In these simpler times consumers were seen as holding producers and sellers accountable by refusing to purchase excessively risky products, while employees were seen as holding employers accountable by demanding higher wages in risky occupations. In the face of these market pressures producers and employers were expected to reduce their risk to acceptable levels or be driven out of business while consumers and workers were expected to insure against any remaining risk. Courts provided a vehicle for risk bearers to exert pressure on third-party risk creators (those with whom they held no contractual relationship and, therefore, were immune from direct market pressures).

Risk management is no longer a private affair. As a result of growth in the magnitude and complexity of risks, the government has become more heavily involved in the process of identifying and controlling these risks. Consumers and employees are increasingly seen as ill informed, particularly concerning those risks involving long latency periods. Even the courts are seen as impotent in dealing with disputes where the number of parties is large, such as in air pollution cases, or where the cause-and-effect relationship between a particular activity, such as producing pesticides, and the onset of cancer some thirty years later is hard to establish.

This transformation in public sector responsibilities has triggered a concurrent quantum increase in the need for analytical support both to

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define an acceptable level of risk and to choose the most desirable ways of achieving it. Are the analytical concepts, the empirical methods, and the available data equal to the task?

Purpose

The Smith-Gilbert chapter attempts to provide a partial answer to this question by focusing on how reliably one kind of analytical technique (the hedonic wage model) values changes in one kind of risk (environmentally induced fatalities). They begin by analyzing the kinds of demands placed on the analysis by the policy process, proceed by developing a theoretical model to value state-dependent risks, continue by estimating a model based on a sample of 16,199 individuals, and conclude by computing alternative risk valuations based on this model for the purpose of evaluating the reliability of the state of the art.

Principal Conclusions

In their own words the principal conclusions of the authors are:

> it is possible to estimate separate, statistically significant effects on real wages for different sources of risk—accidents on the job, health risks that arise from exposure to air pollution, and the long-latency health risks associated with exposure to carcinogens in the workplace. It appears that the statistical significance and direction of these effects are stable for variations in sample composition. (P. 375–76)

> the implicit value of risk associated with air pollution exposure is sensitive to model specification, while that due to job fatalities is not. (P. 380)

> these results provide indirect and tentative support for the need to distinguish estimates of the willingness to pay for risk based on the types of risk and of the effects involved. (P. 380)

> the wage-hedonic framework based on secondary data cannot be regarded as a precise instrument for estimating the value of risk changes. It is simply incompatible with the degree of resolution and detail expected in environmental risk assessment. This incompatibility imposes significant problems for the economic valuation of the estimates of risk changes available from the current structure of risk assessment practices in environmental policy-making. (P. 382)

A Critique

I should say at the outset that I think this is an excellent chapter and, although I am by nature an optimist, I have no disagreement with its rather pessimistic conclusions. Indeed the thrust of my remarks will be to reinforce them. My differences with the authors will be more a question of degree than direction.

The Theoretical Model

Perhaps my strongest difference with the authors is the degree of faith they seem to have in the wage model as a method of valuing risks. They attribute most of the difficulties in interpreting and using the results for policy purposes to the lack of sufficiently rich data, whereas I believe the wage model itself has significant inherent limitations that could not completely be overcome even with the best data we could reasonably expect to derive from actual occupational situations.

At the most general level a basic inconsistency exists between the need to derive these valuations and the use of wage differentials as the means for derivation. The need for these estimates by the public sector has been driven by the conviction that markets do not adequately compensate workers for risk (i.e., that wages do not adequately reflect risk). This implies that actual wage valuations of risk will be biased (upward if the workers are unrealistically fearful or downward if they are unaware of the very real risks they face).

One possible answer to this problem is that those who lack knowledge are only a subset of workers, and the ill-perceived risks are only a subset of the risks workers face. With an appropriate knowledge variable the valuations of the most clearly perceived risks by the most informed workers could be extracted and applied to other cases. The Smith-Gilbert knowledge variable is certainly a step in the right direction, but, as I am sure the authors would readily admit, it is quite crude. This is neither the time nor the place to go into detail on information and uncertainty, but in brief the available empirical evidence seems to cast doubt on the ability of people to process information on low-probability, high-loss events, even when the information is available (see Schoemaker 1982, p. 544). Furthermore, the authors themselves cast doubt on the transferability of one set of risk valuations to a different set of circumstances.

In my opinion the problems with using the wage model to value risk are greater when it is used to value *general environmental* risks (such as exposure to ambient air pollution), than when it is used to value *specific occupational* risks. The compensation for occupational risk, to the extent it takes place in the market at all, will certainly take place in the labor market. The case is less clear for general environmental risks.

For general environmental risks there are other markets in which compensation can occur. Indeed the empirical literature suggests a considerable sensitivity of property values to pollution levels. If these results are valid, are victims receiving complete compensation in both property and labor markets (meaning they are overcompensated in total) or do they derive only partial compensation in each market? If the latter, then labor markets provide only a partial picture of risk valuation for general environmental risks. In any case it is not obvious that labor markets fully compensate for general environmental risks.

My final concern with using the wage model relates to the existence of nonwage forms of payment such as workmen's compensation. The existence of workmen's compensation triggers two rather different problems. First, when a workmen's compensation system exists, more dangerous industries may face higher compensation costs, but these will be borne as premiums paid into the system, not as higher wages. Therefore, wages will not reflect actual risk, though total compensation, correctly defined, would.

The second problem is with a possible bias introduced by workmen's compensation. Some type of accidents have a higher probability of coverage under workmen's compensation than others. For example, health effects with a long latency period and those for which the industrial cause is not obvious have a lower likelihood of coverage. In a perfect market wages would reflect the latter (lower-coverage) risk more accurately than the former (higher-coverage) risk. Unfortunately, however, the lower-coverage risks are precisely those about which the workers probably have the least information and, therefore, are precisely those risks where wage differentials are least likely to capture the "fully informed" risk premium.

The Data

The authors decry the lack of useful data, and I agree with their analysis of the situation. However, I want to add yet another concern about the kind of data that analysts are currently forced to use.

The Smith-Gilbert equations are based on 16,199 observations, but not all variables have that many individual observations. Many of the variables are not measured relative to the individual; they are measured relative to an occupation, an industry, or an SMSA. For these variables the measured intraoccupation, intraindustry or intra-SMSA variance is zero. The only measured variance occurs among occupations, industries, and SMSAs. Unfortunately all of the risk variables—the primary focus of their paper—fall within this category.

This would not be a problem if all workers within each of these categories faced the same risk, but clearly they do not. To take one example, all workers in a city do not face the same pollution level. Their exposure depends on where they live and work. Pollution levels are high in certain parts of the city and low in other (typically less-congested) parts.

This creates an errors-in-variables problem that has two dimensions. First, compared to a measure of actual exposure to risk, these measurements rob us of a significant amount of potentially information-rich variance. An intuitive feel for the importance of this point can be gained by considering an extreme, but nontheless revealing, example. Suppose that the average pollution levels in all cities were the same, although each city had a considerable variance in pollution levels within its boundaries. Suppose further that residents placed a high value on pollution reduction; therefore, those who were most exposed demanded a significant wage premium. In this case the regression model would find no relationship between wages and pollution level whereas, in fact, a significant relationship exists. The type of measurement of exposure to risk mandated by current data availability fails to capture a significant amount of the interesting variance. It also enhances the unpleasant prospect that these proxies may be picking up other determinants of wages that are correlated with the cross-industry, -occupation, or -SMSA variance but have no direct bearing on risk.

The second point to be made about this missing variance is that it applies to some, but not all, of the variables. This differential treatment of variables creates the potential for bias. To illustrate the point consider, as an example, the air pollution variable that varies only among SMSAs in the Smith-Gilbert analysis. All workers within an SMSA have the same measured value of air pollution, though in fact they may experience very different levels. It is probably the case that there is a correlation between the true (unobserved) value of within-city air pollution exposure and other variables in the model for which individual observations are available. The existing empirical air pollution literature (see, for example, Asch and Seneca 1978) suggests that such a correlation exists with race (blacks typically have higher exposures) and with education levels (the least educated tend to experience the highest exposure). If this is the case, some of the variance that would have been explained by the risk variables, had they been correctly measured, is mistakenly attributed to these correlated variables. Thus the coefficients on the risk variables may tend to be biased.

Applying the Data

The Smith-Gilbert chapter provides both theoretical and empirical reasons for believing that the value of lowering the probability of death from an environmental risk depends on the types of risk. Though this result accords well with common sense (the intensity and duration of pain as a factor, for example), it flies in the face of much common practice. It is easier, and of even more importance quicker, to transfer calculations among situations involving risks with some similar attributes than it is to derive separate estimates. Yet until we are able to obtain some firmly established set of propositions on how risk valuations vary systematically with identifiable risk attributes, separate estimates cannot be avoided if the valuations are to be meaningful.

Suggestions for Future Research

Improving the Data

The Smith-Gilbert chapter is helpful in calling our attention to limitations in the available data. Using their analysis and that in the preceding sections of this chapter it is possible to begin setting an agenda for future data collection efforts.

Perhaps one of the more intriguing avenues for further research comes out of the Smith-Gilbert finding that risks involving similar probabilities of fatality are valued differently by workers. This finding introduces a significant difficulty into risk management practices because separate risk valuations are required for each unique risk.

This difficulty could be reduced, however, if we could find identifiable attributes of risk that have a common valuation across various types of risk. In this framework, differences in risk valuations would arise from different bundles of common-valued attributes rather than from different valuations of the attributes themselves. Once the attributes and their values were determined, risk assessment would be rescued from the need for a unique empirical study for every conceivable kind of risk. To establish whether common-valued attributes can be identified and valued, a richer set of data is needed. Specifically *attribute* variables need to be included in the set of risk measures, not merely *exposure* variables. These could include, for example, the voluntariness of the risk, the potential intensity and duration of pain, other effects on the quality of life, and so forth.

Other, more immediate, steps are possible. Great strides could be undertaken if true *individual* risk measures were available for workers. The current use of grouped or common-risk measures opens the door to biased risk evaluation. Although it is not clear how much bias exists in the current estimates, the fact that we do not know is unsettling.

The availability of information on risk to workers is probably another important factor about which we need better measurements. Current variables that control for this are obviously crude. It would not be difficult to design better variables; the problem is going to be collecting this information from the same sample of workers as wage rate information is collected. The responsibilities for collecting wage rate information and for managing worker risk do not reside in the same organization.

Better Use of Existing Data

Though it is obviously easier to construct data wish lists than to confront the task of doing more with what we have, I do have a few modest suggestions. These concern developing a better understanding of the socioeconomic determinants of risk valuation and the role of unions in supplying information.

One question of interest concerns whether risk valuation varies among socioeconomic groups. The current model estimated by Smith and Gilbert controls for race and education, but presents no evidence on the possibility of interactions. It would be a simple matter to include interaction terms for education and risk as well as for race and risk as a point of departure. One could develop any number of scenarios that would lead one to expect differences to arise (e.g., information and income effects), but it remains an empirical question whether these differences are of sufficient magnitude to deserve special emphasis.

The Smith-Gilbert data set includes a binary variable that states whether the worker is a member of a union. Given their predisposition to believe that unions affect the amount of information available, an interaction variable constructed by multiplying union membership by measures of occupational risk would seem appropriate. It might further be possible to separate those unions that tend to make risk information available to their workers from those that do not.

Concluding Comments

This is a balanced and perceptive chapter that has improved our knowledge of the state of the art. The main message is a negative one—we have a long way to go. Yet this message should not obscure another, equally important, message—we have come a long way.

Two aspects of the empirical work in particular suggest that this line of research is worth pursuing. With the exception of the air pollution variables the results are stable across model specifications. Furthermore, again with the exception of one air pollution variable (SO_2), there is a remarkable agreement between those signs suggested by theory and those signs estimated from the data. Though I have qualms about the bias of the estimated coefficients, it does appear that the general approach has validity.

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