VALUING GROUNDWATER PROTECTION BENEFITS

T.D. Crocker, B.A. Forster,
S.E. Atkinson, & J.F. Shogren

1989
Technical Report WWRC-89-36

Technical Completion Report

to the

Wyoming Water Research Center
University of Wyoming
Laramie, Wyoming

Thomas D. Crocker
Bruce A. Forster
Department of Economics
University of Wyoming
Laramie, Wyoming

Scott E. Atkinson
Department of Economics
University of Georgia
Athens, Georgia

Jason F. Shogren
Department of Economics
Iowa State University
Ames, Iowa

July, 1989

TABLE OF CONTENTS

CHAPTER 1
VALUING POTENTIAL AND REALIZED GROUNDWATER PROTECTION BENEFITS

INTRODUCTION

Groundwater is a valuable, renewable natural resource that, if contaminated by economic activities, may be rendered a nonrenewable, unusable, and mobile public hazard. There are reasons to believe, given certain physical and technical aspects of groundwater contamination, that the straightforward piecemeal application of conventional Cost-Benefit analysis will lead to a cumulative loss of groundwater resources.

This report develops and extends features of economic theory appropriate to groundwater contamination issues, provides some empirical applications and reports empirical results, and suggests an easy-to-use technique that will usually allow policymakers to obtain a reasonably accurate and precise prediction of the economic benefits of groundwater protection.

This chapter surveys and synthesizes the analytical literature that deals with the economic value of preventing or remedying groundwater contamination. We identify and resolve several literature omissions and discuss the value implications of alternative analytical frameworks.

CATEGORIZING GROUNDWATER CONTAMINATION PROSPECTS AND EPISODES

Groundwater contamination episodes can be divided into 3 categories. Category I consists of known, currently existing contamination of a given site. The Love Canal fits this category. Category II represents prospective contamination episodes (now unknown but occurring or which may occur in the future) from existing facilities. Every underground storage tank that is not now known to be leaking is in this category. Category III includes those proposed development sites which might introduce groundwater contaminants. This category includes an almost uncountable set of possibilities.

The assessment techniques and requirements for each category differ considerably. In the first the economic issue is one of estimating the benefits and costs of alternative remedial actions in order to determine the appropriate responses to a known episode with specific attributes. The third category involves decisions about the appropriate degree of protection to be taken in designing and locating a future site. For the second category the issues revolve around comparisons of prospective costs and benefits of avoiding damage.

A PROPOSED FRAMEWORK FOR EX ANTE ANALYSIS

Given the strong policy concerns about groundwater contamination, the economics literature that deals with groundwater contamination is surprisingly small. The literature that does exist deals almost exclusively with existing episodes (Category I) and the attendant human health risks.

We believe that the analytical economic frameworks that have thus far been applied to studies of groundwater contamination are deficient in terms of their usefulness to the ex ante design of regulations (Category III) and to estimating the ex ante benefits of monitoring existing sites (Category II). The studies ignore non-life threatening health impacts and the anxiety cost of the possible consequences of an approaching plume or one that could change direction due to geological structure. They ignore the potentially large loss in wealth that households may experience if the threat of explosion from petroleum products requires evacuation of house and home. In general, the existing literature assumes that the economic agent is helpless when confronted by groundwater contamination risks. At best, he is only allowed to expend resources on ex post damages; he supposedly possesses no ability whatsoever to anticipate these damages.

Marshall (1976) shows that exogenous risk requires a complete set of Arrow-Debreu contingent claims contracts. Because the ex post compensation that the contingent claims supply can then maintain the ex ante utility level no matter what the realized state of nature, there are no differences between ex ante and ex post valuations of risk. However, because the writing and enforcement of contracts is costly, complete contracts rarely if ever exist: if he is averse to risk, the individual must therefore choose ex ante between contractually defining states of nature or making an effort to alter states of nature. These endogenous, ex ante contractual and adjustment opportunities affect the individual's relative valuations of alternative prospective states. Though one can always redefine a problem such that the state of nature is independent of human actions, the redefinition will frequently be economically irrelevant. Ehrlich and Becker (1972) ask the reader to consider the probability that a bolt of lightning will burn down a house. The probability of this event will be altered if the owner places a lightning rod upon his roof. One might redefine the state of the world to be independent of the owner's actions by thinking in terms of the probability of lightning striking the house. The owner has no control over the probability of a strike. However, this probability is not economically relevant. The owner is interested in the probability of his house burning and he is able to exercise some control over that event. Psychologists, e.g., Perlmuter and Monty (1979) and Stallen and Tomas (1984), concede that individuals perceive that they have substantial control over uncertain events.

Consider a risk averse individual who must decide how much self-protection to undertake as he confronts the prospect of having some valuable personal asset such as his health exposed to groundwater pollution. Assume that he is immobile for the period in question. For a particular liability regime, his dilemma arises because his prior self-protection expenditures that reduce the likelihood and the severity and hence the costs of any ex post damages that he suffers will also cause his ex ante personal consumption to fall. Because of adverse selection, moral hazard, and nonindependence of risks, the individual chooses not to or cannot acquire enough market insurance to avoid the dilemma completely. Given his insurance purchases and given that his utility is intertemporally separable, we suggest that a minimal formulation appropriate to most prospective groundwater contamination problems is:

$$\underset{s \varepsilon S}{\text{Max}} \ [\int_a^b U(W - C(h;\ s,\ r) - s,\ h)dF(h;\ s,\ r), \qquad (1.1)$$

where E is the expectations operator and U is a von Neumann-Morgenstern (1947) utility index. Expression (1) says that the individual's decision problem is to choose, given a full income, W, and hazard exposures, r, that expenditure on self-protection, s, which maximizes his expected utility. His probability-weighted utility is a function of his personal consumption and health state where $U_W > 0$, $U_h > 0$, $U_{WW} < 0$, and $U_{hh} < 0$. Subscripts refer to partial derivatives. Intertemporal and spatial features can in principle be introduced into (1) by appropriately defining h, s, and r in terms of time and locational distributions.

The probability weights in (1) are represented by a subjective probability distribution function, F(•), defined over the minimum, a, and the maximum, b, health outcomes that the individual's genetics and developmental history allow.

Presume that the interval [a,b] is independent of self-protection. Let $F_s > 0$ and $F_r < 0$. Though the individual acting alone may be unable to influence the extent of pollution, he uses self-protection to reduce his exposure, thus influencing the cumulative distribution, F(•), of health states. This probability distribution of health states is dependent upon self-supplied protection, s, from prospective exposures, r. No restrictions need be placed on the signs of F_{ss}, F_{rr}, and F_{sr} in the immediate neighborhood of the expected utility maximizing level of self-protection, s*.

For each health state that the individual realizes, he selects a minimum cost combination of ex post remedial expenditures. His ex ante efforts to protect himself from pollution influence these costs, C, such that $C_s < 0$, $C_r > 0$, and $C_{ss} > 0$. The signs of C_{rr} and C_{sr} have no restrictions. The absence of signs for F_{sr} and C_{sr} reflects the possibility that these responses depend upon the environmental concentration (quality) of contamination as well as the extent to which the individual chooses to self-protect.

Maximize the expected utility index in (1) by selecting an expected utility-maximizing level of self-protection, s*. This yields the first-order condition:

$$EU_W = -E[U_W C_s] - \int_a^b (U_W C_h - U_h) F_s dh \qquad (1.2)$$

The left-hand side of (2) represents the marginal cost of increased self-protection in terms of the utility of foregone wealth or consumption. The right-hand-side reflects two types of marginal self-protection benefits: the first term is the direct utility effect of enhanced wealth resulting from reduced expected ex post costs; the second term is the indirect utility effect of a stochastically dominating change in the distribution of health outcomes.

The indirect effect was derived by integrating by parts the effect of self protection upon the distribution $\int U(\cdot)dF_s(\cdot)$.

We further develop in Chapter 2 the implications of a version (1) for the evaluation of risky prospects, including groundwater contamination. Our purpose is simply to suggest that in the presence of incomplete contingent claims markets, traditional evaluations of the economic consequences of groundwater contamination have neglected plausibly large chunks of economic reality. Because this neglect combines a disregard of important private adjustment opportunities and a singular focus upon ex post states, there is little reason to believe that its consideration would have only trivial impact upon measures of the economic consequences of groundwater contamination. For example, if both private and collective opportunities exist to reduce risk, a singular focus upon the collective will understate the total value of the risk reduction. In succeeding sections, we present some specifics of why the existing analytical literature is excessively narrow when considered in terms of (1).

ANALYTICAL ISSUES IN GROUNDWATER CONTAMINATION ASSESSMENT

Probability Issues. Raucher (1983) is the seminal contribution to the development of an analytical framework for analyzing groundwater contamination episodes and the benefits of protecting groundwater integrity. He defines the expected net benefits of a collective protection policy i, $E(NB_i)$ as the expected benefits $E(B_i)$ net of protection costs X_i. Thus

$$E(NB_i) = E(B_i) - X_i. \tag{1.3}$$

Expected benefits are defined as the expected damages E(D) avoided as a result of the policy. The expected damages are defined by

$$E(D) = p_c[p_d C_r + (1 - p_d)C_u]. \tag{1.4}$$

In (4) p_c is the probability that a contamination episode will occur in the absence of policy i. p_d is the conditional probability that contamination will be detected prior to the use of the contaminated water. C_r is the cost of the most economically efficient remedial response to the contamination episode and C_u is the cost imposed by continuing to use the contaminated water as before the episode occurred. Since continued use is one policy response it follows that $C_r \leq C_u$; that is, economically efficient remedial responses can be no more expensive than the passive response of continued use of the contaminated water. Moreover, since (4) is simply a probability-weighted average of realized states, it is an ex post measure.

Cast in the fashion of (3) and (4) this framework portrays a binary collective policy choice. That is, if policy i is adopted there will be no contamination; if the policy is not used, there is some positive probability that the contamination will occur. The probability of occurrence and the probability of detection appear as fixed and exogenous to the individual and to the collective decision making process. It is unlikely that individuals and especially policy makers would be faced with either binary choices or exogenously determined probabilities. In fact the policy-maker must decide the degree of stringency of the protective policy. This stringency determines the probability of occurrence of an episode. The desired stringency in turn depends upon the benefits and costs of varying degrees of stringency. Similarly the size of p_d depends upon the resources devoted to monitoring the groundwater or the facility likely to leak.

Main (1986) sets up a decision theoretic framework which allows for possible early detection of a leak. In this case, remedial action could take place prior to exposure. Let the probability of a spill be p_c; the conditional probability of early detection be p_e; and the conditional probability of no early detection and human exposure be p_d. The probability of late detection and no human exposure is then $(1 - p_d)$. If there is no spill, there is no cost. The cost of cleanup with early detection is C_r^1, the cost of clean-up with late detection is C_r^2, and the cost of clean-up and human exposure is $(C_r^2 + C_u)$.

Let $C_r^2 > C_r^1$. The expected damage is then given by:

$$E(D) = p_c p_e C_r^1 + p_c(1 - p_e)p_d(C_u + C_r^2) + p_c(1 - p_e)(1 - p_d)C_r^2,$$

or (1.4')

$$E(D) = p_c[p_e C_r^1 + (1 - p_e)\{p_d(C_u + C_r^2) + (1 - p_d)C_r^2\}].$$

While (4') captures the timing problem, it still treats the probabilities as exogenous. Main (1986) is aware of this as he states: "Protective actions usually affect expected damages by influencing either the probability of a spill or the timing of the discovery of a spill". Thus the values of p_d and p_c are endogenous to the policy making process and as argued above and demonstrated by Adams et al. (1984), one of the determinants of these probabilities is the net benefits estimate.

Raucher (1986b) softens his initial binary treatment by suggesting that collective policies are likely to achieve changes in the relevant probabilities rather than eliminating the likelihood of occurrence altogether. For policies designed to reduce the probability of occurrence he defines the expected benefits as:

$$E(B_i) = -dp_c(i)[p_d C_r + (1 - p_d)C_u] \qquad (1.5)$$

where it is presumed that $dp_c(i) < 0$ and hence $E(B_i) > 0$. For a policy j designed to increase the likelihood of detection given an episode, the expected benefits are defined by:

$$E(B_j) = dp_d(j)[p_c(C_r - C_u)]. \qquad (1.6)$$

Since $C_r \geq C_u$, the $E(B_j) \geq 0$ for any $dp_d(j)$.

While (5) and (6) allow for smooth variations in probabilities, the caveat concerning the dependence upon net benefit estimates still applies to the dp_d and dp_c: properly, the appropriate levels of these differentials are endogenous to the decision making process, whether that process be private or collective.

Locational Issues. The episodes portrayed in (3) and (4) or (5) and (6) are also site and time specific. This focus tends to reduce the expected benefits of a policy to a region. For example, while there may be a small probability of a contamination episode at a given site, the probability of contamination occurring somewhere in a region is likely to be larger (once a spill has occurred). Valuation exercises must therefore refer to lotteries over locations and times rather than to specific sites and times.

The specification of C_r as the least-cost remedial measure at a particular site within a region generates a bias towards sacrificing regional groundwater integrity. The piecemeal approach fails to recognize that for technical or economic reasons the contamination of a groundwater resource can be irreversible. In these circumstances, the least cost remedial measure may be to substitute another regional groundwater source. However, the cost of resorting to this substitute will clearly depend upon its state of contamination. In effect therefore, neither the benefits of preventing contamination at a given regional site nor the costs of remedial actions at this site can be evaluated independently of the state of groundwater contamination throughout the entire region. In the ex ante case, the collective risk and the individual's risk may be indistinguishable.

Population Issues. Raucher (1983) does not refine the C_u measure. In his applications, he takes C_u to be either realized crop yield loss from irrigating with contaminated water or realized health damage from drinking the contaminated water.

Schechter (1985a, b) formalizes the health impact by assuming:

$$C_u = (M_r)(L)Pop \qquad (1.7)$$

where M_r is the incremental health risk, L is the monetary value of life, and Pop is the size of the exposed population. The monetary value of life, L, is taken to be the representative individual's maximum willingness-to-pay (WTP) for a small increment in safety and is given by Sharefkin et al. (1984) as:

$$L = \frac{U(W)}{(1 - M_r)U'(W)} \qquad (1.8)$$

where W is the individuals' wealth or lifetime income and U(W) is the individual's utility function. In this formulation L is the value of a "statistical life" rather than one which is individual-specific. Expression (8) presumes that health is valued only insofar as it contributes to income. It has no intrinsic value.

The approach in (7) and (8) is also problematic in the case of groundwater contamination. The health risks imposed upon individual households are treated as involuntary. For a given health risk, M_r, the control benefits thus depend only upon the size of the exposed population and on the monetary value of the health state.

Perception Issues. As Weinstein and Quinn (1983) argue, a central source of difficulty in measuring the economic consequences of risky events is the divergence between "objective" or "scientific" measures of risk and the individual's perceptions of such a risk. Objective damages (or benefits) are calculated as an objective probability of death (usually drawn from the best available scientific evidence) times a dollar value for safety (usually drawn from labor market studies). In contrast to such "damages", perceived damages for each individual are implicitly equal to a perceived (i.e. subjective) probability of death from the environmental risk at issue, times a perceived value of safety associated with a death brought about by the environmental risk at issue. The possible, if not probable, difference between these two measures of damages raises a fundamental policy problem, although Raucher (1986) dismisses the subjective assessments as not relevant to the policy decision. When the individual's degree of risk of suffering harm is to some degree voluntary, the problem arises in the ex ante case because the subjective probabilities determine the individual's self-protection behaviors, and it is these behaviors that determine value. Moreover, this further implies that the individual's objective probabilities of suffering harm are not independent of his subjective probabilities.

Spence and Zeckhauser (1972) show that involuntary risks, risks with delayed effects, and risks not readily influenced by individual behavioral adjustments impose significant losses in excess of the losses inherent in risks lacking these features. These three features sometimes describe situations that challenge owners of assets threatened by groundwater contamination. Involuntary risks remove the _ex ante_ opportunity to adapt. Lack of influence removes both _ex ante_ and _ex post_ opportunities to adapt. Delayed effects make subsequent as well as present decision-making risky. If the benefits of controlling groundwater contamination are to be fully evaluated, the conventional theory of choice under uncertainty must be extended to include preferences over the timing and the means of resolution of uncertainty.

Reliance on estimates of the value of life, in (8), also overlooks other health impacts that occur short of death. As Schechter (1985b) points out, individuals with cancer suffer while still alive and would be willing-to-pay some positive amount to avoid the suffering. There are also health effects short of cancer and death that impose losses on individuals. Exposure to chlorinated hydrocarbons for example can lead to nausea, dizziness, tremors and blindness (Burmaster, 1982). Individuals would be willing-to-pay to avoid these discomforts.

It is important to consider non-health impacts as well as health impacts. For example, a contaminant plume could result in gases seeping into housing structures or other buildings creating danger of explosion. The effects of these combined health and non-health threats effectively destroy large parts of individual and social wealth as a result of the consequent impacts on property values. In this respect it is interesting to note that a former deputy director of EPA's Office of Underground Storage Tanks sees the groundwater contamination issue as one of economics rather than health. Penelope Hansen is quoted as saying "If gas gets into your water, by and large you smell it and stop drinking it. So much for your health problem. On the other hand the economic cost in terms of clean-up, third party damages and long-term depletion of this increasingly precious resource, can be astronomic".

Temporal Issues. The size of the exposed population in (5) is not a trivial matter. It is not just the current population but also future populations which count. Schechter (1985a, b) acknowledges intergenerational equity issues in groundwater contamination. Nevertheless, there are subtle issues short of mutations appearing in future generations that need to be considered.

Since groundwater can move slowly, the timing of a contamination episode may be separated by decades from the original spill if not detected early (recall the framework of Main (1986)). Housing developments may unknowingly be situated in the path of a contaminant plume that started from a leak in the past. A cost-benefit calculation that either ignored population projections or had faulty projections, would underestimate the likely damages because the housing development that took place was not foreseen and hence not included.

The foregoing highlights the intertemporal nature of groundwater contamination episodes that is absent in a literal interpretation of the framework in (3) through (6). Conventional cost-benefit analysis handles intertemporal aspects by considering the Present Value (P.V.) of the stream of expected net benefits E(N.B.), over some relevant time horizon:

$$P.V. = \sum_{t=1}^{T} \frac{E(N.B._i)_t}{(1 + r)^t} \qquad (1.9)$$

where r is the social rate of discount and T is the relevant time horizon.

Raucher (1983) recognizes the important influence which the selection of the time horizon has on the outcome of an analysis. The longer the time horizon the more benefits of protection are included in the calculation. For example, if a 5 year horizon is used but it will take 10 years for the plume to reach a specific site, then there are no benefits to be included in the 5 year period. A longer time frame also increases the likelihood of contamination. Raucher handles this likelihood by introducing time-dependent probabilities.

A further issue with an extended time horizon is that with positive discounting ($r > 0$), benefits that accrue 20-30 years into the future are likely to be negligible in Present Value terms. Hence, stringent protective measures that dictate high costs in the near term but benefits which accrue in the distant future are likely to be seen as uneconomic. Thus, given the slow nature of groundwater movement, conventional cost-benefit analysis has a bias toward sacrificing future groundwater integrity.

One method of getting around this difficulty is to adopt a zero discount rate. Raucher (1983) considered a zero discount rate as one method of dealing with intrinsic existence and bequest values, but seems to reject this technique as "tinkering" which "presents difficulties" since "using a zero discount rate to reflect concerns over the well-being of future generations would result in a failure to acknowledge other real opportunity costs and the positive rate of time preference that exists intragenerationally". This latter point is offered objectively rather than as an ethical issue open to debate. One is reminded of Ramsay's (1928) accusation that discounting is "a practice which is ethically indefensible and arises merely from the weakness of the imagination".

The use of a lower discount rate when there is an environmental risk has been justified on economic-theoretic grounds by Brown (1983). In situations in which public projects are designed to produce <u>favorable</u> outcomes with uncertain benefits, it is usual to adjust the discount rate <u>upwards</u>. Brown's contribution is to show that when the uncertainty concerns a possible unfavorable outcome it is necessary to adjust the discount rate downwards to allow for this risk.

This result is of direct relevance to groundwater contamination studies. Raucher (1986) claims that Superfund guidelines and the Office of Management and Budget stipulate a 10% discount rate be used in evaluating the benefits and costs of the relevant programs. Sharefkin et al. (1984) use a 10% discount rate. If one believes that the risk-free, long-run discount rate is around 5%, then these procedures adjust the discount rate in the wrong direction! Raucher (1986) calculates his estimates using 0%, 2% and 10%. This approach at least serves to bracket the appropriate estimate.

Some researchers have expressed concern that welfare criteria based on (9) may not provide accurate rankings aside from problems with discounting. Blackorby et al. (1984) identify situations in which the present value is negative but the project is nonetheless desirable. Their general conclusion is that "there do not exist intertemporal preferences for which the sum of discounted instantaneous surpluses is an exact measure of welfare change". This is because the sum fails to account for the individual's opportunities to adapt to the effects of a compensating income change in a particular period by redistributing his consumption and investment activities so as to equate the marginal utility of income across periods. Le Chatelier effects imply that the traditional procedure will underestimate the present value of a time stream of environmental improvements and overestimate the present value of undesirable changes.

Wildasin and Harris (1985) have shown (in a non-intertemporal setting) that when redistribution is not possible between (groups of) agents that the condition for social welfare maximization is the maxi-min condition. That is, policies should be selected which maximize the welfare of the least well-off (groups of) agents. This rule was also called upon by Rawls (1971) in his theory of justice. Invoking this criterion requires expected net benefits to be equal in all generations. This allocation rule is intertemporally inconsistent with expression (9). In the absence of insurance markets for groundwater contamination events, it is not possible for future agents to gain compensation from those who were responsible for the episode. Wildasin and Harris (1985) also show that if complete redistribution is possible, then an unweighted sum of benefits should be used. In an intertemporal context this implies a zero discount rate. Thus if the policy objective is to produce the outcomes that would occur under complete insurability, the time periods should be treated equally. This becomes relevant to the groundwater contamination insurance scheme being proposed by EPA and some states.

CONCLUSIONS

Although the small number of existing studies on the value of inhibiting groundwater contamination may legitimately be viewed as precise, this does not guarantee that their value estimates are either accurate or complete. Current assessments typically ignore many dimensions of the economic consequences of groundwater contamination. In particular the existing literature fails to disentangle the collective and the private provision of protection, insurance, and remediation. It thus produces unnecessarily restrictive policy-relevant information about the relative importances of their combined and their separate influences upon valuation. Inadequate model formulations may lead to inaccurate estimates of consequences. Further, the current assessments fail to include the full set of physical consequences associated with groundwater contamination. This implies an under-valuation of contamination effects. Future research directed at refining and extending some of the model issues and formulations discussed here thus seems worthwhile. Subsequent chapters represent our efforts at such refinements and extensions.

REFERENCES

Blackorby, C., D. Donaldson, and D. Maloney, Consumer's Surplus and Welfare Change in a Simple Dynamic Economy, Rev. Econ. Stud. 51(2), 171-176, 1984.

Brown, S., A Note on Environmental Risk and the Rate of Discount, J. Environmental Econ. Mgmt. 10(2), 282-286, 1983.

Ehrlich, I., and G. Becker, Market Insurance, Self-Insurance, and Self-Protection, J. Political Econ. 80(2), 623-648, 1972.

Harris, R., and D. Wildasin, An Alternative Approach to Aggregate Surplus Analysis, J. Pub. Econ. 13(1), 133-142, 1985.

Main, R.S., Comment on "Impacts, Costs and Techniques for Mitigation of Contaminated Groundwater: A Review," Water Resources Research 21(3), 429-430, 1986.

Marshall, J., Moral Hazard, Amer. Econ. Rev. 66(4), 880-890, 1976.

Neumann, J. von, and O. Morgenstern, Theory of Games and Economic Behavior, Princeton Univ. Press, Princeton, 1947.

Perlmuter, L., and R. Monty, Choice and Perceived Control, L. Erlbaum Assoc., Hillsdale, NJ (1979).

Ramsey, F.P., A Mathematical Theory of Savings, Econ J. 38(4), 543-559, 1928.

Raucher, R.S., A Conceptual Framework for Measuring the Benefits of Groundwater Protection, Water Resources Research 28(3), 320-326, 1983.

Raucher, R.S., Regulating Pollution Sources under a Differential Groundwater Protection Strategy, Amer. J. Agric. Econ. 68(4), 1225-1239, 1986a.

Raucher, R.S., The Benefits and Costs of Policies Related to Groundwater Contamination, Land Econ. 62(1), 33-45, 1986b.

Rawls, J. A Theory of Justice, Harvard Univ. Press, Cambridge, 1971.

Schechter, M., Economic Aspects in the Investigation of Groundwater Contamination Episodes, Groundwater 31(2), 190-197, 1985a.

Schechter, M., An Anatomy of a Groundwater Contamination Episode, J. Environmental Econ. Mgmt. 12(1), 72-88, 1985b.

Sharefkin, M., M. Schechter, and A. Kneese, Impacts, Costs and Techniques for Mitigation of Contaminated Groundwater: A Review, Water Resources Research 19(11), 1771-1783, 1984.

Smith, V.K., and W. Desvousges, The Valuation of Environmental Risks and Hazardous Waste Policy, Land Economics 64(3), 328-338, 1988.

Spence, A.M. and R. Zeckhauser, The Effects of the Timing of Consumption and the Resolution of Lotteries on the Choice of Lotteries, Econometrica 40(1), 401-403, 1972.

Stallen, P., Psychological Aspects of Risks: The Assessment of Threat and Control, Technological Risk Assessment, P. Ricci, et al., eds., Martinus Nijhoff Publishers, The Hague, 1984.

Weinstein, M., and R. Quinn, Psychological considerations in Valuing Health Risk Reductions, Natural Resources J. 21(4), 659-673, 1983.

CHAPTER 2
RISK, SELF-PROTECTION, AND EX ANTE ECONOMIC VALUE

INTRODUCTION

Any person who might suffer harm from exposure to an undesirable state of nature such as groundwater contamination can reduce expected ex post costs by purchasing market insurance. Moral hazard, however, compels insurers to defray only a fraction of these costs [Arrow (1963), Shavell (1979)].[1/] Consequently, individuals use self-protection to reduce both the ex ante probability and expected costs of the uninsured event [Ehrlich and Becker (1972)].[2/] In this chapter, we consider the implications of this for models used to value risks to human health.

In particular, we find that:

1) Given moral hazard, when self-protection influences the probability, the severity, or both of an undesirable state, unobservable utility terms cannot be eliminated from the individual's ex ante valuation expression. Consequently, empirical studies that attribute differences across groups in ex ante value estimates solely to unobserved differences in household health production technologies are misplaced.

2) with moral hazard and self-protection, knowledge of the convexity or nonconvexity of physical dose-response relations is insufficient to sign unambiguously the change in an individual's ex ante marginal valuation for a reduction in the level of the hazard, even when consumer cognition is perfect. Therefore, we do not support the traditional argument that those individuals exposed to

greater risk with greater income must place a higher value on a given risk reduction.

3) with moral hazard, an increase in the level of the environmental hazard does not necessarily lead to an increase in the level of self-protection. Therefore, self-protection expenditures are not a consistent lower bound of the ex ante value a risk averse individual attaches to a reduction in risk.

These three statements imply that several propositions originally developed for cases of exogenous risk and which form the analytical basis for most recent empirical work on the value of health risk changes are not immediately transferable to settings where endogenous risks prevail.[3/]

Berger, et al. (1987) appear to be among the first to consider endogenous risks in the context of human health.[4/] Our treatment differs from their seminal effort in two significant ways. First, though they state the general continuous distribution case of risks to human health, they examine ex ante value only in a world of two mutually exclusive and independent states of nature: survival or death. We extend the ex ante value concept to the general continuous case. By maintaining continuity throughout, we allow the individual to choose between contractually defining states of nature or making an effort to alter states of nature. As noted in Chapter 1, Spence and Zeckhauser (1972) demonstrate that the ability to influence states of nature enhances both the ex ante and the ex post gains from adaptation. In particular, we assume that individuals recognize that outcomes are stochastically related to actions, implying that predictions of behavior and the relative values that motivate it depend not only on preference orderings over outcomes, but also on preference orderings of lotteries over outcomes.

Second, Berger, et al. (1987) model only probability-influencing self-protection. They disregard the severity of the health outcome being risked, even though they concede that prior self-protection can influence both probability and severity. As pointed out by Ehrlich and Becker (1972) the distinction between self-protection that influences probability and self-protection that influences severity is somewhat artificial. The distinction is often said to be made for theoretical convenience [see for example Hiebert (1983)]. In contrast, we model the effects of self-protection that influences both the probability and the severity of the undesired state, and consider the effects on the ex ante value of reduced risk.

THE MODEL

Consider an individual who is involuntarily exposed to a health risk under a particular liability regime. Assume the risk is created by exposure to an ambient concentration of an environmental hazard, r, taken from the real interval, R:

$$R = [\underline{r}, \bar{r}] \tag{2.1}$$

Because of moral hazard, the individual cannot acquire enough market insurance to avoid the risk completely. The individual must decide from a real interval, S how much self-protection, s, to undertake:

$$S = [\underline{s}, \bar{s}] \tag{2.2}$$

Given exposure to the hazard, the individual is uncertain as to which, i, of N alternative health outcomes will occur. Let

$$H = \{h_1, h_2, \ldots, h_N\} \tag{2.3}$$

denote the outcome space where outcomes are the individual's human health capital returns ordered from smallest to largest, given the individual's genetic and development history.

Let $f(h_i; s, r)$ denote the probability of outcome i occurring given that self-protection, s, is undertaken and that the exposure level to the environmental hazard is r. Assume the following about $f(\cdot)$:

Assumption 1: $f(h_i; s, r) > 0$ for every $i \in [1, \ldots, N]$ and every $s \in S$ and $r \in R$.

Let $F(h_i; s, r)$ denote the corresponding distribution function defined over the support [a, b]

$$F(h_i; s, r) = \int_a^b f(h_i; s, r)dh \tag{2.4}$$

where a and b are the minimum and maximum health outcomes.[5] We assume the following about $F(\cdot)$:

Assumption 2: $F(h_i; s, r)$ is twice continuously differentiable in $s \in S$ and $r \in R$ for every $i \in [1, \ldots, N]$.

Assumption 3: $F_s(h_i; s, r) \leq 0$ for every $s \in S$ and $r \in R$ and every $i \in [1, \ldots, N]$ in the sense of first-order stochastic dominance.[6]

Assumption 4: $F_r(h_i; s, r) \geq 0$ for every $s \in S$ and $r \in R$ and every $i \in [1, \ldots, N]$ in the sense of first-order stochastic dominance.

Assumption 5: No restrictions are placed on the convexity of the distribution function in the immediate neighborhood of an optimal level of self-protection, s^*, for all $s \in S$ and $r \in R$ and for every $i \in [1, \ldots, N]$.

The individual is risk averse with a von Neumann-Morgenstern utility index over wealth W, U(W). The following assumptions are made about U(W):

Assumption 6: U is defined over the real interval $(\bar{W}, \infty]$ where $\bar{W}$ is 0.

Assumption 7: $\lim_{W \to \bar{W}} U(W) = -\infty$.

Assumption 8: U is strictly increasing, concave, and thrice continuously differentiable.

For each health outcome the individual might realize, he selects a minimum cost combination of medical care and foregone work and consumption. Let

$$C = C(h_i;\ s,\ r) \tag{2.5}$$

be his ex ante expectation of realized costs which depend on the uncertain health outcome, self-protection, and the exposure level to the hazard. Assume the following about $C(\cdot)$:

Assumption 9: C is strictly decreasing, convex, and thrice continuously differentiable in $s \in S$ for every $i \in [1, \ldots, N]$ such that $C_s < 0$ and $C_{ss} > 0$ for all $h \in H$.

Assumption 10: C is strictly increasing and thrice continuously differentiable in $r \in R$ for every $i \in [1, \ldots, N]$ such that $C_r > 0$. No restrictions, however, are placed on C_{rr} and C_{sr} for all $h \in H$.

Given incomplete insurance purchases, intertemporally separable utility, and constant expected prices for medical care, the individual's choice problem is then

$$\underset{S}{\text{Max}}\ [\int_a^b U(W - C(h;\ s,\ r) - s)dF(h;\ s,\ r)]. \tag{2.6}$$

Note that the price of self-protection has been normalized to unity. The subscript i is suppressed to maintain notational simplicity.

Given the model, we are now able to develop the propositions stated in this chapter introduction.

EX ANTE VALUE AND WILLINGNESS-TO-PAY

Endogenous Risk. A few recent refinements to the willingness-to-pay approach to valuing environmental hazards have acknowledged the frequently endogenous form of the problem. For example, Rosen (1981), Berger, et al.

(1987), and Viscusi, et al. (1987) note that self-protection affects survival or injury probabilities, while Shibata and Winrich (1983) and Gerking and Stanley (1986) allow self-protection to influence the severity of ex post damages. In a nonstochastic world or in an uncertain world with only two feasible states, these studies demonstrate that marginal willingness-to-pay can be expressed solely in terms of the marginal rate of technical substitution between hazard concentrations and self-protection. This result cannot be generalized to a continuous world with endogenous risk.

Proposition 1: Given the model assumptions, when self-protection influences either the probability or the severity of health outcomes or both, the individual's marginal willingness-to-pay for reduced risk cannot be expressed solely in terms of the marginal rate of technical substitution between ambient hazard concentrations and self-protection. In particular, unobservable utility terms cannot be eliminated from expressions for the ex ante value of reduced risk.[7/]

Proof: To show that for a continuous distribution the individual's compensating variation statement of willingness to pay for reduced risk includes the unobservable utility terms, we examine self-protection that influences either the distribution or the severity (costs) of the health outcomes or both.

First, maximize the expected utility index (6) by selecting an optimal level of self-protection $s \varepsilon S$ yielding the following first-order condition for an interior solution

$$EU_w = -E[U_w C_s] + \int_a^b U_w C_h F_s dh. \qquad (2.7)$$

The left-hand side of (7) represents the marginal cost of increased self-protection in terms of the utility of foregone wealth. The right-hand side reflects two types of marginal self-protection benefits: the first term is the direct utility effect of enhanced wealth resulting from reduced expected ex post costs; the second term is the indirect utility effect of a stochastically dominating change in the distribution of health outcomes.

The indirect effect was derived by integrating by parts the effect of self-protection on the distribution

$$\int_a^b U(\cdot)dF_s(\cdot) = UF_s\Big|_a^b + \int_a^b U_w C_h F_s dh$$

$$= \int_a^b U_w C_h F_s dh,$$

since $F_s(a;\cdot) = F_s(b;\cdot) = 0$. Assume that improved health outcomes will decrease the ex post costs, $C_h < 0$.

Solve for the compensating variation statement of the willingness-to-pay for reduced risk by totally differentiating the expected utility index (6), and then applying the first-order condition (7). When self-protection influences both the probability and severity of health outcomes such that $F_s < 0$ and $C_s < 0$, the willingness to pay expression is:

$$\frac{dW}{dr} = -\left[\frac{\int U_w C_h F_r dh - \int U_w C_r dF}{\int U_w C_h F_s dh - \int U_w C_s dF}\right] > 0, \qquad (2.8)$$

where all integrals are evaluated over the support [a, b]. Obviously, the unobservable utility indexes cannot be removed from the individual's willingness to pay expression (8).

Even the assumption of a simple two state world fails to remove the utility terms from (8). For example, let $\pi(s, r)$ and $(1 - \pi(s, r))$ respectively represent the subjective probabilities of healthy and of sick states. Let $U_0(W - s)$ and $U_1(W - s - C(s, r))$ be the expected utility of being healthy or sick, where $U_0 > U_1$. The individual thus chooses $s \in S$ to maximize

$$EU = \pi(s, r)U_0(W - s) + (1 - \pi(s, r))U_1(W - s - C(s, r)). \qquad (2.9)$$

Following the same steps as before, the willingness to pay expression is

$$\frac{dW}{dr} = -\left[\frac{\pi_r[U_0 - U_1] - (1 - \pi)U_1'C_r}{\pi_s[U_0 - U_1] - (1 - \pi)U_0'C_s}\right] > 0, \qquad (2.10)$$

where $\pi_r < 0$, $\pi_s > 0$, $U_1' = \partial U_1/\partial W$, and $U_0' = \partial U_0/\partial W$. Again, utility terms cannot be removed.

Next allow, as do Gerking and Stanley (1986), self-protection to influence the severity, $C_s < 0$, but not the probability, $F_s = 0$, of health outcomes. Further assume that $F_r = 0$ which, with $F_s = 0$, implies that neither collective nor individual actions will influence the probability of a particular health outcome, i.e., hazard concentrations resemble sunspots or the phases of the moon. With these assumptions, expression (8) reduces to:

$$\frac{dW}{dr} = -\frac{E[U_wC_r]}{E[U_wC_s]} = -\left[\frac{EU_wEC_r - \text{cov}(U_w, C_r)}{EU_wEC_s - \text{cov}(U_w, C_s)}\right] > 0. \qquad (2.11)$$

For the unobservable utility terms to be absent from (11), the two covariance expressions must be zero; however, our model assumptions do not allow them to be zero. Therefore the two utility terms cannot be removed.

Finally, assume, as does Rosen (1981), that self-protection affects probability, $F_s < 0$, but not severity, $C_s = 0$. In Rosen's (1981) terms, one cannot be more severely dead. For similar reasons, $C_r = 0$. Under these conditions, expression (8) reduces to:

$$\frac{dW}{dr} = -\frac{\int U_wC_hF_r dh}{\int U_wC_hF_s dh}, \qquad (2.12)$$

and again the willingness-to-pay expression cannot be rid of the unobservable utility terms, which concludes the proof.[8/]

We could examine additional cases. For example, self-protection might influence only the probability of a health outcome, but hazard concentrations could affect probability and severity, or vice versa. The results would not change: utility terms would loom up in the willingness-to-pay expressions, implying that policy efforts to aggregate across individuals and to account simultaneously for the reality of probability and severity unavoidably involve interpersonal utility comparisons.

Nonconvex Dose-Response Relations. Proposition 1 poses hurdles to procedures which would establish a social risk-benefit test by summing unweighted compensating or equivalent variations across individuals.[9] Yet another problem for consistent aggregation is the ambiguous effect that a change in hazard concentrations has on the sign of compensating variation. In a contingent valuation study of the risk valuations attached to hazardous waste exposures, Smith and Desvousges (1986, 1987) report increasing marginal valuations with decreasing risk. This finding is but the latest in a 15-year long series of analytical [Starrett (1972), Winrich (1981)] and empirical [Crocker (1985), Repetto (1987)] papers which use prior information on physical dose-response relations, individual abilities to process information about these relations, or individual perceptions of the relations to produce a declining marginal valuation result for more of a desirable commodity. However, when risk is endogenous, no one has yet asked whether convexity of the marginal value of risk follows when cognition is not an issue.

An individual's compensating variation can be shown to be ambiguous in sign even if the strongest possible case for negative effects of increased hazard exposure is imposed. To illustrate, define strong convexity as follows.

Definition 1: Strong convexity of risk is defined as: convex ex post cost, $C_{rr} > 0$; convexity of the distribution function, $F_{rr} > 0$; and declining marginal productivity of self-protection, $C_{sr} > 0$, $C_{hr} > 0$, $C_{sh} > 0$ and $F_{sr} > 0$. Strong nonconvexity describes the conditions most favorable for the traditional argument that increased risk requires progressively increasing compensation to maintain a constant level of expected utility. Increased exposure increases the probability and the expected ex post costs of undesirable health outcomes to the hazard at an increasing rate; moreover, the marginal productivity of self-protection is decreasing across the board.

The opposite case is strong nonconvexity. Strong nonconvexity defines the weakest case for negative effects of increased exposure to the hazard.

Definition 2: Strong nonconvexity of risk is defined as: nonconvex ex post cost, $C_{rr} < 0$; concavity of the distribution function, $F_{rr} < 0$; and increasing marginal productivity of self-protection, $C_{sr} < 0$, $C_{hr} < 0$, $C_{sh} < 0$ and $F_{sr} < 0$.[10/]

The following proposition states the result:

Proposition 2: Even in the absence of cognitive illusions or failure to consider all scarcity dimensions of the risk-taking problem, a maintained hypothesis of strong convexity of risk is insufficient to guarantee that increased exposure to a hazard requires progressively increasing compensation to maintain a constant level of expected utility. Similarly, strong nonconvexity is insufficient to guarantee progressively decreasing compensation.

The proposition is supported by Dehez and Drèze (1984, p. 98) who show that the sign of the marginal willingness-to-pay for safety given an increase in the probability of death is generally ambiguous. Drèze (1987, p. 172) concludes that any assertions about this sign given a change in safety "...must be carefully justified in terms of underlying assumptions".

Proposition 2 contradicts the argument of Weinstein, et al. (1980) and others that individuals at greater risk must have a greater demand for safety. Consequently, contrary to Rosen (1981), individuals at greater risk with greater wealth cannot necessarily be weighted more heavily when risk reductions are valued. Similarly, the assertions by Kahneman and Tversky (1979) and Smith and Desvousges (1987) that increasing marginal willingness-to-pay for reduced risk constitutes a lapse from rational economic behavior are not supported.[11/]

Proof: To demonstrate that an increase in hazard concentration has an ambiguous effect on an individual's compensating variation, differentiate the compensating variation in expression (8) with respect to the hazard exposure:

$$\frac{d(dW/dr)}{dr} = -\frac{1}{\Omega}\Big[E[U_{ww}C_r^2 - U_wC_{rr}] - 2\int[U_{ww}C_rC_h - U_wC_{hr}]F_r dh + \int U_wC_hF_{rr}dh\Big]$$
$$+ \frac{\Delta}{\Omega^2}\Big[E[U_{ww}C_sC_r - U_wC_{sr}] + \int[U_wC_{hr} - U_{ww}C_hC_r]F_s dh + \int[U_{ww}C_sC_r - U_wC_{sr}]F_r dh + \int U_wC_hF_{sr}dh\Big], \qquad (2.13)$$

where

$$\Omega = \int U_wC_hF_s dh - \int U_wC_s dF > 0,$$

$$\Delta = \int U_wC_hF_r dh - \int U_wC_r dF < 0,$$

and all integrals are evaluated over the support [a, b].

The terms on the right-hand side of (13) can be defined in terms of direct and indirect utility effects given an increase in exposure to a hazard. $\Omega > 0$ and $\Delta < 0$ represent the combined first-order direct and indirect utility effects of s and r. The first and fourth terms in (13) represent second-order direct utility effects on expected costs with an increase in exposure. Given strong convexity, the sign of the first term is negative. The sign of the fourth term is ambiguous in the sense that alternative parameterizations are conceivable in which either $U_{ww}C_sC_r$ or U_wC_{sr} dominates in absolute magnitude. The second, fifth, and sixth terms are second-order direct and indirect utility effects weighted by the marginal effect on the distribution of either s or r. Given strong convexity, the signs of all three terms are ambiguous in the above sense. Without prior information on the magnitude of the marginal effects on the expected cost function, there is no reason to expect one term to dominate. The third and seventh terms represent the second-order indirect and cross-indirect utility effects of increased exposure. By the definition of strong convexity, the sign on both terms is negative. Without knowing the relative magnitude of all the direct and indirect utility effects, however, strong convexity is insufficient to sign (13) unambiguously. Likewise, the assumption of strong nonconvexity is also insufficient to sign (13). Whether one imposes strong convexity or strong nonconvexity the sign of (13) is ambiguous. Although sufficient conditions for increasing or decreasing marginal willingness-to-pay can be determined, there is, in the absence of prior information or simple ad hoc assumptions, no reason to expect that one or two terms will dominate expression (13). This concludes the proof.

Self-Protection Expenditures as a Lower Bound. Consideration of self-protection has not been limited to problems of ex ante valuation under uncertainty. A substantial literature has emerged, e.g., Courant and Porter (1981), and Harrington and Portney (1987), which demonstrates that under perfect certainty the marginal benefit of a reduction in a health threat is equal to the savings in self-protection expenditures necessary to maintain the initial health state. This result cannot be extended to the uncertainty case when self-protection influences both ex ante probability and ex post severity.

Proposition 3: Neither strong convexity nor strong nonconvexity of risk is sufficient to sign the effect of a risk change upon self-protection expenditures. Therefore these expenditures cannot be used to determine the welfare effect of a risk change.

Proposition 3 contradicts Berger et al.'s (1987) argument that if increased exposure increases the marginal productivity of self-protection, $F_{sr} < 0$, then self-protection will increase with exposure. Consequently, Berger, et al.'s (1987 p. 975) sufficient conditions for "plausible" results do not hold when self-protection influences both probability and severity.

Proof: To demonstrate that strong convexity is insufficient to determine the effect increased hazard exposure has on self-protection, take the first-order condition in equation (7) and apply the implicit function theorem. The effect of increased exposure on self-protection is

$$\frac{ds}{dr} = -\Big[E[U_{ww}C_r(1 + C_s) - U_wC_{rs}] + \int[U_wC_{sh} - U_{ww}C_h(1 + C_s)]F_r dh + \int[U_wC_{hr} - U_{ww}C_rC_h]F_s dh + \int U_wC_hF_{sr} dh\Big]/D \qquad (2.14)$$

where

$$D \equiv E[U_{ww}C_s(1 + C_s) - U_wC_{ss}] + 2\int[U_wC_{sh} - U_{ww}C_hC_s]F_s dh - \int U_{ww}C_hF_s dh + \int U_wC_hF_{ss} dh < 0 \qquad (2.15)$$

and all integrals are evaluated over the support [a, b]. D is the second-order sufficient condition of the maximization problem (6), and is assumed to hold whenever (7) holds.

Given D < 0, the sign of (14) depends on the sign of its right-hand-side numerator. The first term in the numerator of (14) is the direct utility effect of increased exposure on expected costs. Given strong convexity of risk and $(1 + C_s) > 0$ from the first-order condition, the sign of the first term is negative. The second term reflects the indirect utility effect of increased exposure on the distribution. Given strong convexity, its sign is ambiguous in the earlier defined parameterization sense. The third term is a direct utility effect weighted by the marginal effect of self-protection on the distribution $(F_s < 0)$, and its sign is also ambiguous. The signs for the second and third effect are ambiguous since there is no a priori reason to believe that any one set of terms dominates the others. The fourth term in the numerator is the cross-indirect utility effect of increased exposure. Given strong convexity, its sign is negative. Therefore, without prior information on the relative magnitudes of the four direct and indirect utility effects, strong convexity is insufficient to sign (14) unambiguously. Given the conditions most favorable to the traditional argument that increased risk will increase self-protection, we still require prior information on the impact that increased exposure has on the marginal productivity of self-protection to support the argument.

Following the logic above, an assumption of strong nonconvexity of risk leads to a similar conclusion of an ambiguous effect of increased exposure on self-protection. Consequently, since self-protection may decrease as exposure to a hazard increases, self-protection cannot be considered a consistent lower bound on the ex ante value a risk averse individual attaches to a reduction in risk. This concludes the proof.

CONCLUSIONS AND IMPLICATIONS

Individuals and policymakers use self-protection activities to influence both their ex ante risks and their expected ex post consequences. The implications of this for models used to value risks to human health are unequivocally negative. We show that unobservable utility terms cannot be eliminated from marginal willingness-to-pay expressions, implying that empirical efforts which identify marginal rates of substitution with willingness-to-pay are misdirected. We also show that even under the most favorable restrictions increased risk need not imply progressively increasing levels of compensation in order to restore initial utility levels. Consequently the traditional argument that those who are exposed to greater risk and have greater wealth must value a given risk reduction more highly does not follow. Finally, we demonstrate that increased risk need not imply increased self-protection expenditures; thus changes in these expenditures may not bound the value of a risk change.

Some succor for health risk valuation efforts could be obtained by stepping outside professional boundaries to draw upon prior information from psychology, biomedicine, and other disciplines. Insight might therefore be gained into the signs and the relative magnitudes of many terms in expressions (13) and (14). It is odd that the field of economics which explicitly recognizes the policy relevance of incomplete markets has historically been reluctant to use information from other disciplines in order to simulate the valuation results of a complete market. We recognize that there is a growing trend to incorporate restrictions drawn from other disciplines into the behavioral postulates of economic models.[12/] The results of this chapter suggest that the incorporation process should be accelerated.

Incorporation will not overcome, however, the aggregation problems posed by the presence of utility terms in individuals' willingness-to-pay expressions. Approaches to aggregate risk-benefit analysis do exist other than the mechanical summation of consumer surpluses calculated from the singular value judgement that social welfare and aggregate total income are synonymous. Given that individual consumer surpluses can be estimated, one possibility is to draw upon the extensive equivalence scale literature, e.g., Deaton and

Muellbauer (1986), in order to weight each individual or household. Tradeoffs can then be evaluated using an explicit social welfare function which recognizes that personal health is in part self-produced and inalienable. Alternatively, utilities might be calculated directly, or measures for settings in which individuals directly express valuations might be developed. The next chapter reports results of controlled experiments in which individuals were allowed to express directly their valuations of risky prospects. These experiments also generate information about and thus restrictions upon the signs and magnitudes of some of the terms in the complicated willingness-to-pay expressions of this chapter.

FOOTNOTES

1/ Moral hazard refers to the tendency of insurance to influence an individual's incentive to prevent loss.

2/ Self-protection includes everything from installing home water filters in order to reduce pollutant concentrations in drinking water to medical care and the use of tort law. [See Laffont (1980), Crocker (1984)]

3/ The empirical human health valuation literature typically assumes that health risks are: (i) independent of individual actions; and (ii) usually for the sake of analytical and empirical tractability, individuals require progressively increasing levels of compensation to maintain constant expected utility when confronted by increasing risk. Jones-Lee, et al. (1985), for example, embodies both conditions. We argue these assumptions are unnecessarily restrictive in the sense that they stretch the ability of economic analysis to cover the domain of risky phenomena.

4/ Psychologists agree that individuals perceive that they have substantial control over uncertain events [Perlmuter and Monty (1979)]. Stallen and Tomas (1984) conclude that "...the individual is not so much concerned with estimating uncertain parameters of a physical or material system as he is with estimating the uncertainty involved in his exposure to the threatening event and in opportunities to influence or control his exposure" [emphasis added].

5/ The [a, b] interval could also be influenced in subsequent periods by self-protection. We disregard this issue.

6/ Subscripts represent partial derivatives.

7/ Assumptions of a risk-neutral individual with an identity map of ex post costs would eliminate the unobservable utility expressions. These assumptions seem excessively restrictive.

8/ One might eliminate the utility terms by using the pointwise optimization technique that Mirrless (1974) and Holmstrom (1979) employ. However, pointwise optimization evaluates self-protection choices individually at each and every health state rather than in terms of lotteries over health states. It thus adopts an ex post rather than an ex ante perspective.

9/ See Polemarchakis, et al. (1986) for thinking on aggregation under exogenous risk.

10/ Rogerson (1985) assumes that the distribution function must generally satisfy the convexity of the distribution function condition (CDFC). Therefore, the assumption of a concave distribution in r and s is perhaps restrictive. As shown by Jewitt (1988), however, the CDFC assumption is not universally required in that it satisfies very few of the standard distributions set forth in statistics textbooks.

11/ Close inspection of the questionnaire formats upon which these assertions are based reveals that respondent opportunities to influence risk and/or severity were not fully controlled.

12/ See Warneryd (1986), Weinstein and Quinn (1983) and Smith and Johnson (1988), for example.

REFERENCES

Arrow, K. (1963). Uncertainty and the Welfare Economics of Medical Care. American Economic Review 53: 941-969.

Berger, M., Blomquist, G., Kenkel, D., and Tolley, G. (1987). Valuing Changes in Health Risk: A Comparison of Alternative Measures. Southern Economic Journal 53: 967-983.

Courant, P., and Porter, R. (1981). Averting Expenditures and the Cost of Pollution. Journal of Environmental Economics and Management 8: 321-329.

Crocker, T.D. (1984). Scientific Truths and Policy Truths in Acid Deposition Research. Economic Perspectives on Acid Deposition Control. (T.D. Crocker, ed.). Boston, MA: Butterworth Publishers.

Crocker, T.D. (1985). On the Value of the Condition of a Forest Stock. Land Economics 61: 244-254.

Deaton, A.S. and Muellbauer, J. (1986). On Measuring Child Costs: With Applications to Poor Countries. Journal of Political Economy 94: 720-744.

Dehez, P., and Drèze, J.H. (1984). State-Dependent Utility, the Demand for Insurance and the Value of Safety. Premium Calculation in Insurance. (de Vylder, Goovaerts, and Haezendonck, eds.). Boston, MA: D. Reidel Publishing Co.

Drèze, J. (1987). Essays on Economic Decision under Uncertainty. New York, NY: Cambridge University Press.

Ehrlich, I., and Becker, G. (1972). Market Insurance, Self-insurance, and Self-protection. Journal of Political Economy 80: 623-648.

Gerking, S., and Stanley, L. (1986). An Economic Analysis of Air Pollution and Health: The Case of St. Louis. Review of Economics and Statistics 68: 115-121.

Harrington, W., and Portney, P. (1987). Valuing the Benefits of Health and Safety Regulation. Journal of Urban Economics 22: 101-112.

Heibert, L. (1983). Self Insurance, Self Protection, and the Theory of the Firm. Southern Economic Journal 50: 160-168.

Holmstrom, B. (1979). Moral Hazard and Observability. Bell Journal of Economics 10: 74-91.

Jewitt, I. (1988). Justifying the First-Order Approach to Principal-Agent Problems. Econometrica 56: 1177-1190.

Jones-Lee, M.W., Hammerton, M., and Philips, P.R. (1985). The Value of Safety: Results of a National Sample Survey. The Economic Journal 95: 49-52.

Kahneman, D., and Tversky, A. (1979). Prospect Theory: An Analysis of Decision Under Risk. Econometrica 47: 263-91.

Laffont, J.J. (1980). Essays in the Economics of Uncertainty. Cambridge, MA: Harvard University Press.

Mirrlees, J. (1974). Notes on Welfare Economics, Information, and Uncertainty. Essays on Economic Behavior under Uncertainty. (Balch, McFadden, and Wu, eds.). Amsterdam: North Holland Publishing Co.

Perlmuter, L., and Monty, R. (1979). Choice and Perceived Control. Hillsdale, NJ: L. Erlbaum Assoc., Publishers.

Polemarchakis, H.M, Seldent, L., Zipkin, P., and Pohlman, L. (1986). Approximate Aggregation under Uncertainty. Journal of Economic Theory 38: 189-210.

Repetto, R. (1987). The Policy Implications of Non-convex Environmental Damages: A Smog Control Case Study. Journal of Environmental Economics and Management 14: 13-29.

Rogerson, W. (1985). The First-Order Approach to Principal-Agent Problems. Econometrica 53: 1357-1367.

Rosen, S. (1981). Valuing Health Risk. American Economic Review Papers and Proceedings 71: 241-245.

Shavell, S. (1979). On Moral Hazard and Insurance. Quarterly Journal of Economics 93: 541-562.

Shibata, H., and Winrich, J.S. (1983). Control of Pollution when the Offended Defend Themselves. Economica 50: 425-437.

Smith V.K., and Desvousges, W. (1986). Asymmetries in the Valuation of Risk and the Siting of Hazardous Waste Disposal Facilities. American Economic Review Papers and Proceedings 76: 291-294.

Smith, V.K., and Desvousges, W. (1987). An Empirical Analysis of the Economic Value of Risk Change. Journal of Political Economy 95: 89-115.

Smith V.K., and Johnson, F.R. (1988). How does Risk Perceptions Respond to Information: The Case of Radon. Review of Economics and Statistics.

Spence, A.M., and Zeckhauser, R. (1972). The Effect of the Timing of Consumption Decisions and the Resolution of Lotteries on the Choice of Lotteries. Econometrica 40: 401-3.

Stallen, P., and Tomas, A. (1984). Psychological Aspects of Risk: The Assessment of Threat and Control. Technological Risk Assessment (P. Ricci, L. Sagan, and C. Whipple, eds.) The Hague: Martinus Nijhoff Publishers.

Starett, D. (1972). Fundamental Nonconvexities in the Theory of Externalities. Journal of Economic Theory 4: 180-199.

Viscusi, W.K., Magat, W.A., and Huber, J. (1987). The Rationality of Consumer Valuations of Multiple Health Risks. The Rand Journal of Economics 18: 465-479.

Warneryd, K.E. (1986). Economic and Psychological Approaches to the Study of Economic Behavior: Similarities and Differences. New Directions in Research on Decision Making. (B. Brehmer, H. Jungerman, P. Lourens, and G. Sevon, eds.). New York: North Holland Publishing Company.

Weinstein, M. and Quinn, R. (1983). Psychological Consideration in Valuing Health Risk Reductions. Natural Resources Journal 23: 659-674.

Weinstein, M.C., Shepard, D.S., and Pliskin, J.S. (1980). The Economic Value of Changing Mortality Probabilities: A Decision-Theoretic Approach. Quarterly Journal of Economics 94: 373-396.

Winrich, J. (1982). Convexity and Corner Solutions in the Theory of Externality. Journal of Environmental Economics and Management 9: 29-41.

CHAPTER 3
RISK REDUCTION MECHANISMS AND RISK VALUATION: AN EXPERIMENTAL STUDY

INTRODUCTION

An individual confronted by financial or personal risks can use market insurance to redistribute income and associated consumption opportunities toward undesirable prospective outcomes. Given actuarially fair insurance, decreasing marginal utility of income, and complete markets, insurance would be acquired in those amounts that make the individual indifferent as to which of a set of feasible states of nature ultimately occurs [Ehrlich and Becker (1972)]. No matter what the realized state of nature the ex post compensation which the insurance supplies maintains the ex ante utility level. The questions of ex ante versus ex post valuation of risk that Helms (1985) and others have treated therefore become irrelevant.

With incomplete contingency markets, individuals cannot fully insure themselves. Ex ante measures are then appropriate measures of the value of greater safety. However, the combination of incomplete markets and the ex ante setting means that observable, everyday transactions from which to infer values are absent. Risk reduction valuation efforts have therefore sought to construct hypothetical markets via contingent valuation or controlled experiment techniques. By providing the individual the opportunity to make payments for risk reductions, these techniques enhance the efficiency with which he can allocate his wealth among states of nature [Cook and Graham (1977)].

This chapter reports the outcomes of controlled experiments to test whether risk valuation varies with the form of the payment opportunity. Despite the Spence and Zeckhauser (1972) demonstration that the individual's ability to influence states of nature enhances both the ex ante and the ex post gains from adaptation, contingent valuation risk reduction studies generally grant respondents only one type of payment opportunity. In particular, respondents are to value only a collectively - supplied and therefore exogenous change in risk against which they are unable to self-insure, e.g., Smith and Desvousges (1987). As Marshall (1976) shows, exogenous risk implies complete contingent claims markets.

Individuals can self-protect.[1/] For example, the construction worker can wear safety equipment in order to reduce his probability of injury. This same worker, by adopting a better diet, self-insures, thereby reducing the severity of or easing his recovery from an injury.[2/] Risk combines probability and severity [Ehrlich and Becker (1972)]. Changes in each may be collectively or privately supplied.

In this chapter, we extend the experiments in Shogren (1988) to report results for five distinct market forms. One market is collective and four are private-collective combinations. Two private-collective combinations provide protection, while the other two offer insurance. The null hypothesis is that individuals' willingnesses-to-pay are statistically similar across the five market forms. A finding that they are dissimilar would imply that the near-exclusive focus of contingent valuation risk reduction studies upon collective provision without self-protection or self-insurance fails to mimic many real risk reduction efforts. The studies therefore may provide biased estimates of the values of these efforts.

Given that the individual cannot participate in more than a single market at a time, Shogren (1988) found that valuations among asset markets are statistically dissimilar: the value of reduced risk depends on whether probability or severity is reduced and upon whether the reduction is collectively or privately provided. The highest valuation is generated by an asset market in which probability - influencing self-protection can be acquired; the lowest occurs in a market that collectively supplies severity - influencing insurance. However, we show here that when the individual can participate simultaneously in more than one market, valuations among pairs of markets are statistically indistinguishable. It follows that researcher decisions about the form of the market presented to participants in risk valuation exercises affect valuation estimates. In particular, reasonable conformity in these exercises to real world settings requires that self-protection and self-insurance be allowed participants.

Additional key results of this experiment can be summarized as follows: (a) expanded substitution possibilities increase the value of risk reductions, (b) self provision of safety is valued more highly than collective provision, (c) no clear evidence emerges that protection is valued more highly than insurance or vice versa, (d) learning and value formation are not particularly rapid in combined markets, (e) learning and value formation might be more rapid in private markets than in collective markets, and (f) repeated market participation reduces individuals' propensities to overestimate the impacts of low probability events.

A final important result is that the risk premium for collective risk reduction can be negative if self-protection or self-insurance opportunities are available. This implies contingent valuation experiments focusing solely on collective protection may be underestimating the total economic value of reduced risk.

ANALYTICAL FRAMEWORK

Consider an individual who is uncertain about which of two mutually exclusive and jointly exhaustive states of nature will occur. This individual, whose preferences and income are independent of these states, makes an atemporal choice in a von Neumann-Morgenstern framework where his expected utility is an increasing, strictly concave, and differentiable function of his wealth. Thus in the absence of self-protection, self-insurance, or a payment to a collective provider, an individual's expected utility, EU, is

$$EU = \pi_0 U(M - L) + (1 - \pi_0)U(M + G), \tag{3.1}$$

where E is the expectations operator; $\pi_0 (0 \leq \pi_0 \leq 1)$ is his degree of belief in a loss, L; $1 - \pi_0$ is his degree of belief in a gain, G; and $U(M + G) > U(M - L)$. Following Freeman (1985), option price, X, is that set of ex ante sure payments that holds expected utility constant when the probability of a loss changes; that is,

$$\pi U(M - L - X) + (1 - \pi)U(M + G - X) = \pi_0 U(M - L) + (1 - \pi_0)U(M + G), \tag{3.2}$$

where $\pi < \pi_0$.

Few, if any, empirical studies have asked the extent to which the magnitude of X required to achieve (3) varies with market opportunities offered participants.[3/] Lumping payments to a collective provider, self-protection, and self-insurance into X produces neither analytical nor empirical information about the relative importance of their combined and their separate influences upon valuation. In order to disentangle these influences, let the individual be one among a number of potential beneficiaries of a risk reduction program, any one of whom by increasing the size of a voluntary payment to a collective provider can enhance the probability of a personal gain, G, or reduce the severity of a personal loss, L. Similarly, the individual might improve his probability of privately commanding G or of privately reducing his L by adopting assorted self-protection or self-insurance strategies.

When opportunities for collective provision payments, self-protection, and self-insurance are simultaneously available, the left-hand-side of (2) can be rewritten as:

$$EU = \pi(s,q)U(M - L(z) - s - z - q) + [1 - \pi(s,q)]U(M + G - s - z - q), \quad (3.3)$$

where s is self-protection expenditures, z is self-insurance expenditures, and q is collective provision payments which may provide protection and reduce severity. The individual selects s, z, and q to maximize (3). Defining A = M - L - s - z - q, and B = M + G - s - z - q, the following first-order Kuhn-Tucker conditions result, given that the unit prices of self-protection and self-insurance are independent of collective provision payments:

$$EU_s = \pi_s[U(A) - U(B)] - \pi U_A - (1 - \pi)U_B \leq 0, \quad s \geq 0, \quad s(EU_s) = 0; \quad (3.4)$$

$$EU_z = -\pi U_A(1 - L_z) - (1 - \pi)U_B \leq 0, \quad z \geq 0, \quad z(EU_z) = 0; \quad (3.5)$$

$$EU_q = \pi_q[U(A) - U(B)] - \pi U_A - (1 - \pi)U_B \leq 0, \quad q \geq 0, \quad q(EU_q) = 0. \quad (3.6)$$

Subscripts denote partial derivatives. The terms $\pi_s(\cdot)$ and $\pi_q(\cdot)$ represent the expected marginal utilities of a change in the subjective probability of L. The U_A and U_B terms are the marginal costs, in terms of altered money incomes. If the expected marginal utilities or marginal benefits of the probability change equal the marginal costs of s, z, or q, then an interior solution to the individual's utility maximization problem is implied. In this case, the individual makes collective provision payments and self-protection and self-insurance expenditures as well. The relative amounts purchased of each will depend upon their relative marginal productivities in securing personal protection increases and severity reductions. Chang and Ehrlich (1985) obtain a similar result.

Consider, for example, a combination of collective protection and self-protection. If the marginal costs of a decreased money income exceed the marginal benefits of an increase in the probability of G such that

$$\pi U_A + (1 - \pi)U_B > \pi_s[U(A) - U(B)] \tag{3.7}$$

or

$$\pi U_A + (1 - \pi)U_B > \pi_q[U(A) - U(B)], \tag{3.8}$$

then a corner solution is obtained, implying that either the collective provision payment, the self-protection expenditures, or both will be zero. Alternatively, one might force (7), for example, to occur in a contingent valuation exercise by removing all opportunities to self-protect. Basically, by allowing self-protection (or self-insurance) as well as collective provision, one expands the individual's choice set, thereby improving his ability to allocate risk among states. The reduction in utility discrepancies among states, as is evident from (4) - (6), increases total utility and, consequently, increases the total value of a risk reduction [Graham (1981)]. Relatively large collective provision payments can arise only when the individual is an inefficient self-protector or self-insurer or if he is uninformed about these opportunities. More generally, the individual's ability to endogenize risk through self-protection and self-insurance implies that collective provisions of risk reductions may be redundant, thereby providing no additional welfare benefits.

EXPERIMENTAL DESIGN AND PROCEDURES

The operating conditions of the experimental markets are described below.

a) One of the 5 asset markets offered only collective protection; the remaining 4 offered combinations of collective and self-protection and insurance.

b) Each experimental market had a fixed group of subjects (n=6) who were identifiable only by their randomly assigned number.[4] Prior to the opening of any market, an asset bundle, M, was given each subject. M = \$10 was identical across subjects and across markets, as was L = \$4 and G = \$1.

c) Subjects confronted 40%, 20%, 10%, and 1% probabilities of suffering wealth losses.

d) In each market and for each loss probability, each subject made 12 bids to reduce the probability of loss to zero. Two bids were hypothetical (inexperienced and experienced) and 10 were nonhypothetical.[5/]

e) Self-protection and self-insurance nonhypothetical bids were placed in Vickery (1961) sealed bid second price auctions; collective nonhypothetical bids were made in modified Smith (1980) auctions.[6/] In the Vickery auctions, both the number of the winner and the second highest bid were posted as public information at the end of each bidding round. In the Smith auctions, the cost of reducing loss probabilities to zero was set equal to the sum of the subjects' expected consumer surpluses.[7/] This cost was never posted. Hypothetical bids correspond to the same market structures as the nonhypothetical bids.

f) The nonhypothetical collective protection market had 10 bidding rounds. The nonhypothetical combination markets had 5 rounds, with a collective bid and a private bid being made in each round. The sequence in which private and collective opportunities (self-protection or insurance) were offered differed among these markets. Before the opening of a market, subjects were informed of the sequence that would occur.

g) For the two markets in which self provision opportunities were offered initially in each round, the identity of the highest bidder and the price he paid (the second highest bid) were posted. Subjects, including the highest bidder, were then required to report a bid for collective provision. If the sum across subjects of these collective bids exceeded cost (aggregate expected consumer surplus), then the mean collective bid was posted as the reigning price of collective protection or insurance. Unanimity was required such that any one subject could veto group acceptance at this price. Collective provision was also rejected if the summed bids were less than cost. Communication was forbidden among subjects. Rejection for either reason resulted in a draw from an urn containing π red chips and $1-\pi$ white chips, where a red chip was a $4 loss for each subject and a white chip brought a $1 gain to each subject. Drawn chips were replaced at the end of each round. The market offering only collective protection operated similarly.

h) The procedures when collective and then private provision opportunities were offered were identical to (g). However, if the sum of the bids for collective provision exceeded cost, the market for self provision did not operate. When this sum failed to exceed cost and was not vetoed, the subjects competitively bid for self provision. A draw from the urn then determined the lottery outcome.

i) At the end of a round, each subject's initial asset level of $10 was restored, thereby avoiding capital gains and losses. For each market, subjects bid to reduce loss probability levels in the following order: 20%, 10%, 1%, 40%.

j) The experiment proceeded by allowing the subjects to read the instructions at least once, and then listening as the monitor read the instructions once. After all questions were answered, the experiment began.

The detailed instructions given to subjects for each market are available from the authors.

RESULTS

One hundred and fifty subjects participated in the experiment. Five experimental sessions with six subjects each were run for each of the five asset markets. Table 1 summarizes the results for all experiments. The first two columns describe the five markets and wealth loss probabilities. The table reports two measures of central tendency and one measure of dispersion for each type of bid and each loss probability.

We now state the main results of our risk reduction valuation experiments:

Expanded substitution possibilities increase the value of risk reductions. Comparisons across identical loss probabilities in Table 1 show that the sums of the nonhypothetical private and collective bids in combined markets always exceeded the bids in the market with only the nonhypothetical collective bid. This is consistent with an expansion of the choice set that enhances the individual's ability to reduce marginal utility discrepancies among states, thereby increasing the total value of a risk reduction.

The structure of combined markets influences the value of risk reductions. Table 2 displays the statistics for a Wilcoxon rank sum test applied to the private bids and the collective bids in each of the 4 combined markets.[8/]

TABLE 3.1

Summary Statistics of Bids in $

Market[a]	Loss Probability	Inexperienced Hypothetical Bid ($)			Nonhypothetical Private Bid ($)[b]			Nonhypothetical Collective Bid ($)[b]			Experienced Hypothetical Bid ($)		
		Median	Mean	Variance	Median	Mean	Variance	Median	Mean	Variance	Median	Mean	Variance
Collective protection only[c]	1%	1.00	2.79	12.37	Not Applicable			0.06	0.84	3.30	0.06	0.78	0.06
	10%	2.00	2.74	6.57	Not Applicable			0.54	0.80	0.60	0.48	0.75	0.48
	20%	3.00	2.77	3.04	Not Applicable			1.02	1.27	0.89	0.90	1.00	0.90
	40%	3.00	3.04	2.39	Not Applicable			2.02	2.13	1.46	2.00	2.09	2.00
Self-protection, then collective protection	1%	0.50	1.97	9.29	0.30	0.81	1.53	0.14	0.51	0.85	0.13	0.79	3.53
	10%	1.63	2.37	5.27	1.28	1.50	1.21	0.75	1.89	1.46	1.00	1.33	1.82
	20%	2.00	2.50	3.45	1.50	1.84	1.16	1.00	1.34	0.76	1.80	1.65	1.17
	40%	2.48	2.93	5.32	2.71	2.64	0.98	1.94	1.95	0.72	2.50	2.64	1.85
Collective protection, then self-protection	1%	0.75	2.53	12.38	0.19	0.59	0.54	0.40	1.22	4.06	0.13	1.09	2.91
	10%	1.63	2.36	5.13	1.12	1.21	1.00	1.06	1.84	3.50	0.88	1.36	2.32
	20%	2.00	2.40	2.63	1.37	1.50	0.59	1.57	1.72	1.07	1.50	1.82	2.59
	40%	2.00	2.45	2.61	1.63	1.92	1.09	1.29	1.87	2.05	1.55	1.97	3.73
Self-insurance, then collective insurance	1%	0.38	1.43	5.65	0.32	1.03	2.31	0.21	0.50	0.42	0.30	1.45	6.06
	10%	1.45	2.12	3.90	1.25	1.95	3.37	0.86	1.20	1.40	1.03	2.15	4.97
	20%	2.13	2.78	3.58	2.25	2.50	2.19	1.64	1.96	1.55	2.50	2.72	3.29
	40%	3.68	3.71	5.15	2.85	2.97	1.17	2.25	2.16	1.60	2.75	3.17	2.13
Collective insurance, then self-insurance	1%	0.25	1.64	10.49	0.12	0.23	0.08	0.13	0.32	0.26	0.10	0.61	3.37
	10%	1.00	2.03	6.37	0.75	0.87	0.53	0.57	0.84	1.08	0.75	1.00	1.52
	20%	2.00	2.40	3.66	1.70	1.83	0.53	1.65	1.08	1.28	1.75	1.91	1.97
	40%	3.00	3.26	5.13	2.19	2.08	0.87	2.04	2.07	0.99	2.63	2.61	3.13

[a] n = 30 for all experimental markets

[b] The numbers represent the nonhypothetical bids averaged over the 5 trial periods.

[c] From Shogren (1988).

NOTE: Except for the 1% loss probability in the experienced hypothetical bid version of the "collective insurance, then self insurance" market, we reject at the .01 level with a one tailed test the null hypothesis that the population mean is zero.

Table 3.2

Wilcoxon Rank Sum Tests between Average Private and Collective Bids for Combined Markets

Market	Loss Probability	Test Statistic	Observed Significance Level
Self-protection, then collective protection	1%	-2.403	.02
	10%	-3.347	.00
	20%	-3.347	.00
	40%	-3.643	.00
Collective protection, then self-protection	1%	-1.935	.05
	10%	-1.678	.09
	20%	-1.676	.09
	40%	-0.714	.48
Self-insurance, then collective insurance	1%	-3.095	.00
	10%	-2.664	.01
	20%	-2.664	.01
	40%	-2.896	.00
Collective insurance, then self-insurance	1%	-1.416	.16
	10%	-1.038	.30
	20%	-1.038	.30
	40%	-0.669	.50

For each loss probability in each combined market, statistically significant differences between private arithmetic mean bids and collective arithmetic mean bids always occurred if the private bids were the initial bids; however, if collective bids were first, significant differences between private and collective bids were infrequent. In the former case, significant differences took place 100% of the time; in the latter case, their frequency was only 12.5%. The relative lack of significant differences in the latter case results from the fact that the market for self provision did not operate if the sum of the initial bids for collective provision exceeded expected consumer surplus.

Self provision is valued more highly than collective provision. An initial offering in nonhypothetical markets of self provision always resulted in the private bid being greater than as well as significantly different from the collective bid. When collective provision was initially offered, in only one instance (protection and 20% loss probability) was the collective bid both greater than and significantly different from (.05 level) the private bid. These results again imply that valuation exercises operating solely in a collective provision context may substantially underestimate the value of risk reductions [also see Shogren (1988)].

No clear evidence emerges that protection is valued more highly than insurance or vice versa. Expressions (4) - (6) imply that the amounts of personal and collective protection and insurance that an individual purchases will depend upon their relative marginal productivities in securing personal protection increases and severity reductions. Among nonhypothetical markets where these relative marginal productivities are not preordained, this implies that valuations of risk reduction alternatives will differ nonsystematically, in accord with differences in individuals' idiosyncratic risk perceptions. The Wilcoxon matched sample sign tests reported in Table 3 show that in only 2 cases out of 16 can it be said that protection bids and insurance bids exhibited statistically significant difference, i.e., were drawn from different parental distributions.

In combined markets, learning, as represented by the number of bidding rounds, did not strongly influence value formation. In a single market, Coppinger, et al. (1980), Brookshire and Coursey (1987), and others have shown that value formation is influenced by the opportunity to learn dominant strategies. In a Vickery or a Smith auction, true preference revelation is the dominant strategy. If enhanced opportunities to learn and increases in the number of bidding rounds are synonymous, there is but weak evidence at best in our combined market experiments that learning influences value formation. Table 4 displays the Wilcoxon matched sample sign test statistics for the inexperienced and the experienced hypothetical bids. The experienced bids for each probability loss level in each combined market occurred after 5 rounds of nonhypothetical bids. In only 7 of 16 cases were there statistically significant differences between the inexperienced and the experienced hypothetical bids. In the single market experiments of Shogren (1988), 14 of 16 cases displayed a significant difference.

Learning and value formation might be more rapid in private markets than in collective markets. Consider separately the private and the collective nonhypothetical bids in the combined markets of Table 1. The final private nonhypothetical bids were significantly different from the inexperienced hypothetical bids in 8 of 16 cases; the final collective nonhypothetical bids were significantly different from the inexperienced hypothetical bids in 11 of 16 cases. However, the final private nonhypothetical bids differed significantly from the experienced hypothetical bids in only 1 of 16 cases,

Table 3.3

Wilcoxon Matched Sample Sign Tests between Protection and Insurance for Combined Markets

		Private Bid		Collective Bid	
Matched Markets	Loss Probability	Test Statistic	Observed Significance Level	Test Statistic	Observed Significance Level
Self-protection, then collective protection and self-insurance, then collective insurance	1%	0.49	.63	0.73	.46
	10%	0.33	.74	-0.15	.88
	20%	1.66	.10	1.94	.05
	40%	0.99	.32	0.63	.53
Collective protection, then self-protection and collective insurance, then self-insurance	1%	-1.43	.15	-0.82	.41
	10%	-2.61	.01	-0.92	.36
	20%	-0.04	.97	1.78	.08
	40%	1.61	.11	0.83	.41

Table 3.4

Wilcoxon Matched Sample Sign Test between Inexperienced and Experienced Hypothetical Bids

Market	Loss Probability	Test Statistic	Observed Significance Level
Self-protection, then collective protection	1%	-3.254	.00
	10%	-2.785	.01
	20%	-2.843	.00
	40%	-0.765	.44
Collective protection, then self-protection	1%	-1.900	.06
	10%	-2.642	.00
	20%	-2.453	.01
	40%	-1.320	.19
Self-insurance, then collective insurance	1%	-0.524	.60
	10%	-0.125	.90
	20%	-0.445	.66
	40%	-1.590	.11
Collective insurance, then self-insurance	1%	-2.578	.01
	10%	-2.248	.02
	20%	-1.009	.31
	40%	-1.569	.12
Collective protection only	1%	-4.076	.00
	10%	-4.444	.00
	20%	-4.360	.00
	40%	-2.550	.01

while the collective nonhypothetical bids differed from the experienced hypothetical bids in 8 of 16 cases. Learning thus appears to be greater in private than in collective markets.

Inexperienced hypothetical bids generally explain much less than half of the variations in final nonhypothetical bids. Table 5 shows the percentage variation (R^2) in final nonhypothetical bids explained by the inexperienced hypothetical bid, where the former is made a linear function of the latter and a constant. Note that R^2 is adjusted for degrees of freedom.

Individuals overestimate the impact of low probability events. Economists as well as psychologists have repeatedly found empirical evidence of violations of the independence axiom (linearity improbabilities) of expected utility theory [Machina (1982)]. Typically, individuals are found to be oversensitive to changes in the probabilities of low risk events and undersensitive to similar changes in high risk events. This implies that the premium relative to expected consumer surplus that a risk averse individual is willing to pay to change the probability of a low risk event exceeds his premium for a high risk event. Table 6 reports the ratio of the mean risk premium to expected consumer surplus for changes in each loss probability in each combined market. The ratio of risk premium to expected consumer surplus increases monotonically with declines in the status quo loss probability. For the 1% status quo loss probability the ratio for the inexperienced hypothetical bids often approaches being an order of magnitude greater than the ratio for high status quo loss probabilities. Note, however, that experience causes this discrepancy to fall, whether the bids be hypothetical or nonhypothetical.

Table 3.5

Inexperienced Hypothetical Bids as Predictors of Final Nonhypothetical Bids

Ordinary Least Squares: n = 30.

Market	Loss Probability	$\bar{R}^2$
Self-protection, then collective protection	1%	.48
	10%	.39
	20%	.42
	40%	.10
Collective protection, then self-protection	1%	.00
	10%	.25
	20%	.54
	40%	.01
Self-insurance, then collective insurance	1%	.03
	10%	.27
	20%	.32
	40%	.25
Collective insurance, then self-insurance	1%	.11
	10%	.00
	20%	.10
	40%	.09

Table 3.6

Ratio of Mean Risk Premia to Expected Consumer Surpluses*

Market	Loss Probability	Inexperienced Hypothetical Bid	Nonhypothetical Private Bid	Nonhypothetical Collective Bid	Experienced Hypothetical Bid
Self-protection, then collective protection	1%	39.40	16.20	10.20	15.80
	10%	4.74	3.00	3.78	2.66
	20%	2.50	1.84	1.34	1.65
	40%	1.47	1.32	0.98	1.32
Collective protection, then self-protection	1%	50.60	11.80	24.40	21.80
	10%	4.72	2.42	3.68	2.72
	20%	2.40	1.50	1.72	1.82
	40%	1.23	0.96	0.94	0.99
Self-insurance, then collective insurance	1%	28.60	20.60	10.00	29.00
	10%	4.24	3.90	2.40	4.30
	20%	2.78	2.50	1.96	2.72
	40%	1.86	1.49	1.08	1.59
Collective insurance, then self-insurance	1%	32.80	4.60	6.40	12.20
	10%	4.06	1.74	1.68	2.00
	20%	2.40	1.83	1.73	1.91
	40%	1.63	1.04	1.04	1.31

*The expected consumer surpluses are respectively $.05, $.5, $1, and $2 for loss probabilities of 1%, 10%, 20%, and 40%.

The risk premium for collective risk reduction can be negative if self-protection or self-insurance opportunities are available. Define the risk premium, y, as

$$y = X - ES, \qquad (3.9)$$

where X is the option price of (2) and ES is expected consumer surplus. As in Cook and Graham (1977), ES is the individual's ex ante benefit from having an entitlement to the desirable state, G. If self-protection or self-insurance is an efficient choice for the individual, then in accordance with the argument surrounding (7) and (8), option price, if defined solely in terms of collective provision, can be small or zero. From (9), it follows that y can then be zero or even negative since it is perfectly plausible that $ES > s > X$, that is, $y = -ES < 0$.

In the combined markets, we did in fact observe the highest individual bidder attaching negative risk premia to collective provision. When markets opened with private provision opportunities, the highest bidder always bid in excess of expected consumer surplus, implying $y > 0$. However, when collective provision opened the market, the highest private bidder's collective bid was greater than expected consumer surplus in only 62.5% of the cases. This implies that he attached a negative risk premium to collective provision in more than one-third of the cases where he knew that he would subsequently have an opportunity to self-protect or self-insure.

This proportion must be viewed as a lower bound given that the collective mechanism was a Smith auction with unanimity voting rules. Any participant could veto the purchase of the collective risk reduction by stating a nay vote. In nearly 91 percent of the cases, the highest private bidder used his or her veto power to cancel any collective action.[9]

SUMMARY AND CONCLUSIONS

As shown by Helms (1985) and others, individual preferences for a public safety policy should be examined in an ex ante valuation framework. Arguably, other than hedonic valuations of capital assets, the only valuation technique that captures the elements of the ex ante view is the contingent valuation method. Contingent valuation, however, is only as good as its underlying assumptions and structural incentives. One often has difficulty controlling these incentives in a field study. The desire to gain more control over structural incentives and to better understand the implications on value formation leads naturally to the use of tightly controlled experiments. This chapter has examined risk reduction mechanisms and risk valuation in a laboratory setting. Our goal was to control and isolate various aspects of risk reduction, thereby increasing our information on the behavioral implications of incentive structures. Applying the insights from lab experiments to contingent valuation prior to field implementation can help to improve this controversial nonmarket valuation technique. Alternatively, given the sensitivity found in these experiments to the manner in which the market is structured, one might give more consideration to approaches other than contingent valuation. In the next chapter, the theoretical properties of an alternative approach, hedonic prices, are considered.

FOOTNOTES

1/ Ehrlich and Becker (1972) make the point vividly. They suggest that the probability of a house being struck by lightning is exogenous to the householder, but that the risk the economist should be concerned with is the self-induced risk of the house burning if the individual places a lightning rod on its roof. Psychologists agree that individuals perceive that they have substantial control over uncertain events [Perlmuter and Monty (1979)]. Stallen and Tomas (1984) conclude that "...the individual is not so much concerned with estimating uncertain parameters of a physical or material system as he is with estimating the uncertainty involved in his exposure to the threatening event and in opportunities to influence or control his exposure" [emphasis added].

2/ Much self-protection influences both probability and severity.

3/ A few such studies consider the impact of alternative collective payment forms upon X, but none venture to consider either self-protection or self-insurance. See Weinstein, et al. (1980), Greenley, et al. (1981), Brookshire, et al. (1983), Walsh, et al. (1984), and Smith and Desvousges (1986, 1987), for example.

4/ The subjects were undergraduate university students. Bennett (1987) found student responses in these settings to be statistically no different from those of the general population.

5/ In the hypothetical auctions, statements of self-protection or self-insurance purchase intentions were not binding, real money did not change hands, and the risk reduction did not occur. An inexperienced hypothetical bid is the initial bid in an auction prior to any nonhypothetical bids. An experienced hypothetical bid is the final bid in an auction after the subject had the opportunity to participate in all nonhypothetical trials. Contingent valuation surveys typically correspond to the inexperienced hypothetical bid.

6/ The modifications were: (i) because subjects were asked to bid on opportunities to remove all risk, they were not asked to bid on the quantity of the collective good; (ii) no rebate rule was used; and (iii) after unanimous agreement, there was no stopping rule.

7/ As shown in Bishop (1982) the expected consumer's surplus, ES, for a binary lottery is the difference between maximum ex post wealth, (M + G), and the expected value of the lottery $\pi(M-L) + (1-\pi)(M+G)$ such that

$$ES = (M+G) + \pi(M-L) - (1-\pi)(M+G) = \pi(L+G).$$

For example, for the 20% risk,

$$ES = (\$10 + \$1) - .2(\$10 - \$4) - .8(\$10 + \$1) = \$1.$$

8/ See Siegel (1956) for the properties of the Wilcoxon test.

9/ The unanimity voting rule was used so the experiments with two mechanisms were consistent with the single mechanism experiments in Shogren (1988). An obvious extension is to change voting rules to, say a majority voting scheme. The highest private bidder would then have less power to dictate the collective decision with his or her vote.

REFERENCES

Bennett, J., "Strategic Behavior," J. of Public Economics 32(1987), 355-368.

Brookshire, D.S., and D. Coursey, "Measuring the Value of a Public Good: An Empirical Comparison of Elicitation Procedures," The American Economic Review 77(1987), 554-566.

Brookshire, D.S., L.S. Eubanks, and A. Randall, "Estimating Option Prices and Existence Values of Wildlife Resources," Land Economics 59(February 1983), 1-15.

Chang, Y.M., and I. Ehrlich, "Insurance, Protection from Risk, and Risk Bearing," Canadian J. of Economics 18(1985), 574-586.

Cook, P.J., and D.A. Graham, "The Demand for Insurance and Protection: The Case of Irreplaceable Commodities," The Quarterly J. of Economics 91(February 1977), 143-156.

Coppinger, V., V.L. Smith, and J. Titus, "Incentives and Behavior in English, Dutch and Sealed-Bid Auctions," Economic Inquiry 18(1980), 1-22.

Ehrlich, I., and G.S. Becker, "Market Insurance, Self-Insurance, and Self-Protection," J. of Political Economy 80(July/August 1972), 623-648.

Freeman, A.M. III, "Supply Uncertainty, Option Price, and Option Value," Land Economics 61(May 1985), 176-181.

Graham, D.A., "Cost-Benefit Analysis under Uncertainty," The American Economic Review 71(September 1981), 715-725.

Greenley, D.A., R.G. Walsh, and R.A. Young, "Option Value: Empirical Evidence from a Case Study of Recreation and Water Quality," The Quarterly J. of Economics 96(November 1981), 657-673.

Helms, L.J., "Expected Consumer Surplus and the Welfare Effects of Price Stabilization," International Economic Review 26(October 1985), 603-617.

Machina, M., "Expected Utility Analysis without the Independence Axiom," Econometrica 50(1982), 277-323.

Marshall, J., "Moral Hazard," The American Economic Review 66(December 1976), 880-890.

Perlmuter, L., and R. Monty, Choice and Perceived Control, Hillsdale, NJ: L. Erlbaum Associates (1979).

Shogren, J.F., Valuing Risk in Experimental Asset Markets: Implications on Nonmarket Valuation, Working paper, Department of Economics, Appalachian State Univ., Boone, NC (November 1988).

Shogren, J.F., Valuing Risk in Experimental Markets, A report to the USEPA for Research Contract No. CR814560-01-0, Department of Economics, Appalachian State Univ., Boone, NC (November 1988).

Siegal, S., Nonparametric Statistics for the Behavioral Sciences, New York, NY: McGraw-Hill Book Co. (1956).

Smith, V.K., and W. Desvousges, "An Empirical Analysis of the Economic Value of Risk Changes," J. of Political Economy 95(February 1987), 89-114.

Smith, V.K., and W. Desvousges, "Asymmetries in the Valuation of Risk and the Siting of Hazardous Waste Disposal Facilities," The American Economic Review: Papers and Proceedings 76(May 1986), 292-294.

Smith, V.L., "Experiments with a Decentralized Mechanism for Public Good Decisions," The American Economic Review 70(1980), 584-590.

Spence, A.M., and R. Zeckhauser, "The Effect of the Timing of Consumption Decisions and the Resolution of Lotteries on the Choice of Lotteries," Econometrica 40(March 1972), 401-403.

Stallen, P., and A. Tomas, "Psychological Aspects of Risk: The Assessment of Threat and Control," in P. Ricci, et al., eds., Technological Risk Assessment, The Hague, Netherlands: Martinus Nijhoff Publishers (1984), 123-142.

Vickery, W., "Counterspeculation, Auctions and Competitive Sealed Tenders," J. of Finance 16(1961), 8-37.

Walsh, R.G., J.B. Loomis, and R.A. Gillman, "Valuing Option, Existence, and Bequest Demands for Wilderness," Land Economics 60(February 1984), 14-29.

Weinstein, M.C., D.S. Shepard, and J.W. Plisken, "The Economic Value of Changing Mortality Probabilities: A Decision-Theoretic Approach," The Quarterly J. of Economics 94(March 1980), 373-396.

CHAPTER 4
USING HEDONIC METHODS TO VALUE RISK CHANGES

INTRODUCTION

Previous chapters present an analytical basis for evaluating individual's ex ante, endogenous responses to groundwater contamination risks and the results of a series of experiments designed to test several propositions developed from the analytical basis. The framework and the experiments highlight the importance of an ex ante perspective and the availability of adjustment possibilities. However, experiments are an impractical device for policymakers to use in their everyday efforts to deal with groundwater contamination. In the following chapters, we suggest a more practical means, establish its analytical connection with our fundamental ex ante valuation framework and present two examples of devices by which the means might be empirically implemented.

THE HEDONIC METHOD

Starting with Ridker and Henning (1967) and Anderson and Crocker (1971), the hedonic method has been used many times to assess the relationship between willingness-to-pay, residential property values, and environmental changes. Properties with different lot sizes could be viewed as different commodities, one commodity for each lot size. A separate demand function would then be estimated for each property. This would mean, however, that most individuals would consume zero units of each commodity. Rosen (1974) suggested alternatively that houses be viewed as a single commodity, each unit of which is differentiated by the amounts of various attributes that it embodies. This is the fundamental insight of the hedonic method.

The hedonic property value method presumes the existence of a household opportunity locus that relates property sale prices to site-specific property attributes. The locus results from consumer and landlord interactions, implying that in principle it contains information on the underlying preferences and technologies if only ways can be found to extract that information. Consumers try to make the lowest possible bid for a site, thus maximizing their utility. Landlords try to get the highest possible offer, thus maximizing their rents. The market reconciles these conflicting objectives through an equilibrium matching of consumers to landlords such that no consumer can increase his utility by making a different choice and no landlord can increase his rents. Graphically, this is represented by Rosen's (1974) widely-known diagram where the bid and offer functions "kiss" each other to form the opportunity locus. The derivative of this locus with respect to any attribute of interest represents a price function which can be used to calculate the implicit market price for the attribute. Given the fulfillment of a number of still much-debated conditions, these implicit market prices can then be used to construct a surrogate demand price-quantity schedule, the integral of which can be shown to represent the willingness-to-pay for the attribute in question.

More formally, the hedonic method says that the household opportunity locus is given by

$$z = z(x), \tag{4.1}$$

where z is the annualized market price of a property, and x is a vector of its site-specific structural, neighborhood, and environmental attributes. The marginal or hedonic price, p, of an additional unit of an attribute i, i = 1,...,n, is then

$$p_i = \frac{\partial z}{\partial x_i}. \tag{4.2}$$

The individual householder tries to maximize a concave, at least twice-differentiable utility function U(q, x), where q is a numeraire commodity subject to a budget constraint

$$y = q + z(x). \tag{4.3}$$

y is the individual's income. The first-order necessary conditions are then

$$\frac{U_x}{U_z} = p. \tag{4.4}$$

where subscripts represent partial derivatives.

Substitution of (4) into (3) gives

$$V(y, x) = U(y - z(x), x) \tag{4.5}$$

Upon applying the implicit function theorem and holding utility constant, the willingness-to-pay, w, for given attribute quantities is

$$V(y - w, x) = \bar{V}, \tag{4.6}$$

since

$$w = w(y, x, \bar{V}), \tag{4.7}$$

where $\bar{V}$ is the fixed utility level. Marginal willingness-to-pay is then simply w_x. As Rosen (1974, p. 39) shows, w_x is equal to p at the optimal choice of x. Thus estimation and partial differentiation of (1) with respect to any x_i of interest will provide an estimate of the marginal willingness-to-pay for that x_i. More complete treatments of the analytical foundations of the hedonic price method can be found in Rosen (1974) and Palmquist (1984).

EX ANTE VALUATION OF RISK AND HEDONIC METHODS

Suppose that the risk (probability and severity) of an adverse event varies across space and that individuals know about these variations. Muth (1969), among others, shows that competition for housing locations assures an inverse relation between housing prices, z, and the undesirable risky event, x_i, that is, $\partial z/\partial x_i < 0$. Let j denote the location of a house and, for simplicity, assume that risk, x_i, is the only attribute that differs across space. Presume a two-state world such that the event occurs with probability π and does not occur with probability $(1-\pi)$. Given his income, y, and the severity of the risky event, x_{ij}, the individual must choose that location which maximizes his expected utility:

$$\max_{x} E(U) = \pi V[y - z(x_{ij}), x_{ij}] + (1 - \pi)V[y - z(x_{ij}), 0]. \tag{4.8}$$

His necessary condition is

$$\frac{-\partial z}{\partial x_{ij}} = \frac{\pi(\partial V/\partial x_{ij})}{(1 - \pi)(\partial V/\partial y) + \pi(\partial V/\partial y)} \tag{4.9}$$

In a state-dependent setting, the $\partial V/\partial y$ in the denominator may differ, i.e., the marginal utility of money may vary across states of the world.

The left-hand-side of (9) is the negative of the slope of the hedonic price function; the right-hand-side is the ex ante value of a reduction in x_i. Expression (9) thus requires that the marginal hedonic price of housing locations be set equal to the marginal value of risk reductions. Thus, given that the housing market clears, the slope of the hedonic price function, $\partial z/\partial x_{ij}$, or marginal hedonic price, is the ex ante marginal value of risk reductions.

USING HEDONIC METHODS TO MEASURE EX ANTE RISK VALUATIONS

The result in (9) is widely known; however, an inspection of the literature soon reveals that a variety of interpretations about what constitutes marginal hedonic prices can be found. For example, time-to-sale as well as sale price is in principle a component of hedonic price. Palmquist (1980) and Nelson (1982) conclude that time-to-sale is not affected significantly by environmental factors. Bartik (1988) provides a thorough treatment of the valuation implications of the alternatives. The remainder of this chapter draws extensively upon his results.

One strand of the literature, e.g., Lind (1973) and Starrett (1981), looks at the ex post relation between an environmental change and property values. Clearly, this ex post approach does not allow changes which have yet to occur to be evaluated since realized environmental changes will have caused z(x) to shift. That is, expected environmental changes will alter the marginal rates of substitution among attributes. Moreover, the informational demands of the ex post approach are heavy since both the ex ante and the ex post hedonic price functions must be known.

A second literature strand, e.g., Freeman (1974) and Polinsky and Shavell (1976), examines the benefits of an environmental change in an area that is open to migration and is small relative to the market. Given zero moving costs, the change cannot affect consumer utility. All benefits of the change will then accrue to landlords in the area that experiences the change. The z(x) prior to the change can be used to evaluate its benefits because the function will not shift after a change that affects only a small area i.e., the small environmental change will not cause the marginal rates of substitution among attributes to be altered. The prices of properties experiencing the risk reduction will rise to the price levels of properties now having similar risks, but the hedonic price function will be invariant. Consumers originally in houses where the risk reduction occurred will move elsewhere to similar unimproved houses with their original rents. Similarly, the improved sites will now be occupied by consumers who had lived in similar houses previously. Net effects of the risk reduction on consumers will thus be zero. Therefore, the original z(x) can be used to provide ex ante evaluations of the benefits of the environmental change.

Yet another literature strand considers the benefits of small environmental changes that take place over a large area. Small (1975) and Pines and Weiss (1976) show that the benefits of a small environmental change are then the sum of the marginal hedonic prices of the consumers who originally chose those locations where the change subsequently occurred. Though z(x) will shift, it results only in pecuniary effects. Consumer and producer adjustments can be dismissed because these individuals are, by definition, already at an optimum. That is, the envelope theorem applies [Silberberg (1978)]. In this case, ex ante benefit evaluation is feasible using no more than the original z(x).

In sum, the literature concludes that the original z(x) can be used for assessing the ex ante benefits of the change when: (1) the area in which the change occurs is relatively small; or (2) when the change itself is relatively small. In short, given either of these conditions, one can simply estimate the manner in which property values originally varied with respect to any x_i and use this estimate to predict accurately the economic benefits of a change in that x_i.

Unfortunately, many prospective groundwater contamination problems do not meet either of these two conditions. In an ex post context, these problems often do affect relatively small areas or pose only small additional risks to life and property. However, as we have previously argued, an ex ante context is appropriate for most groundwater contamination issues. This context implies that relatively large areas can suffer from the <u>prospect</u> of being contaminated by a suspected source. Similarly, though the true probability of a single site being affected by a newly suspected source may be small, individuals often exaggerate the chances of low probability events [Kahneman and Tversky (1979)]. These perceptions influence individual's choices and thus determine their economic valuations of alternative adaptation opportunities. Finally, given that groundwater contamination occurs, the consequences for life (injury, disease, or death) and property (explosion and destruction) are frequently severe. Arguably therefore, the ex ante valuation of groundwater contamination requires consideration of a distinctly nonmarginal perspective. This would be unfortunate since estimates of $\partial z/\partial x_i$ are easy to obtain. Alternatively, given that neither of the two conditions necessary for (9) to hold exactly are often found, one might ask the degree of error likely to be introduced by applying (9) to nonmarginal changes. These nonmarginal changes arise because of the ability of consumers to influence their risks of exposure to a contaminant and because landlords' supply decisions can be affected by these exposure risks. The ability of consumers and landlords to adjust or adapt to contamination risks increases the benefits of a risk reduction simply because the reduction provides opportunities for utility or pecuniary gains that were previously unavailable.

TAKING ACCOUNT OF ALL FACTORS THAT AFFECT BENEFITS IS DIFFICULT

Expressions (3)-(9) refer only to the housing consumer. Householders consume housing; they also produce it. In their guise as landlords, households own sites and choose to supply numbers of housing units, m, and vectors of housing characteristics, x. Householders - landlords are constrained by the hedonic price function z(x) as well as a cost function C(x, m). A householder who is also a landlord obtains a capital gain from a risk reduction. The capital gain is an increase in the implicit rent that he pays himself. The landlord's rent maximization problem is

$$\max_{x,m} \alpha = mz(x) - C(x, m). \tag{4.10}$$

The first-order conditions are

$$\frac{\partial z}{\partial x} = \left(\frac{\partial C}{\partial x}\right)/m, \tag{4.11}$$

and

$$z = \frac{\partial C}{\partial m}. \tag{4.12}$$

Expression (11) says that the vector of characteristics that landlords supply equates marginal characteristic prices and their costs; expression (12) equates the marginal price of units and their costs.

The equilibrium hedonic price function matches demand and supply for each housing type. This equilibrium price function may thus shift due to any factor shifting demand and supply, such as changes in the environment, costs, income, or migration.

The effects of these shifts are extremely complex. Consider first the consumer and the benefits to him of a reduction in groundwater contamination risks. This risk reduction increases the supply of sites with relatively low risks, thus reducing the hedonic price differential between relatively high and low risk locations. Moreover, the rent accruing to high risk locations would decline since the supply of desirable (low risk) locations has increased. Rent is simply the return to an activity at a site after all factor payments and opportunity costs have been covered.

The increased supply of low risk sites will reduce relative prices of these sites, thus causing consumers to substitute toward these sites. It follows that the reduction in each household's chosen risk level will cause any given risk level to attract more lower income households.

In addition, the increase in supply of low risk sites will reduce the demand for site attributes that are substitutes for the risk attribute and increase demand for sites that are complements to the risk attribute. Thus, for example, the demand for sites along major transportation arteries (a complement) would increase and that for sites near public fire protection or water supply facilities (a substitute) would fall. The overall effect on the demand for low risk sites depends on the joint influences of these substitution and complementarily effects plus the income changes of the households who choose to locate at these sites.

Landlords also are affected by increases in the numbers of low risk sites and the consequent shifts in the pattern of site demands and rents. For a given risk level, the quantity of housing units and non-risk housing attributes supplied will fall in response to the rent decline. However, for those sites where there has been a substantial reduction in risk, higher prices and higher demands for many non-risk housing attributes will generally induce greater production of housing units and increases in the levels of better quality attributes. An exception would occur when a better quality was a substitute for a high risk of groundwater contamination.

In sum, the economic benefits caused by a reduction in the risk of suffering health or property damage from groundwater contamination are the sum of the willingnesses-to-pay less rents of all consumers and landlords for the changes that take place. Any housing consumer or landlord at sites where the change occurs will be directly affected. Moreover, shifts in z(x) that are induced by the risk change will indirectly affect the surpluses and rents of those who were not and will not be at sites experiencing the risk change. For example, consumers may experience lower risks at their original sites, they may confront a new housing supply, their rents may change, or the hedonic function with which they must deal may shift for any number of reasons. Similarly, landlord costs may be affected, their rents may change, and landlords too must cope with shifts in the hedonic price function. In general, the sum of consumer and landlord willingnesses-to-pay less rents is virtually impossible to calculate. It requires exact knowledge of how the equilibrium z(x) is affected by the risk change and how this affects the choices of consumers and landlords. Except under the most stringent assumptions, this "general equilibrium" problem is not readily solved analytically. Simulation methods could be employed, but their results are rarely generalizable beyond their immediate loci.

CONSUMER WILLINGNESS-TO-PAY IS AN UNDERESTIMATE OF TRUE BENEFITS

Given the difficulties of empirically implementing the general equilibrium, correct version of hedonic pricing, it is worthwhile to consider the value measurement implications of simpler versions. One such version is consumers' willingnesses-to-pay for a reduction in risk at their initial sites. If, as in Bartik (1988), one adopts the heuristic device of breaking down the effects of the risk reduction into three stages, it is easy to show that this measure must underestimate true benefits.

Assume in Stage 1 that no one can move or otherwise adjust and that rents do not change. Given this assumption, only consumers and landlords at the sites where risks have been reduced will be affected. Consumer benefits are simply their willingnesses-to-pay for the risk reduction at their original sites. Landlords will be affected only if the risk reduction directly affects their costs.

Let the hedonic price function, z(x) shift in Stage 2, but do not allow either consumers or landlords to adjust. Rents will thus change, implying a redistribution but not an increase in magnitude of consumer and landlord benefits. Benefits cannot increase because consumers and landlords are now in disequilibrium.

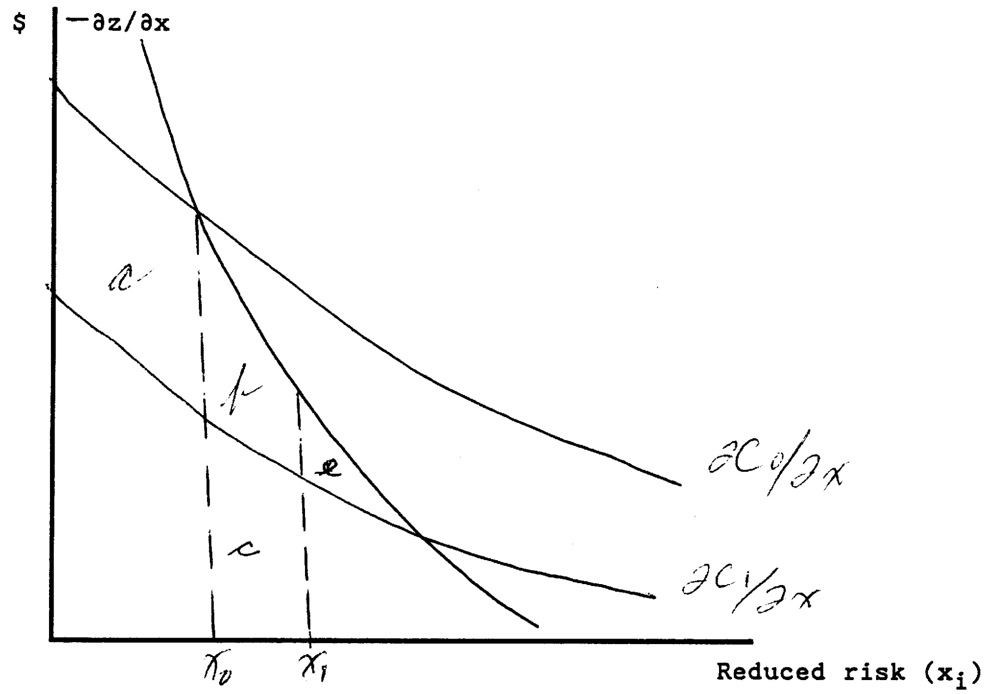
In Stage 3, allow consumers and landlords to adjust. The Le Chatelier principle [Silberberg (1978)] implies that this relaxation of constraints expands consumers' and landlords' choice sets and must therefore leave them at least as well off as they were prior to the expansion. Because the hedonic price function shifts, these adjustments need not be limited to individuals originally located at sites where groundwater contamination risks have changed.

This three-stage breakdown demonstrates that measures focused solely upon the willingnesses-to-pay of individuals originally located at sites where risks have declined will underestimate benefits. True benefits include this willingness-to-pay plus the cost-savings of landlords (Stage 1), the profit gains that landlord adjustments generate (Stage 3), and the utility gains that consumer adjustments provide (Stage 3). If and only if the risk decline induces no landlord cost-savings or consumer and landlord adjustments will a willingness-to-pay measure focused solely upon original residents of the improved sites provide an accurate measure of economic benefits. The measure can nevertheless be viewed as a lower bound for risk reductions.

When the problem in question involves a risk increase rather than a decrease, the meaning of the willingness-to-pay measure is ambiguous. If the risk increase neither raises landlord costs nor induces landlord adjustments,

Figure 4.1

The Willingness-to-Pay Measure



then the measure will be an upper bound. Only consumers will then matter, and the measure will neglect consumer opportunities to soften the impact of the risk increase by substituting away from locations and activities involving it.

The immediately preceding analysis is easily presented diagrammatically. In Figure 4.1, the consumer's inverse demand function for the risk reduction is $-\partial z/\partial x_i$. The risk reduction causes a shift in landlords' marginal rent schedule from $\partial C_0/\partial x$ to $\partial C_1/\partial x$, and the consumer enjoys a risk reduction as well as a reduction in his rents. Assume that the risk level declines from x_0 to x_1. If the consumer is unable to move, then his welfare gain is _a_ plus _b_. Area _a_ represents a gain to him because of the reduced rent on the original risk level and area _b_ is a gain because of the availability of reduced risk at prices below the consumer's marginal willingness-to-pay. On the other hand, area _a_ is lost to the landlord because his rent receipts are reduced but the reduced risk allows him to gain area _c_. The landlord's loss of area _a_ cancels the consumer's gain of area _a_. The net gain to the landlord and the consumer when the latter makes no adjustments is therefore area _a_ plus area _b_. However, if the consumer does make adjustments, then his gain is _a_ + _b_ + _e_. The change in the landlord's welfare remains _c_ - _a_, so the net gain to both parties is then _b_ + _c_ + _e_.

CONSUMER WILLINGNESS-TO-PAY MEASURES ARE DIFFICULT TO ESTIMATE

In addition to being an underestimate of true economic benefits, anyone who wishes to use any consumer willingness-to-pay measure, whether or not it allows or disallows adjustments, must face substantial estimation problems. These problems arise from the difficulty of distinguishing between the demand function and the supply function for housing attributes. Brown and Rosen (1982) and Diamond and Smith (1985) have shown that attribute demands and supplies cannot be identified in the absence of an exogenous source of variation in marginal hedonic prices that is independent of these demands and supplies. The exogenous source shifts the market-clearing hedonic price function causing, as previously noted, the marginal rates of substitution among attributes to change. Because of locational fixity, transactions costs, repackaging difficulties, and the durability of residential housing, the equilibria of housing markets are thought to differ across space and time. Two kinds of rather ad hoc empirical solutions are commonly proposed for this identification problem.

First, following Mendelsohn (1985) or Quigley (1986), one might achieve identification in a unified (single) market by employing an instrumental variable procedure or by making the hedonic price function and the demand and supply functions have different forms. Bartik (1987) shows, however, that unobserved household tastes will make structural demand and supply estimates based on these approaches inconsistent.

Data drawn from multiple housing markets is the second proposed empirical solution to the identification problem. However, Ohsfeldt and Smith (1985) show that, even when the standard rank and order conditions are satisfied and there are no measurement errors or omitted variables in the system, identification requires "large" variations in the exogenous component of marginal hedonic prices. Epple (1987) demonstrates that identification of hedonic system parameters in the presence of omitted variables and errors-in-variables requires "relatively strong" orthogonality conditions among variables and random components. Atkinson and Crocker (1987) show that these orthogonality conditions are very unlikely to be fulfilled and that the failure to fulfill them gives rise to abundant biases from omitted variable and measurement error problems. In general, one might reasonably conclude that though the consumer willingness-to-pay approach has analytical appeal, its empirical implementation is seriously fraught with difficulties.

Finally, in spite of frequent literature references to multiple housing markets, it is not at all evident what constitutes a unified market nor whether a unified market exists for some attributes but not for others. Thus, given the analytical incompleteness and the empirical difficulties in the consumer willingness-to-pay version of hedonic pricing, it becomes worthwhile to consider alternative approaches. The primary alternative is the use of the original hedonic price function to predict the benefits of a risk reduction.

AN ORIGINAL HEDONIC PRICE FUNCTION WILL OVERESTIMATE THE ECONOMIC BENEFITS OF A RISK REDUCTION

The property value increase due to a risk reduction can be projected from the original (ex ante) hedonic price function, i.e., the hedonic price function existing prior to the risk reduction. This projection represents an overestimate of the economic benefits of the risk reduction. It usually does not represent the actual property value changes that will occur since a nonmarginal risk reduction will shift the hedonic price function.

In order to demonstrate the overestimate, again consider, decomposing the economic effects of the risk reduction, as in Bartik (1988). During Stage 1, the hedonic price function does not shift, implying that consumers and landlords at unaffected sites endure no economic consequences. Nothing changes at these sites. However, at the sites where risk has been reduced, rents increase because there is upward (reduced risk) movement along an invariant hedonic function. Given that their costs do not increase with risk reductions, landlords are better off because their rents have increased. Consumers, however, are worse off because a risk reduction has been imposed upon them but they still confront the same hedonic function. They are unable to equate their marginal willingness-to-pay to the marginal hedonic price, i.e., they cannot fulfill expression (9).

In Stage 2, the hedonic function still does not shift but landlords are allowed to adjust their housing supply. This adjustment must increase landlord rents; otherwise it would not occur. Consumers in the improved area are reassigned to housing units within that area, but because the hedonic function remains unchanged, the reassignment cannot generate consumer benefits. Otherwise the consumers would voluntarily reassign themselves.

In Stage 3, landlords and consumers respectively produce the housing supplies and are assigned to the sites they will choose after the hedonic price function has shifted. However, because this function has not shifted, landlord rents must be less than in Stage 2, and consumer utility must be less than in Stage 1.

When Stage 4 occurs, rents at each site change to reflect the shifted hedonic price function. However, these rent changes simply represent a pecuniary transfer from consumers to landlords or vice versa. No economic benefits are generated.

The net economic benefits from the 4 steps are the first and second stage increases in landlord rents, less landlord losses in rents from the disequilibrium in Stage 3, and less consumer utility losses from the disequilibria in Stages 1 through 3. It follows that the increases in landlord rents in Stages 1 and 2 represent an upper bound to the economic benefits that the risk reduction generates.

The Stage 2 landlord supply adjustments and their effects on rents are complex to estimate because landlord opportunity sets must be taken into account. However, the economic benefits from these adjustments are likely to be quite small. First, many housing characteristics can be altered only with difficulty, i.e., at substantial cost. Second, market competition will cause the hedonic price function to reflect housing cost differentials, thus greatly reducing or, in the perfectly competitive case, even eliminating any rent gains [Topel and Rosen (1988)]. Lower cost sites will attract housing suppliers. As supply increases, rents will be driven down until rent differences across sites are eliminated. Moreover, in a perfectly competitive setting, returns in excess of costs (rents) will be dissipated because, by definition, rents are a return over and above the opportunity costs of the assets devoted to the housing supply activity. For these two reasons, it is highly likely that the second stage rent increase will be smaller in absolute value than the disequilibrium landlord losses in Stage 3 and the disequilibrium consumer utility losses in Stages 1 through 3. If the second stage rent increase is smaller in this sense, then the first stage rent increase will be an upper bound to the economic benefits of the risk reduction.

An identical 4-stage decomposition can be used to show that the true economic benefits of a risk reduction are bounded from below by the property value increases that the ex post hedonic price function predicts.

IMPLICATIONS OF MOVING COSTS FOR THE BOUNDS

Moving costs (financial, search, and psychological) do not affect the earlier conclusion that consumer willingness-to-pay is a lower bound to the true economic benefits of a risk reduction. In the earlier 3-stage willingness-to-pay decomposition, neither consumers nor landlords incur moving costs until Stage 3, where they are allowed to adjust optimally to the risk reduction. These adjustments can only add to benefits; otherwise they would not occur. Moving costs simply mean that adjustments are less likely to take place. Thus Stage 3 benefits are still weakly positive in Stage 3. A focus solely upon Stage 1 then implies that the willingness-to-pay benefits occurring during this stage will continue to be a lower bound.

Moving costs do reduce the likelihood that the property value increases projected from the ex ante hedonic price function will constitute an upper bound to true economic benefits. Again, moving costs reduce the gain that consumers can obtain by adjusting. The loss that they suffer by not being able to adjust during Stage 1 of the ex ante hedonic price function analysis will thus be reduced. If the presence of moving costs prior to risk reduction caused their marginal willingness-to-pay for a risk reduction to exceed the marginal hedonic price, then the reduction will result in a gain to consumers. This gain obviously increases the economic benefits taking place during Stage 1. However, it is bounded by the magnitude of moving costs, because if the initial disequilibrium had been greater than moving costs, the consumer would already have moved. Thus, especially given the high mobility of U.S. households, moving costs seem unlikely to cause the property value measure to be significantly less than the true upper bound of economic benefits.

CONCLUSION

The usual hedonic measure of the value of a risk reduction, the willingness-to-pay of consumers initially at sites where the reduction occurs is an underestimate of true economic benefits. Its measurement also requires application of complex econometric techniques. A much more easily estimable measure, the property value increases predicted by the ex ante hedonic price function, will be a close approximation to the upper bound of benefits. Though this measure will not be an upper bound if landlords can readily adjust their housing supply, they are very unlikely to be able to do so in the near or intermediate term. A lower bound to true economic benefits can be obtained by estimating and then projecting from the ex post hedonic price function.

REFERENCES

Anderson, R.J., Jr., and T.D. Crocker, "Air Pollution and Residential Property Values," Urban Studies 8(1971), 171-180.

Atkinson, S.E., and T.D. Crocker, "A Bayesian Approach to Assessing the Robustness of Hedonic Property Value Studies," J. of Applied Econometrics 2(1987), 27-45.

Bartik, T.J., "Estimating Hedonic Demand Parameters with Single Market Data: The Problems Caused by Unobserved Tastes," The Review of Economics and Statistics 69(Feb. 1987), 178-180.

Bartik, T.J., "Measuring the Benefits of Amenity Improvements in Hedonic Price Models," Land Economics 64 (May 1988), 172-183.

Brown, J.N., and H. Rosen, "On the Estimation of Structural Hedonic Price Models," Econometrica 50(May 1982), 765-768.

Diamond, D.B., and B.A. Smith, "Simultaneity in the Market for Housing Characteristics," J. of Urban Economics 17(May 1985), 280-292.

Epple, D., "Hedonic Prices and Implicit Markets: Estimating Demand and Supply Functions for Differentiated Products," J. of Political Economy 95(Feb. 1987), 59-80.

Freeman, A.M., "On Estimating Air Pollution Control Benefits from Land Value Studies, " J. of Environmental Economics and Management 1(1974), 74-83.

Kahneman, D., and A. Tversky, "Prospect Theory: An Analysis of Decision under Risk," Econometrica 47(1979), 263-291.

Lind, R.C., "Spatial Equilibrium, the Theory of Rents, and the Measurement of Benefits from Public Programs," The Quarterly J. of Economics 87(1973), 188-207.

Mendelsohn, R., "Identifying Structural Equations with Single Market Data," The Review of Economics and Statistics 67(August 1985), 525-529.

Muth, R.F., Cities and Housing, Chicago, IL: The Univ. of Chicago Press (1969).

Nelson, J.P., "Highway Noise and Property Values," J. of Transport Economics and Policy, 16(1982), 117-138.

Ohsfeldt, R.J., and B.A. Smith, "Estimating the Demand for Heterogeneous Goods," The Review of Economics and Statistics 67(1985), 165-171.

Palmquist, R.B., "Alternative Techniques for Developing Real Estate Price Indexes," The Review of Economics and Statistics 52(1980), 442-448.

Palmquist, R.B., "Estimating the Demand for the Characteristics of Housing," The Review of Economics and Statistics 66(1984), 394-404.

Polinsky, A.M., and S. Shavell, "Amenities and Property Values in a Model of an Urban Area," J. of Public Economics 5(1976), 119-129.

Quigley, J., "The Evaluation of Complex Urban Policies: Simulating the Willingness-to-Pay for Subsidy Programs," Regional Science and Urban Economics 16(1986), 31-42.

Ridker, R.G., and J.A. Henning, "The Determinants of Residential Property Values with Special Reference to Air Pollution," The Review of Economics and Statistics 49(May 1967), 246-257.

Rosen, S., "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition," J. of Political Economy 82(1974), 34-55.

Silberberg, C., The Structure of Economics, New York, NY: McGraw-Hill Book Company (1978).

Starrett, D., "Land Value Capitalization in Local Public Finance," J. of Political Economy 89(1981), 306-327.

Topel, R., and S. Rosen, "Housing Investment in the United States," J. of Political Economy 96(August 1988), 718-740.

CHAPTER 5
THE EXCHANGEABILITY OF HEDONIC PROPERTY PRICE STUDIES

INTRODUCTION

Two empirical themes dominate the hedonic property price literature. The first focuses upon the variation of housing expenditures with respect to structural and neighborhood attributes; the other portrays the attribute supply and demand functions that determine these expenditures. The object of studies with the first theme is to construct indices of spatial and temporal variations in housing costs [Gillingham (1983), Topel and Rosen (1988)]; studies with the second theme try to obtain consumer or producer valuations of individual housing attributes [Harrison and Rubinfeld (1978); Palmquist (1984)].

Observations drawn from multiple markets are essential to each theme. A unified market for housing implies that a weighted average of the coefficients in a hedonic price regression will be the same for all households. Therefore a price index cannot be defined since, by construction, all households confront identical market circumstances, i.e., the same hedonic price function.

If, instead, interest focuses upon the valuation theme, Brown and Rosen (1982) and Diamond and Smith (1985) have shown that attribute demands and supplies cannot be identified in the absence of an exogenous source of variation in marginal hedonic prices that is independent of these demands and supplies. The exogenous source shifts the market-clearing hedonic price function, causing the marginal rates of substitution among attributes to change. Because of locational fixity, transactions costs, repackaging difficulties, and the durability of residential housing, the short-run equilibrium of housing markets is thought to differ across space and time. Data drawn from multiple housing markets is therefore commonly proposed as an empirical solution to the identification problem.[1/] However, Ohsfeldt and Smith (1985) show that, even when the standard rank and order conditions are satisfied and there are no measurement errors or omitted variables in the system, identification requires "large" variations in the exogenous component of marginal hedonic prices.[2/]

In spite of frequent literature references to multiple housing markets, it is not immediately evident what constitutes a unified market nor whether a unified market exists for some attributes but not for others. In this chapter, we employ Bayesian methods to test the null hypothesis of unified markets for housing and for housing attributes. We assess the transferability of entire hedonic price functions from one site and time to another, the transferability of hedonic prices for particular attributes, and the degrees of similarity that hedonic prices must have in order to be transferable.[3/]

We exploit the Bayesian concept of exchangeability [Lindley and Smith (1972)]. Assuming that coefficients of previous hedonic studies were generated randomly as if selected from a fixed normal urn, we use them to form a prior mean vector. These prior means and a sample-based prior covariance matrix are then combined with sample data from Chicago, Illinois, to compute posterior means. This procedure shrinks our ordinary least squares (OLS) estimates for Chicago toward the common prior mean. If the resulting posterior means out perform the OLS coefficients based on the Chicago data, previous studies are judged highly consistent with our Chicago data and the market unity that hedonic prices from different places and times exhibit is strong. Otherwise, market unity is weak.

We gather prior means from other hedonic property value studies and form a prior variance-covariance matrix using Zellner's (1983) g-prior methodology.

We then compute two measures of the performance of our estimated posterior means relative to those obtained via OLS. Both involve obtaining the extreme bounds on estimated posterior means as the weight we attach to our prior mean weakens.

To calculate the first measure, we randomly divide our sample in half and combine the first half of this data with our priors to compute posterior means. We then forecast property values for the second half using these posterior means. The corresponding root-mean-square error (RMSE) loss function is computed as a function of different scalar weights on the precision of our prior means. These RMSEs are then compared to those obtained from OLS coefficients. The second measure is computed using a version of Leamer's (1978) "extreme bounds analysis" (EBA). This calculates the extreme values of our estimated coefficients again as a function of different scalar weights on the precision of our prior means.

Weak or nonexistent exchangeability is the key to successful use of pooled data to estimate hedonic price indices or to identify household demand and seller supply functions. We find that hedonic price functions are statistically indistinguishable with small sample sizes but that their exchangeability vanishes with even moderately sized data sets. However, hedonic price estimates for structural housing attributes such as floor space are fairly exchangeable while neighborhood attributes such as pollution exhibit little exchangeability.

The rest of the chapter is organized as follows. In the next section, we provide brief, heuristic treatments of the concept of exchangeability and the Bayesian estimator that we shall employ. A third section supplies an overview of our prior information and our data, as well as our results. The chapter is summarized and conclusions are drawn in the last section.

EXCHANGEABILITY AND THE ESTIMATORS

Exchangeability. Exchangeability presumes the existence of a grand model which generates random samples in a number of distinct groups: the individual groups are *a priori* thought to possess characteristics sufficiently similar that a common structure applies to each.[4/] Thus if there are h(h = 1, 2, ..., k) property attributes for j(j = 1, 2, ... n) properties in i(i = 1, 2, ..., m) cities or locales, the hedonic multiple regression model for the ith locale is written as:

$$y_{ij} = \underline{\beta}_i \underline{X}_{ij} + \varepsilon_{ij} = \sum_{h=0}^{k} \beta_{hi} X_{hig} + \varepsilon_{ij}, \qquad (5.1)$$

with $\varepsilon_{ij} \sim N(0, \sigma_i^2 I)$ independently of all other ε's. $\underline{\beta}_i$ is the usual vector of property attribute coefficients in the ith locale corresponding to the attributes $\underline{X}_{ij}$, where X_0 is a vector of ones, and σ_i^2 is the residual variance for the ith locale. We assume that the $\underline{\beta}_i$ are random variables with a distribution across locales that is multivariate normal with mean vector $\underline{\mu}$ and variance-covariance matrix $\underline{H}^{-1}$. That is, the $\underline{\beta}$ are generated as if selected randomly from a fixed normal urn.

Exchangeability requires that there exist no prior knowledge which relates more to one $\underline{\beta}_i$ or $\underline{\sigma}_i$ than to any other, so that one's prior knowledge of the sets of $\underline{\beta}$'s and $\underline{\sigma}$'s is exchangeable or unaltered by permutations of the i subscripts. In effect, the $\underline{\beta}_i$ and the $\underline{\sigma}_i$ are treated as independent random variables. The prior distributions are selected so as to be conjugate to the likelihood arising from (1) and are expressed in terms of the hyperparameters

$\underline{\mu}$, $\underline{H}^{-1}$, ν(degrees of freedom), and σ^2.

The Lindley and Smith (1972) formulation produces a weighted average of the data from other samples and data from the locale of concern, where the weights are determined by the precisions of the pooled versus the individual sample estimates. Thus rather than simply assuming that markets across locales either are or are not similar, one can evaluate the extent to which they are similar. Complete exchangeability implies that the identical hedonic price function applies to all locales and times.

Nearly all applications of the exchangeability concept have been in the context of the empirical Bayes technique, where the data from one sample are pooled using a Bayesian estimator with other samples presumably sharing a common structure.[5/] Exchangeability is thus treated as a maintained hypothesis [Casella (1985)], and the question of interest is typically the extent to which the empirical Bayes technique minimizes a loss function relative to classical least squares. In this chapter, we treat exchangeability as a null hypothesis and assess it using only the $\underline{\beta}_i$ from other hedonic property price studies, without their sample data which is either unavailable or costly to obtain. We perform sensitivity analyses allowing us to ascertain the informativeness which priors must possess in order to restrict posterior estimates of hedonic prices to specific bounds and to make ambiguities in posteriors less than would occur with diffuse priors or OLS. Although some arbitrariness is necessarily involved in any set of prior means, the set we adopt represents the median for each hedonic price coefficient of a broad selection of previous estimates. To arrive at the family of inferences which more diffuse and more informative versions of the aforementioned priors create, we obtain RMSE forecasts based on Zellner's (1983) g-prior technique and compute coefficient extreme bounds with

Leamer's (1982) bounded variance priors technique. We use the former to evaluate the contribution made by the priors to accurate predictions of property price levels and the latter to evaluate the sensitivity of individual parameters as we weaken the precision of these purportedly informative priors. Each technique frees the investigator from the often onerous burden of specifying a unique prior variance-covariance matrix.

The g-prior distribution. Consider again the normal general linear model in (1). Application of Bayesian methods to this model is difficult because the applied researcher typically has vague priors regarding the elements of a multivariate prior variance-covariance matrix. Zellner (1983) suggests that this difficulty can be overcome by forming a prior probability density function in which the prior σ is diffuse, and by constructing a positive definite symmetric prior precision matrix $A = gX'X$, where $g = \lambda^{-1}$, is any non-negative constant scalar selected by the researcher.

Bounded variance priors. Leamer (1978) shows that by assuming the normal conjugate prior for $\underline{\beta}$ in (1) with (Kx1) prior mean vector $\bar{\underline{\beta}}$, and (KxK) prior covariance matrix, $V = A^{-1}$, the (Kx1) vector of posterior means for $\underline{\beta}$ can be written, via Bayes' Theorem, as

$$\hat{\underline{\beta}} = E(\underline{\beta} \mid \underline{y}, A, W)^{-1}(A\bar{\underline{\beta}} + W\underline{b}) \tag{5.2}$$

where b is the (Kx1) vector of estimated sample means with (KxK) sample precision matrix, $W = \sigma^{-2}(X'X)$. In (2), the researcher inputs prior means for "doubtful" variables. Variables whose inclusion is not doubted are "free". The prior means for these free variables are computed by OLS subject to prior restrictions on the doubtful variables.

However, Chamberlain and Leamer (1976) and Leamer (1982) argue that a Bayesian analysis based on any particular prior distribution might be of little interest because such distributions are difficult to measure without error or due to differences in readers' prior judgments. In order to examine the range of plausible priors and to determine those features of a prior having a major influence on a posterior, they take the prior mean as given and develop the correspondence between transforms of the prior precision and the posterior mean. Leamer (1982) has shown how restrictions on V imply restrictions on the feasible set of posterior means. The V matrix is allowed to assume any value in the interval $\lambda^{-\infty}V_L \leq V \leq \lambda^{\infty}V_U$, where V_L and V_U are respectively lower and upper bounds, λ is a scalar greater than unity on the prior variances, and where $V - V_L$ and $V_U - V$ are positive semidefinite. Since $\lambda(X'X)^{-1}$ is the prior variance-covariance matrix, prior covariances need not be zero, nor are the prior standard errors necessarily equal.

APPLICATIONS

The data. Our data set embodies information on more than 297 structural and neighborhood attributes for 1,283 federal FHA-insured detached, single family residential properties in Chicago, from 1964 through 1967. These properties comprise nearly half of such properties sold in the city during the 4-year period. In spite of the peculiar features of FHA-insured financing, the sale prices of the homes in our sample are comparable to the assessed values and owner-reported values of homes in the immediate neighborhoods.[6] All three measures had 1965 mean values of about $16,000, with standard deviations between $3,000 and $3,700. Sale prices of the FHA-insured sample homes range up to $60,000. Strictly cash transactions are excluded.

Investigator energies, if not computer limitations, require that parameters be economized in any empirical exercise. In a survey of 15 published hedonic property price studies, Atkinson and Crocker (1987) found that regression coefficients for approximately 110 distinct covariates were reported. Even though our data set contains some measure of nearly all of these covariates, the construction of a composite model would make us and, we presume, most readers uncomfortable. We instead confine our attention to a parsimonious vector of 11 covariates which have very frequently appeared in the published literature, are important contributors in dollar terms to property price, and are representative of a range of property structure and neighborhood attributes. A semi-log specification of a reduced form hedonic price equation with these elements as the only relevant explanatory variables is taken to be our earlier mentioned grand model. Table 5.1 displays the definitions, sources, sample and prior means, standard deviations, and places and times of sales price and the 11 covariates. At least for the Chicago data set, additional covariates add very little explanatory power and, as shown in Atkinson and Crocker (1987), substantially increase the likelihood of confounded interpretations arising from measurement error problems.

Prior means. Table 5.1 presents our prior means, assuming that a semi-log form is appropriate for the hedonic price expression. With three exceptions, each mean, after having accounted for differences among studies in units of measurement, is the median coefficient of the vector, $\underline{\beta}$, of coefficients for each covariate in the aforementioned 15 hedonic studies. Since there is little agreement in this literature about what might constitute informative prior means for Air Pollution, Time of Sale, and Property Taxes, the prior means for these three covariates are set equal to their respective posterior means calculated in a preliminary estimate in which diffuse priors were assumed for all coefficients.

We first randomly divide in half our full sample of 1,283 observations. The first half, or 641 observations, is used for estimation; these estimates are then used to forecast the sales prices in the second half. In order to examine the effect of increased sample size, we randomly sampled 80, 160, and 320 observations from the first half of the split. Given the selected set of prior means, we then estimated for each first half sample the posterior densities using $\lambda(X'X)^{-1}$ as our prior variance-covariance matrix, thereby avoiding the difficult task of specifying a reasonable covariance matrix on a high-dimensional space. This was done for a range of λ-values, the weights assigned to the prior precision matrix. We then used the posterior means obtained for each first half sample to forecast the property sale prices for the second set of 642 observations. Comparisons based on RMSE over the forecast sample for a range of λ-priors relative to the RMSE found using only diffuse priors (equivalent to OLS) provides a measure of the degree of exchangeability between models developed in other locales and years and in Chicago during the 1964-67 period.[7/] The λ-value which minimizes RMSE for the informative priors maximizes exchangeability. Finally, a comparison across sample sizes of RMSE when presumably informative priors and when diffuse priors are used indicates the effects on exchangeability of increased sample size.

Figure 5.1 depicts the RMSE results obtained from applying the above procedure to 80 observations. The horizontal line represents the RMSE obtained with a diffuse prior for all covariates; the curved line shows the behavior of RMSE when the previously described supposedly informative priors are employed with different λ-values. The λ-value for sample size 80 which minimizes RMSE and therefore maximizes exchangeability is 0.75. RMSE is reduced by about 15 percent relative to OLS. For the 80 observation sample, the use of prior information reduces RMSE over a quite wide range of λ-priors. Thus for this sample size, we conclude that substantial exchangeability is present between hedonic property price studies done in other locales and at other times and our Chicago, IL data set.

However, when sample size is increased to 160 and to 320, and the same g-values as in Figure 5.1 are applied, an incorporation of the same prior mean information always increases RMSE relative to OLS. Thus for 160 observations or more, exchangeability is absent. We shall not attempt to mimic Ohsfeldt and Smith (1985) in order to assess whether or not this absence implies price variability sufficient to identify attribute supply and demand parameters. Nevertheless, this finding makes it likely that prior information drawn from other hedonic studies can substitute for some fair portion of the several thousand pooled sample observations that Ohsfeldt and Smith (1985) conclude identification requires.

We now apply Leamer's (1982) bounded variance prior diagnostic technique to evaluate how informative priors on individual attributes must be in order to judge that prior information and sample information on each attribute come from similar markets. Even though no two producers or users of hedonic property price studies are likely to have identical priors, they are likely to agree that most of their priors are not diffuse. Accordingly, except for Air Pollution, Time of Sale, Property Taxes, and the constant we view all covariates as doubtful in the sense that we doubt that the prior means in Table 5.1 are exact. The prior variance for each of the three free variables is set at zero, since in specifying a variable as free, we implicitly assume that the posterior variance of its coefficient is completely described by the sample data. The prior mean for the constant is calculated by minimizing, subject to the prior restrictions, the sum of the squared errors. However, as with the earlier application of the g-prior technique, we also allow the <u>prior</u> precision of the doubtful variables to be described solely by the sample data. For all covariates, the prior locations are taken to be the prior means of Table 5.1, but the prior variances are allowed to lie in an interval $\lambda^{-2}V_L \leq V \leq \lambda^2 V_U$. By varying λ over a substantial range, one can entertain a wide variety of prior opinions about the contribution of particular property attributes to selling price. The greater the variety of opinions to be accommodated, the less the transferability of the results of previous studies to the locale and the time of interest.

In Table 5.2, the column on the extreme left shows the initial Bayesian estimates with 320 observations, where the prior means are again those listed in Table 5.1. The estimates are "initial" because $\lambda = 1$ means that the initially inputted prior variance matrix is employed, implying that the probability of the parameter values of the prior being consistent with the sample data is maximized. As one proceeds rightward in the table, the range of the examined prior variance matrix becomes progressively larger. For example, if $\lambda = 2$, the range of prior standard errors can be twice as large or half as small as that in V. At $\lambda = \infty$, this range becomes unbounded. The extreme bounds, U and L, represent the upper and the lower bounds of all posterior mean estimates.

In general, Table 5.2 shows that unless there is a broad consensus that the prior covariance matrix is very nearly exact as initially inputted, the ranges of the estimates for all covariates except Living Area, Time of Sale, and Property Taxes typically include the origin. Zero is much closer to the midpoint of the bounds of the neighborhood attributes such as Percent Black and

Air Pollution than it is for structural attributes of the residence. A similar pattern emerges with sample sizes of 80 and 160, though increasing the sample size to 320 does cause considerable compressions in bounds. Generally, but especially for neighborhood attributes, minor perceived differences across locales and times in the influence of attributes upon residential property values lead to large differences in posterior estimates. This implies that rather small differences in the hedonic prices of a neighborhood attribute signal a distinctive residential property market for that attribute.

The contribution to a narrowing of the bounds of a doubling of sampling size is consistently greater than the contribution which results from compressing the prior variance matrices. For example, if $\lambda = 4$, an increase from 80 to 160 observations reduces the bounded interval for the coefficient of Age from 17.57×10^{-3} to 11.65×10^{-3}, a reduction of 34.95 percent. However, if λ is set equal to 2 rather than 4 for 80 observations, such that the precision of one's prior information is increased by a factor of 4, the bounded interval for the coefficient of Age declines by only 14.17 percent. The bounded intervals for other covariates behave similarly. We therefore conclude that, when sample size is rather small, a doubling in the number of observations from the sample locale and time will contribute substantially more to the precision of posterior estimates than will a 4-fold increase in the precision of one's prior information drawn from the existing hedonic property value literature. Again, if $\lambda = 4$, an increase from 160 to 320 observations decreases the bounded interval for the coefficient of Age from .01143 to .0083, a reduction of 27.4 percent in interval width. However, if λ is set equal to 2 rather than 4 for 160 observations, the bounded interval for the coefficient of Age declines by only 18.6 percent. Thus not only does prior information drawn from other times and places contribute little in absolute terms as a supplement to sample information; it contributes only modestly relative to additional sample information.

The findings reported in Table 5.3 reinforce the above results. This table shows the minimum prior variance intervals, stated in terms of joint values of the scalars, λ^{-2} and λ^{2}, which will cause the corresponding intervals for the posterior means to pass through the origin. For all covariates, the intervals get broader, sometimes much broader, as sample size increases, implying that a wider range of prior opinions about coefficients can be accommodated without causing coefficient sign switches. However, the bounds for the neighborhood covariates which are often the focus of research interest remain quite narrow. Consequently, seemingly minor differences in prior opinions about the influences of these covariates upon sales prices can lead to major discrepancies in estimated posteriors. Given the obvious sensitivity of posteriors to the choice of prior variance-covariance matrices, nearly anyone can find a matrix which is close to that employed here but which reproduces <u>his</u> prior mean as a posterior estimate. It follows that the variance of neighborhood attribute hedonic price estimates across place and time must be very small in order to conclude that they are exchangeable. Pooling data from different places and times will provide substantial neighborhood attribute hedonic price variation but is much less likely to generate additional variation in the hedonic prices for structural residence attributes.

SUMMARY AND CONCLUSIONS

A lack of exchangeability is the key to successful use of pooled data to estimate demands for neighborhood and structural residence housing attributes. Based on our EBA analysis and a RMSE loss function, we conclude that, except for our smallest sample size, data and results from other locales and times are not readily exchanged with the locale and time of our Chicago data. Our data speaks much more clearly about the form of the hedonic price function in the Chicago housing market of the mid-1960's than does a highly representative set of priors drawn from the existing hedonic property price literature. We suspect that this low degree of exchangeability among hedonic prices for different locales and times is near-universal, especially for neighborhood attributes.

Hedonic theory predicts that hedonic price estimates for neighborhood attributes will be less exchangeable than for structural residence attributes. If cost functions are similar across housing suppliers, Rosen's (1974) seminal article demonstrated that the hedonic price function will be identical to this common cost function. Therefore, if the cost function is similar across suppliers in different times and locales, the hedonic price estimates on structural residence attributes will be similar across cities and times, given the same production technologies.

The situation is quite different for neighborhood attributes. Profit-maximizing suppliers do not produce these attributes. Therefore the market-clearing hedonic price function in a specific locale depends on what set of prices is required to match the available stock of neighborhood attributes in the locale to local household demand for these attributes. The supply of and possibly the demand for neighborhood attributes is idiosyncratic across locales and times. Hence, one cannot generally expect estimates of hedonic prices for neighborhood attributes such as groundwater contamination to be exchangeable.[8] In short, extrapolation of ex ante hedonic pricing results for groundwater contamination from one setting to another will generally introduce substantial errors. Because the hedonic price function for a neighborhood attribute such as groundwater contamination differs significantly across settings, each setting requires that a separate hedonic price function be estimated.

FIGURE 5.1
VALUES OF ROOT MEAN SQUARE ERROR FOR PREDICTED
DEPENDENT VARIABLE

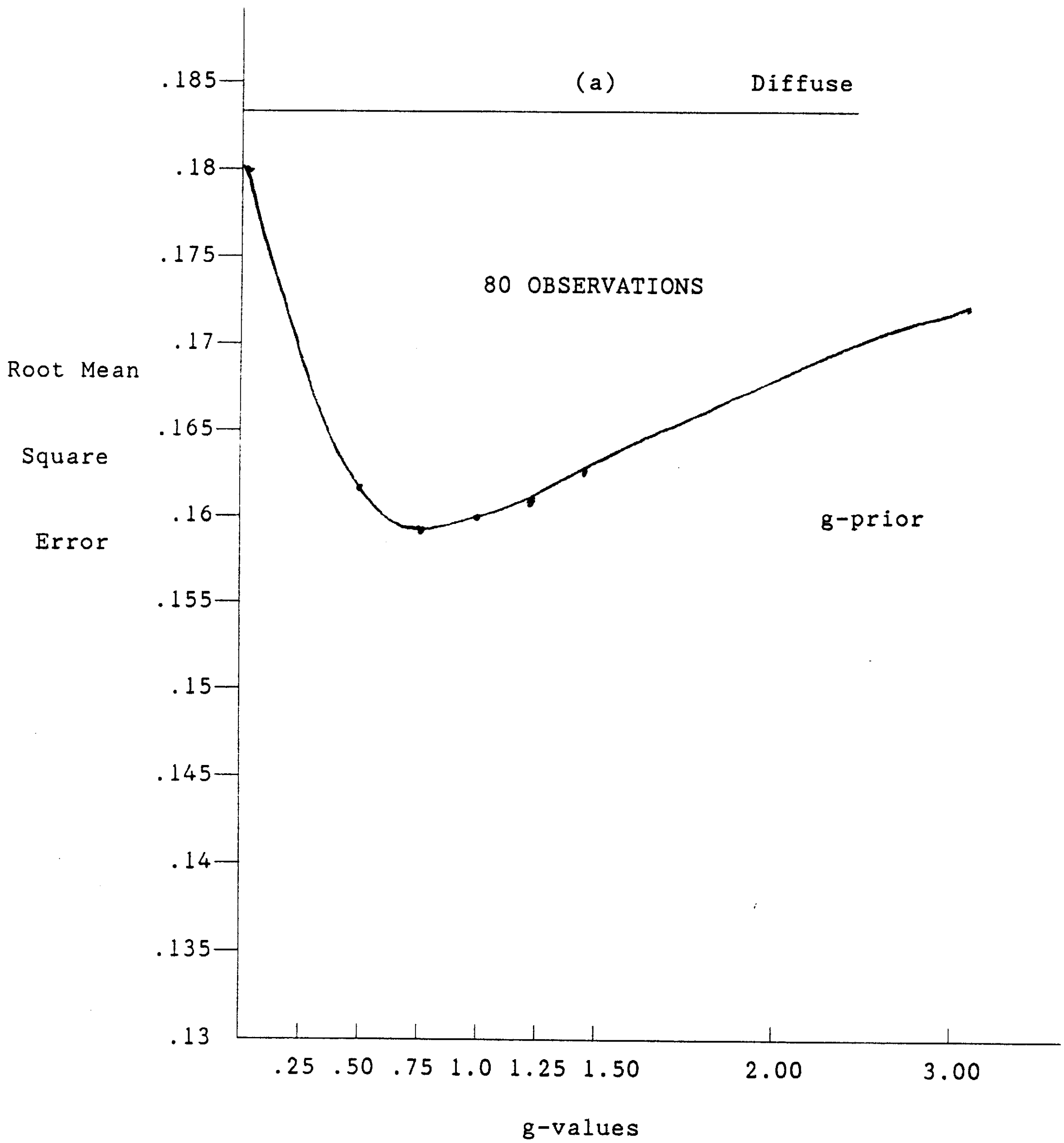


TABLE 5.1

VARIABLE DEFINITIONS, SOURCES, AND SUMMARY STATISTICS

Covariate	Definition and Source	Sample Mean	Sample Standard Deviation	Prior Mean	Source of Prior	Locale of Prior	Year(s) of Prior
Dependent							
Price	Mortgage amount plus mortgagor's actual cash outlay. Source: FHA.	16227.60	3619.52				
Exogenous							
Age	Age in years of major living unit. Source: FHA. Represents current safety and capacity of structural features.	30.99	17.74	-2.50×10^{-3}	Schnare and Struyk (1976)	Boston	1971
Lot Size	Square feet in lot. Source: FHA. Represents potential and existing outdoor amenities such as plantings.	4297.99	2347.62	3.00×10^{-6}	Schnare and Struyk (1976)	Boston	1971
Living Area	"The total square foot area of a house appropriately improved for the intended use and in compliance with the minimum property standards for new homes and with generally accepted criteria for existing homes." Source: FHA.	1215.62	308.72	3.00×10^{-4}	Johnson and Lea (1982)	Buffalo	1978
Crime	The mean 1962-65 community area male delinquency rate as a percentage of the rate for the Chicago metropolitan area. Source: Shaw and McKay (1969). The criteria used to define a community area are set forth in De Vise (1967). Represents market participants' perceptions of dangers to person and property.	0.80	0.44	-5.40×10^{-2}	Harrison and Rubinfeld (1978)	Boston	1970
Distance	Distance in tenths of miles to the intersection of State and Madison Streets in Loop area of downtown Chicago. Source: contemporary city maps. Represents access to employment shopping, and entertainment opportunities.	100.04	22.00	-2.18×10^{-3}	Butler (1982)	St. Louis	1967
Median Income	Median 1960 income of the census tract in which the residence was located. Source: U.S. Bureau of the Census (1962), Table P-1. Represents exclusivity and social status.	7548.95	1119.94	2.80×10^{-5}	Jud and Watts (1981)	Charlotte	1977

TABLE 5.1 Continued

VARIABLE DEFINITIONS, SOURCES, AND SUMMARY STATISTICS

Covariate	Definition and Source	Sample Mean	Sample Standard Deviation	Prior Mean	Source of Prior	Locale of Prior	Year(s) of Prior
Percent Black	Percentage black of April 1966 population in the community area. Source: De Vise (1967). Represents supply of housing for blacks and demand of blacks for housing.	0.13	0.28	-2.70×10^{-2}	Brookshire, et al. (1982)	Los Angeles	1977-78
School Quality	Arithmetic sum (0-10) by school district of mean 1963 reading and arithmetic achievement tests in public elementary schools. Source: Havighurst (1964, p. 39). Represents capital and labor inputs of public schools.	6.68	0.05	5.60×10^{-2}	Butler (1982)	St. Louis	1967
Air Pollution	Annual arithmetic mean monthly total suspended participation in $\mu g/m^3$ for the 48-month period from Jan. 1964 to Jan. 1968. Source: Chicago Air Pollution Control District records. Extrapolated from nearest 3 monitoring stations.	130.15	11.24	Diffuse [a)]	Sample	Chicago	1964-67
Time of Sale	Month of sale: January 1964 = 1,..., Dec. 1967 = 48. Represents time shifts in supply of and demand for detached, single family housing.	26.37	13.52	Diffuse [a)]	Sample	Chicago	1964-67
Property Taxes	Annual property taxes in tens of dollars and any continuing nonrepayable special assessments. Source: FHA. In 1966, Chicago's median nominal property tax rate (annual tax billed as a percentage of taxable assessed value) was 5.43 percent according to the U.S. Bureau of the Census (1968). The median assessment ratio (gross assessed value as a percentage of market value) was 35.80 percent. Represents assessment practices.	26.05	8.08	Diffuse [a)]	Sample	Chicago	1964-67

a) The prior means is computed via restricted least squares by minimizing the sum of squared errors subject to the prior means for all other coefficients imposed as restrictions.

TABLE 5.2
BOUNDED VARIANCE PRIOR ESTIMATES WITH 320 OBSERVATIONS

$$\lambda^{-2}V_L \leq V \leq \lambda^2 V_U$$

Covariate	λ = 1	2	4	∞
Age				
U	-2.8×10^{-3}	0.78×10^{-3}	1.34×10^{-3}	1.54×10^{-3}
L	-2.8×10^{-3}	-6.28×10^{-3}	-6.96×10^{-3}	-7.24×10^{-3}
Lot Size				
U	1.18×10^{-5}	2.63×10^{-5}	2.90×10^{-5}	3.00×10^{-5}
L	1.18×10^{-5}	0.68×10^{-5}	-1.04×10^{-5}	-1.18×10^{-5}
Living Area				
U	1.95×10^{-4}	3.76×10^{-4}	4.08×10^{-4}	4.20×10^{-4}
L	1.95×10^{-4}	0.64×10^{-4}	0.36×10^{-4}	0.24×10^{-4}
Crime				
U	-3.13×10^{-3}	1.06×10^{-1}	1.24×10^{-1}	1.30×10^{-1}
L	-3.13×10^{-3}	-1.33×10^{-1}	-1.90×10^{-1}	-2.22×10^{-1}
Distance				
U	-6.55×10^{-4}	1.37×10^{-3}	1.65×10^{-3}	1.74×10^{-3}
L	-6.55×10^{-4}	-3.46×10^{-3}	-4.38×10^{-3}	-4.86×10^{-3}
Median Income				
U	2.38×10^{-5}	6.65×10^{-5}	7.38×10^{-5}	7.64×10^{-5}
L	2.38×10^{-5}	-1.86×10^{-5}	-3.59×10^{-5}	-4.54×10^{-5}
Percent Black				
U	0.72×10^{-1}	2.18×10^{-1}	2.39×10^{-1}	2.46×10^{-1}
L	0.72×10^{-1}	-1.24×10^{-1}	-1.73×10^{-1}	-1.95×10^{-1}
School Quality				
U	0.43×10^{-1}	1.08×10^{-1}	1.27×10^{-1}	1.35×10^{-1}
L	0.43×10^{-1}	$-.20\times10^{-1}$	-0.67×10^{-1}	-0.89×10^{-1}
Air Pollution				
U	-1.60×10^{-3}	0.20×10^{-3}	2.50×10^{-3}	6.04×10^{-3}
L	-1.60×10^{-3}	-3.53×10^{-3}	-3.90×10^{-3}	-4.05×10^{-3}
Time of Sale				
U	2.33×10^{-3}	3.30×10^{-3}	3.50×10^{-3}	3.59×10^{-3}
L	2.33×10^{-3}	1.48×10^{-3}	1.34×10^{-3}	1.29×10^{-3}
Property Taxes				
U	1.39×10^{-2}	1.93×10^{-2}	2.05×10^{-2}	2.11×10^{-2}
L	1.39×10^{-2}	0.85×10^{-2}	0.77×10^{-2}	0.75×10^{-2}
Constant	8.85	8.85	8.85	8.85

U = Upper extreme bound; L = Lower extreme bound

TABLE 5.3

SMALLEST JOINT VALUES OF λ^{-2} AND λ^{2} LEADING TO COEFFICIENT SIGN SWITCHES

Covariate	80 Observations	160 Observations	320 Observations
Age			
λ^2	2.00	2.00	2.00
λ^{-2}	0.50	0.50	0.50
Lot Size			
λ^2	1.00	1.00	1.00
λ^{-2}	0.25	0.25	0.25
Living Area			
λ^2	4.00	4.00	∞
λ^{-2}	0.50	0.50	∞
Crime			
λ^2	1.00	1.00	1.00
λ^{-2}	0.50	0.50	0.50
Distance			
λ^2	1.00	1.00	1.00
λ^{-2}	0.50	0.25	0.25
Median Income			
λ^2	1.00	1.00	1.00
λ^{-2}	0.50	0.25	0.25
Percent Black			
λ^2	0.50	0.50	0.50
λ^{-2}	0.25	0.25	0.13
School Quality			
λ^2	1.00	1.00	1.00
λ^{-2}	0.50	0.13	0.13
Air Pollution			
λ^2	1.00	1.00	1.00
λ^{-2}	0.25	0.25	0.25
Time of Sale			
λ^2	1.00	∞	∞
λ^{-2}	0.25	∞	∞
Property Taxes			
λ^2	32.0	∞	∞
λ^{-2}	0.00	∞	∞

FOOTNOTES

1/ Alternatively, following Mendelsohn (1985) or Quigley (1986), one might achieve identification in a unified market by employing an instrumental variable procedure or by making the hedonic price function and the demand and supply functions have different forms. Bartik (1987) shows that unobserved household tastes will make structural demand and supply estimates based on these approaches inconsistent.

2/ Epple (1987) demonstrates that identification of hedonic system parameters in the presence of omitted variables and errors-in-variables requires "relatively strong" orthogonality conditions among variables and random components. Atkinson and Crocker (1987) find abundant omitted variable and measurement error problems arising from multicollinearities in hedonic housing studies.

3/ Butler (1980), Edmonds (1985), and Linneman (1980) provide the only empirical attempts to treat similar questions of which we are aware. Their approaches and most of their findings differ very considerably from ours. Most importantly, their statistical techniques do not allow an assessment of the extent of similarity among housing markets.

4/ For a more detailed yet accessible treatment of exchangeability, see Aigner and Leamer (1984).

5/ See Rubin (1980), DuMouchel and Harris (1983), Aigner and Leamer (1984), and Chamberlain (1988), for example.

6/ Conventional loans were available at about 6 percent simple interest during this period. The FHA rates were about 5 1/2 percent. Moreover, the FHA-insured loans had only a small or nonexistent prepayment penalty, whereas conventional loans often had penalties of as much as 6 months interest.

7/ We recognize that, at best, the prediction criterion is an incomplete means of evaluating alternative models. For example, model A may forecast better than model B, but the latter may nevertheless have a higher posterior probability of being the correct model. Nonetheless, the prediction criterion, appropriately supplemented as with consideration of Types I and II errors, can prove useful for distinguishing among legitimate and illegitimate management applications of alternative models.

8/ We do not pretend that our empirical results are conclusive, even though they are consistent with hedonic theory. Specification uncertainty and measurement error problems could riddle the studies from which we took our prior means, thus causing them to be unreliable. We cannot refute such a claim.

REFERENCES

Aigner, D.J., and E.E. Leamer, "Estimation of Time-of-Use Pricing Response in the Absence of Experimental Data," J. of Econometrics 14(1984), 205-227.

Atkinson, S.E., and T.D. Crocker, "A Bayesian Approach to Assessing the Robustness of Hedonic Property Value Studies," J. of Applied Econometrics 2(1987), 27-45.

Bartik, T.J., "Estimating Hedonic Demand Parameters with Single Market Data: The Problems Caused by Unobserved Tastes," The Review of Economics and Statistics 69(Feb. 1987), 178-180.

Brookshire, D.S., M.A. Thayer, W.D. Schulze, and R.C. d'Arge, "Valuing Public Goods: A Comparison of Survey and Hedonic Approaches," The American Economic Review 72(March 1982), 165-176.

Brown, J.N. and H. Rosen, "On the Estimation of Structural Hedonic Price Models," Econometrica 50(May 1982), 765-768.

Butler, R.V., "Cross-Sectional Variation in the Hedonic Relationship for Urban Housing Markets," J. of Regional Science 20(Nov. 1980), 439-453.

Butler, R.V., "The Specification of Hedonic Indices for Urban Housing," Land Economics 58(Feb. 1982), 96-108.

Casella, G., "An Introduction to Empirical Bayes Data Analysis," The American Statistician 39(May 1985), 83-87.

Chamberlain, G., and E.E. Leamer, "Matrix Weighted Averages and Posterior Bounds," J. of the Royal Statistical Society, B., 37(1976), 73-84.

Chamberlain, P.J., "An Empirical Bayes Approach to Modeling Drought," Western J. of Agricultural Economics 13(1988), 92-99.

De Vise, P., Chicago's Widening Color Gap, Chicago, IL: Interuniversity Social Research Committee, Report #2 (Dec. 1967).

Diamond, D.B., and B.A. Smith, "Simultaneity in the Market for Housing Characteristics," J. of Urban Economics 17(May 1985), 280-292.

DuMouchel, W.H., and J.E. Harris, "Bayes Methods for Combining the Results of Cancer Studies in Humans and Other Species," J. of the American Statistical Association 78(June 1983), 293-308.

Edmonds, R.G., Jr., "Some Evidence on the Intertemporal Stability of Hedonic Price Functions," Land Economics 61(Nov. 1985), 445-451.

Epple, D., "Hedonic Prices and Implicit Markets: Estimating Demand and Supply Functions for Differentiated Products," J. of Political Economy 95(Feb. 1987), 59-80.

Gillingham, R., "Measuring the Cost of Shelter for Homeowners: Theoretical and Empirical Considerations," The Review of Economics and Statistics 65(May 1983), 254-265.

Harrison, D., Jr., and D.L. Rubinfeld, "Hedonic Housing Prices and the Demand for Clean Air," J. of Environmental Economics and Management 5(March 1978), 81-102.

Havighurst, R.J., The Public Schools of Chicago, Chicago, IL: The Board of Education of the City of Chicago (1964).

Johnson, M.S., and M.J. Lea, "Differential Capitalization of Local Public Service Characteristics," Land Economics 58(May 1982), 189-203.

Jud, G.D., and J.M. Watts, "Schools and Housing Values," Land Economics 57(Aug. 1981), 459-470.

Leamer, E.E., "Sets of Posterior Means with Bounded Variance Priors," Econometrica 50(May 1982), 725-736.

Leamer, E.E., Specification Searches: Ad Hoc Inference with Nonexperimental Data, New York, NY: John Wiley and Sons (1978).

Lindley, D.V., and A.F.M. Smith, "Bayes Estimates for the Linear Model," J. of the Royal Statistical Society B, 34(1972), 1-41.

Linneman, P., "Some Empirical Results on the Nature of the Hedonic for the Urban Housing Market," J. of Urban Economics 8(July 1980), 47-68.

Mendelsohn, R., "Identifying Structural Equations with Single Market Data," The Review of Economics and Statistics 67(Aug. 1985), 525-529.

Ohsfeldt, R.J., and B.A. Smith, "Estimating the Demand for Heterogeneous Goods," The Review of Economics and Statistics 67(1985), 165-171.

Palmquist, R.B., "Estimating the Demand for the Characteristics of Housing," The Review of Economics and Statistics 66(1984), 394-404.

Quigley, J., "The Evaluation of Complex Urban Policies: Simulating the Willingness to Pay for Subsidy Programs," Regional Science and Urban Economics 16(1986), 31-42.

Rosen, S., "Hedonic Prices and Implicit Markets: Product Differentiation in Pure Competition," J. of Political Economy 82(Jan. 1974), 34-55.

Rubin, D.B., "Using Empirical Bayes Techniques in the Law School Validity Studies," J. of the American Statistical Association 75(Dec. 1980)

Schnare, A.B., and R.J. Struyk, "Segmentation in Urban Housing Markets," J. of Urban Economics 3(April 1976), 146-166.

Shaw, C.R., and H.D. McKay, Juvenile Delinquency and Urban Areas, Chicago, IL: Univ. of Chicago Press (1968).

Topel, R. and S. Rosen, "Housing Investment in the United States," J. of Political Economy 96(Aug. 1988), 718-740.

U.S. Bureau of the Census, 1967 Census of Governments, Vol. 2: Taxable Property Values, Washington, D.C.: Government Printing Office (1968).

U.S. Bureau of the Census, 1960 Census of Population: Chicago, Washington, D.C.: U.S. Government Printing Office (1962).

Zellner, A., "Applications of Bayesian Analysis in Econometrics," The Statistician 32(1983), 23-34.

CHAPTER 6
THE EX ANTE VALUATION OF RISK CHANGES: TWO CONTINGENT VALUATION-PROPERTY VALUE SURVEYS

INTRODUCTION

In Chapter 1, we identified several issues that currently-existing studies of groundwater contamination do not address. Most of the studies concern existing episodes and threats to human health. We argued that the frameworks do not address the ex ante value of preventing contamination and the consequent impacts other than health impacts.

Leaking underground storage tanks create a mobile fire hazard as petroleum products float along the water table. If gasoline or vapors seep into the basements of residential and non-residential structures these buildings are subject to increased risk of explosion or fire. This may lead to a substantial loss of property. In 1988 there were at least 120 known leaking underground storage tanks in the state of Wyoming. Most storage tanks will leak by age 16. Those currently in place but not leaking are likely to do so. The spills lead to a spreading contaminant plume. The Wyoming towns of Powell and Worland for example, had 8 and 14 plumes respectively as of the winter of 1988. As the plume spreads, structures can be impacted and the risk of fire is elevated.

In Worland one spill dumped over 40,000 gallons of gasoline leading to a flow of gasoline 2 feet thick on top of the water table. The fumes infiltrated the Washakie County School District No. 1's administration building leading it to be abandoned. In the Brookhurst subdivision of Casper, Wyoming at least 110 homes have had their well-water contaminated. This problem has been alleviated through alternative water supplies; however, gasoline fumes are now being found in the basements of some of these homes. Little America Refinery Co. is under an EPA directive to monitor homes above the gasoline plume for fumes.

In May 1989, the Security State Bank of Basin, Basin, WY was damaged by fire caused by gasoline seeping into the basement of the bank. A spark from a hot water heater started the fire.

200 homes in the Rawhide Village subdivision of Gillette, Wyoming have been evacuated as a result of methane gas seepage creating the threat of explosion. A Wyoming DEQ spokesperson said the current market value of these homes is "zip"! While the Rawhide episode is not believed to be attributable to industrial pollution, the same impacts can occur and hence this case is illustrative.

VALUING CHANGES IN FIRE-RISK

The above discussion demonstrates that a major consequence of leaking underground storage tanks is an elevated risk of fire in residential and non-residential structures. One component of the benefits of preventing such leaks is the collective willingness-to-pay to avoid the consequent increased fire-risk.

A survey by Delta Environmental Consultants, Inc. (DECI) during the fall of 1988 revealed that 14 of 15 properties investigated along Third Street in Laramie, Wyoming had contaminated soil and/or groundwater. Many of these sites had free gasoline floating on the water table. DECI concluded that there was no immediate health risk associated with the discovered contamination. However, they note the following potential future problems:

1. Explosive or hazardous hydrocarbon vapors in utility corridors or other subgrade structures.
2. Free phase hydrocarbons or contaminated ground water entering utility corridors or other subgrade structures.
3. Contamination of unidentified water wells.

4. Explosive or hazardous hydrocarbon vapors in excavations.

A door-to-door survey revealed that one residence had noted odors and that a hydrocarbon rainbow was apparent on water that seeped into the basement.

The DECI survey demonstrates that the potential for fire as a result of leaking underground storage tanks exists in Laramie. We designed two surveys to elicit the value that Laramie residents place upon variations in risk of fire to their residence.

CONTINGENT VALUATION OF HOUSING CHARACTERISTICS

Both surveys use Contingent Valuation methods. One of the surveys was designed to measure directly the amount that individuals would be willing-to-pay to avoid an increase in the risk of fire. The survey instrument is in Appendix 6A.

The survey collected individual background information concerning the respondents' age, sex, household size, years lived in Laramie, education and occupation. The characteristics of the property were also documented such as the number of rooms, age of house, size of house and size of lot.

This survey was used only for home-owners. Respondents were asked their perception of the current market value of their home and whether they would accept an offer of this value. If not they were asked for the minimum price they would accept. The extent of fire-insurance coverage on the perceived market value was also asked.

In question 20, the respondents were faced with two hypothetical fire risk values. The first value was to be assumed as the status quo. The second value represented an increase (or decrease) in fire-risk. The risks were stated as a given number of chances in 1000. The values to be used were (as pairs) (1, 2), (5, 10), (10, 20) and (25, 50). The reason for the variation in risk was not specified since the mechanism may lead to bias. That is people may respond differently to a given change in fire risk depending upon the factor causing the change. Our interest is in the fire-risk value per se.

Respondents were asked what change in house price they would make given the change in the fire-risk they face. The change in house-price is then the measure of the value of the change in fire-risk.

The survey was conducted by two interviewers. The investigators went through the survey with the interviewers. Each interviewer used a different survey technique.

One interviewer used a random telephone survey and completed 24 interviews lasting about 10 minutes on average. There were 11 males and 13 females interviewed. The average age of the respondents in this group was 43.5 years and the average years of education was 16. The average perceived value of their house was $70 thousand. 12 of the 24 respondents indicated that they would not accept their perceived market value. 3 of these did not indicate what value they would accept. The remainder indicated that they would accept higher prices with the increases ranging from $5 thousand to $25 thousand. 16 respondents believed that they had 100% fire-insurance; 1 had 95% coverage; 6 had 90% coverage; and 1 had 80% coverage.

Surprisingly, none of the respondents in this sample were prepared to change the minimum house-price when faced with a change in fire-risk!

The second interviewer performed door-to-door, face-to-face interviews. Results were achieved with 16 respondents and partial responses were obtained from 2 additional respondents. These interviews took a longer time than the telephone survey, lasting 20 to 30 minutes. The survey selected houses at random but in an older, established section of town. 11 males and 7 females were interviewed. The respondents were slightly older in this sample with the average being 46 years old. The average years of education was the same at 16. The perceived market value was higher, being $83 thousand on average. All but one respondent believed that they had 100% fire-insurance coverage. Most said that they would accept the perceived market price.

Once again, virtually all respondents indicated that they would not accept a drop in house price if faced with an increased risk, nor would they require a higher price if the risk were lowered! One respondent was willing to accept a $5 thousand decrease in the house price when the risk was increased from one chance in 1,000 to 2 chances in 1,000. Another respondent increased the required house price by $2 thousand when faced with a risk increase from 25 to 50 chances in 1,000 which is the opposite to what would be expected.

Both interviewers noted reluctance of individuals to participate in the survey. The first interviewer observed that older respondents were nervous about the background data. The second interviewer observed that many male respondent were "skeptical" and wondered why the survey was being conducted. Individuals were reluctant to give information concerning the value of their house or their minimum bids. Two respondents in the door-to-door survey refused to complete some of the monetary questions. One individual had difficulty with the survey because he/she "does not think about fire". Another felt there were too many economic details to consider. One respondent was "not in the market to sell" so was not interested in the survey.

While most people believed that they had 100% fire insurance coverage, they were confused as to what all was covered. In general, most individuals did not change house-values because they were "covered" by insurance. However, even those with less than full coverage did not adjust their asking price.

HOUSING CHARACTERISTICS TRADE-OFF GAME

A second study was a combined Contingent Valuation Hedonic Property Value study. The survey instrument for this study is Appendix 6B. The questionnaire collected the same personal background information as the other survey.

Individuals are asked to participate in a simulation game in which they select different combinations of housing characteristics given the annualized prices of the characteristics. In order to become familiar with the characteristics, respondents in Step 1 were to select the level of each characteristic that best described their current residence (ignoring the cost figures).

In Step 2 all individuals were told to assume that they had an annual allotment of $3,500 for expenditure on housing. Then given the annualized cost information for the characteristics they were to select the levels of each characteristic that they prefer while staying within the $3,500 budget allocation. One of the characteristics (M) was the fire-risk with lower risk being more expensive than high risk.

The respondent was asked to repeat the exercise in Step 3 with the cost of each fire-risk category (See N.) doubled while all other characteristics had the same money cost and the overall budget was still $3,500. In economic parlance, the price of achieving a given fire-risk class doubled relative to all other characteristics i.e., the relative price of each risk class doubled. In general, such relative price changes induce consumers to adjust their budget allocation assuming the budget constraint is binding. The reallocations indicate the individuals' preferences concerning risk categories.

In Step 4 the respondents perform the trade-off again but in this case the risk-categories are replaced by an insurance scheme (O.) in which the individual selects different degrees of fire-loss compensation given the prices for each compensation category.

The investigators went through the questionnaire with the interviewers to demonstrate the logic involved and then had the interviewers do the questionnaire themselves prior to undertaking the survey in the field.

One interviewer used three alternative interview methods. Initially, the interviewer went door-to-door. If the individual was agreeable to participating, the interviewer explained the structure of the trade-off game. The respondent was then left with the form to complete and the interviewer would call back at a later time to pick-up the completed form. This was intended to put as little pressure on, and create as little inconvenience for, the respondent as possible.

The initial interviews revealed that individuals had conceptual difficulties with the questionnaire. The interviewer then sent out 24 of the questionnaires with an addressed-stamped return envelope to members of a professional women's association. The members then received a telephone call to remind them to complete and return the forms. About 10 individuals did not return the questionnaire.

The interviewer again went door-to-door. In this case the interviewer stayed with the respondent during the trade-off game interacting at each stage. This proved helpful to the respondents.

In all, 22 of 32 forms were completed to some degree (plus the interviewer's) by this interviewer. The face-to-face interviews took between 30-45 minutes to complete. As a result of the selection process 19 of the 22 respondents were female. The average age of the respondents was 49 years and the average years of education was 18. Out of the 22 respondents, 19 were home-owners and 3 were renting.

The responses to the fire-risk categories in Step 2 are quite interesting with the respondents distributed quite evenly across the categories as shown in Table 6.1 with at least one respondent in each category and no more than 3 in any one category.

Table 6.1
Fire-Risk Category, Cost and Selection

Category	Cost	No. of Respondents in Category
1 chance in 10,000	1,000	2
1 chance in 1,000	500	3
5 chances in 1,000	350	3
1 chance in 1,000	250	3
2 chances in 100	150	1
5 chances in 100	50	3
10 chances in 100	0	1

The respondents who selected the highest risk category at zero cost was a renter rather than a home-owner.

In Step 3, the cost figures for each category are doubled. Only 19 of the respondents completed the adjustment from Step 2 to Step 3. Of these almost half (9) kept the same risk category. 4 individuals kept adjusting their risk category to maintain the same cost allocation to this characteristic. One individual behaved perversely and selected a lower risk category when its cost had risen, which may indicate confusion on this persons' part.

A total of 11 respondents made no change whatsoever to their form. For those that did make re-allocations, the most frequent adjustments were a reduction in floor space (6 respondents) and a reduction in yard size (4 respondents). Other reductions selected by one respondent each were length of appliance life, car space, indoor temperature, altitude above the Laramie River and the structural type.

In Step 4 the respondents select an insurance compensation rather than a risk-category. The responses for each compensation level are shown in Table 6.2.

Table 6.2
Responses to Insurance Compensation

Responses to Insurance Compensation

Degree of Compensation	Cost	No. of Responses
Full compensation	900	8
90% compensation	750	4
75% compensation	600	1
50% compensation	500	2
33% compensation	300	0
0% compensation	0	1

Half of the respondents opted for the full compensation package. One quarter were satisfied with 90% compensation. These self-selections are similar to the perceptions of actual coverage found in the survey discussed in section 6.3?????? The individual that selected 0% for no cost changed the selection from full to 90% and then to 0% casting some doubt on the credibility of this response.

A second interviewer collected a small sample of 5. These were done as face-to-face and were interactive. There were 2 males and 3 females. The average age was lower for this sample at 41 years and the average years of education was 16. The results for this sample are in general agreement with those outlined above for the larger sample and will not be discussed in detail.

GENERAL COMMENTS ON THE SURVEYS

The interviewers noted the reluctance of individuals to take the time to complete the questionnaires. This was true for even the shorter direct property-value questionnaire and more so for the more time-consuming trade-off game.

For the trade-off game the high opportunity cost of time for individuals shows up in the results in several potential ways. First, a number of people simply would not take the time to fill out the questionnaire even when they were allowed a time interval in which to schedule it at their convenience. Of the 22 responses obtained by the main interviewer in the trade-off game, 6 were incomplete. 5 of these respondents did not go past Step 2 and 2 respondents did not go past Step 1.

Even for those that did complete the questionnaire there is possible evidence of "short-cuts" to end the game more quickly. For example, the 11 respondents that made no changes to any of the categories. For those that made re-allocations, the interviewers noted that respondents made a decision concerning the desired risk-category and hen looked for the easiest category to obtain the requisite funds. The small number of realignments may be for this reason.

The incompleteness and short-cutting may be due to factors other than the opportunity cost of time. Several respondents found the surveys too complicated. Even in the property value-fire risk survey, respondents had difficulty comprehending the notion of risk. As a result all but two respondents refused to vary house prices with risk. FOr some this is because they had 100% coverage. This seems to ignore the non-property costs associated with destruction of one's home. There are psychic impacts, adjustment problems, loss of family heirlooms, loss of unique artwork which while insured can be replaced by only an imperfect substitute.

The greatest difficulties were encountered with the longer trade-off game. A number of respondents did not like "playing" with numbers. Others seemed simply confused about what they were supposed to be doing. Some respondents thought there was too much detail, while others thought that various characteristics required more detail! In this latter group individuals were confused as to what they could assume in the various categories. It became clear that different individuals had quite different notions as to what was in each of the characteristic bundles. The concept of risk in this questionnaire also caused people trouble.

These surveys demonstrate convincingly that it is very difficult to convey to individuals the notion of risk. People have trouble comprehending the concept and they have trouble understanding that they can make choices between alternative risk categories. All of this is inspite of the fact that the decisions they make routinely in every day-life involve the trade-offs that involve these issues.

Appendix 6A
Department of Economics
University of Wyoming
Contingent Valuation of Housing Characteristics

I. INTRODUCTION

Hello, I am __(Name)__ from the Department of Economics at the University of Wyoming. As part of a research program sponsored by the U.S. Environmental Protection Agency and the University of Wyoming, we are interested in the tradeoffs Laramie residents are willing to make among housing property characteristics and other commodities. If you are able to spare about 20 minutes, we would like to know the tradeoffs that you believe you might be willing to make. Your responses will be anonymous and will be strictly confidential.

II. BACKGROUND INFORMATION

1. Age: _____ years.
2. Sex: _____ M; _____ F.
3. Number in household, including spouse: _____.
4. Number in household < 17 years: _____.
5. Years lived in Laramie: _____.
6. Tenure status: _____ Rent; _____ Own.
7. Education: _____ years.
8. Current address: ____
9. Years at this address: _____.
10. Occupation: ____

III. PROPERTY CHARACTERISTICS

11. Number of rooms in this house, including basement: _____.
12. Age of house: _____ years.
13. Size of house: _____ square feet.
14. Size of lot: _____ acres or square feet (circle).

IV. CONTINGENT VALUATION

15. Do you plan to move in the next 12 months? _____ yes/no.

16. If you were to try to sell this house within the next 4 months, what is the best offer that you believe you could get? $ _________.

17. What percentage of #16 does your current homeowners' fire insurance cover? ________ percent.

18. Would you accept the offer of __________ in #16? _____ yes/no.

19. If NO to #18, what is the minimum offer that you would accept? $_______.

20. Suppose there exists _____ chance in 1,000 that your home will be totally destroyed by fire within the next 12 months. Suppose that the risk of such a fire has been increased (reduced) to _____ chances in 1,000. Would you reduce (increase) the minimum offer of $ _____ in #19 above that you would accept? _____ yes/no.

21. If YES to #20, by how much? _________ (change or absolute).

Appendix 6B
Department of Economics
University of Wyoming
Housing Characteristic Trade-Off Game

I. INTRODUCTION

Hello. I am (Name) from the Department of Economics at the University of Wyoming. As part of a research program sponsored by the U.S. Environmental Protection Agency and the University of Wyoming, we are interested in the tradeoffs Laramie residents are willing to make among housing and property characteristics. If you are able to spare about 30 minutes, we would like to know the tradeoffs you are willing to make. Your responses will be anonymous and will be strictly confidential.

II. INSTRUCTIONS

There are 4 steps involved in this tradeoff game. Please read the following carefully.

Step 1. Review the property characteristics list (A through M) and choose the level for each characteristic that best represents your current housing situation. Circle the number that you choose for each characteristic and then enter your choice on the summary form on page 4.

Step 2. Suppose you have just moved to Laramie, do not currently own a house, and are considering buying a house. You hold your current job. Furthermore, you have just won a lottery that guarantees you $3,500 a year as long as you stay in Laramie and never purchase more than one house.

On the characteristics form are listed the annual costs to you of various levels of each of a set of housing characteristics in Laramie. Your total annual expenditures for all characteristics cannot exceed $3,500. You do not have to spend the entire $3,500 on housing. After having considered the annual costs, record your characteristic level selections in the Step 2 column and transfer the associated cost to the Step 2 column in the summary table.

Step 3. Consider characteristic M, the chance of not having a fire within a year that would totally destroy the house that you have just purchased in Step 2. Presume that the percentage chances and associated costs are now as given in N on page 3. Remember that you still cannot spend more than $3,500 each year on all housing characteristics. Revise your spending on any or all characteristics as you see fit while staying within your spending limit. Now record your characteristic level selections in the Step 3 column and transfer the associated cost to the Step 3 column in the summary table.

Step 4. Consider again your purchases of characteristics in Step 3. Now suppose that you could purchase insurance that would compensate you for any fire losses that you suffer. Let the costs of various percentages of guaranteed compensation for total destruction by fire be as in O on page 3. Purchase whatever compensation percentage that you wish, remembering that you must still revise your spending on all characteristics in order to stay within your $3,500 spending limit.

Characteristics Levels and Annual Costs

Characteristic	Cost ($)
A. Floor space	
600 sq. ft.	400
800 sq. ft.	500
1,000 sq. ft.	600
1,400 sq. ft.	700
2,000 sq. ft.	1,000
2,500 sq. ft.	1,250
3,000 sq. ft.	1,500
4,000 sq. ft.	2,000
B. Yard size	
No land (apartment)	-----
500 sq. ft.	50
1,000 sq. ft.	75
2,000 sq. ft.	100
5,000 sq. ft.	300
10,000 sq. ft.	400
1/2 acre	500
1 acre	750
2 acres plus	1,000
C. Distance to the UW campus	
1/10 mile	300
1/4 mile	250
1/2 mile	200
1 mile	50
2 miles plus	-----
D. Distance from public water and sewer	
Zero	150
1/10 mile	100
1/4 mile	25
1/2 mile plus	-----
E. Remaining life of carpeting and appliances	
Zero	-----
1 year	200
3 years	400
5 years	500
10 years plus	750
F. Enclosed car spaces	
Zero	-----
1/2 (Carport)	25
One	100
Two	150
Three plus	300

Characteristic	Cost ($)
G. Interior temperature	
65°F	150
68°F	250
69°F	375
70°F	500
71°F	750
72°F	1,000
H. Altitude above Laramie River	
10 feet	-----
20 feet	25
50 feet	50
100 feet	100
200 feet	250
400 feet	300
I. Vegetation per 500 sq. ft.	
Original	-----
Lawn grass only	20
4 ft. tree or shrub	30
10 ft. tree or shrub	50
20 ft. tree	75
40 ft. tree	100
J. Type of structure (common walls)	
Apartment or condo	-----
Townhouse	100
Duplex	150
Single family	300
K. Age (includes wiring and plumbing)	
New	500
1 year	400
5 years	300
10 years	250
20 years	100
30 years plus	-----
L. Distance to paved road	
Zero	200
1/10 mile	100
1/4 mile	50
1/2 mile plus	-----
M. Chance of avoiding total destruction by fire	
1 chance in 10,000	1,000
1 chance in 1,000	500
5 chances in 1,000	350
1 chance in 100	250
2 chances in 100	150
5 chances in 100	50
10 chances in 100	-----

Step 3 Card
Perturbation of Characteristic N

N. Chance of avoiding total destruction by fire	Cost ($)
1 chance in 10,000	2,000
1 chance in 1,000	1,000
5 chances in 1,000	700
1 chance in 100	500
2 chances in 100	300
5 chances in 100	100
10 chances in 100	-----

Step 4 Card
Insurance Card

O. Fire loss compensation	
Full compensation	900
90 percent compensation	750
75 percent compensation	600
50 percent compensation	500
33 percent compensation	300
Zero compensation	-----

III. BACKGROUND INFORMATION

Age: ________ years.

Sex: _______ M; _______ F.

Number in household, including spouse: ________.

Number in household < 17 years: _________.

Years lived in Laramie: _________.

Tenure status: __________ Rent; _________ Own.

Education: _______ years.

Current address: ____

Years at this address: ____________.

Occupation: ____

Summary Card

Characteristic	Step 1	Step 2	Step 3	Step 4
A. Floor space				
B. Yard size				
C. UW distance				
D. Public water distance				
E. Appliance life				
F. Car spaces				
G. Temperature				
H. Altitude				
I. Vegetation				
J. Structural type				
K. Age				
L. Road distance				
M. Fire				
N. Insurance compensation				

CHAPTER 7
SUMMARY AND CONCLUSIONS

This study extends and empirically implements methodologies potentially useful for assessing the prospective economic benefits associated with protecting groundwater integrity in Wyoming's urban and residential areas. Chapter 1 remarks that this focus upon the value of protection rather than remediation is absent in the small existing volume of economics literature that deals with groundwater contamination. This received literature emphasis results in the outright neglect of many significant economic issues. Most importantly, the literature has been blind to the significance to valuation of individuals' responses to risk and to the manner in which these responses are affected by the type and extent of opportunities to adjust to risk. We show in Chapter 2 that several traditional, theoretically-derived restrictions placed upon the dimensionality of groundwater contamination valuation exercises are inappropriate when the individual is able to adjust to risk.

Chapter 3 presents the empirical results from a series of controlled experiments designed to explore the sensitivities of individuals' risk valuations to the form of adjustment opportunities. Among numerous other results, we find that private risk reduction efforts are valued more highly than are collective efforts, that valuations are very sensitive to the particular details of adjustment opportunities (e.g., the sequence in which different types of opportunities are offered), and that one-time responses to posed hypothetical risk problems are poor predictors of actual valuation behavior. Taken together, these experimental results imply that contingent valuation survey exercises must put a premium upon carefully realistic descriptions of any risk problem of policymaker interest. A failure to be realistic and to offer survey respondents many rather than one-time opportunities to participate in the hypothetical market will result in seriously inaccurate valuation estimates, i.e., estimates that differ from true valuations by as much as an order of magnitude. Given the complexity of prospective groundwater contamination problems, we seriously doubt that realism and respondent understanding can simultaneously be served adequately in one-time contingent valuation exercises. We therefore suggest that policymakers adopt hedonic property value techniques to value the economic benefits of reducing groundwater contamination risks to health and property.

Chapter 4 shows that generally close upper bound approximations of the value of a groundwater contamination risk reduction can be readily obtained by extrapolation from an ex ante (before the reduction) hedonic price function. The theory and ease of practical implementation of these functions is thoroughly reviewed in Freeman (1979) and in Follain and Jimenez (1985). This ex ante hedonic measure will be exact when the area at risk is a small portion of the area covered by the local housing market or when worthwhile adjustment opportunities are few. It should be noted that local property tax and real estate value assessors often collect ex ante hedonic price functions.

Although it is easy to obtain quantitative measures of ex ante hedonic price functions, care must be exercised that the appropriate function is applied to each groundwater contamination problem. Chapter 5 empirically demonstrates that transfers across locations or times of hedonic price information referring to the structural attributes of a residential property will involve little or no error; that is, information about the price of additional floor space, for example, at site A will also be highly informative about the price of additional floor space at site B. For neighborhood attributes such as groundwater contamination, such transferability is shown to be quite poor. It follows then that each groundwater contamination problem is very likely to require development of a distinctive ex ante hedonic price function, if accurate upper bound estimates of the value of a risk reduction are desired.

Chapter 6 represents an empirical example of the difficulties and the ambiguities inherent in applications of contingent valuation methods to groundwater contamination issues. Its results reinforce the analytical arguments made in Chapter 4 for the use in policymaker problem settings of ex ante hedonic price functions.

REFERENCES

Follain, J.R., and E. Jimenez, "Estimating the Demand for Housing Characteristics: A Survey and Critique," Regional Science and Urban Economics 51(1985), 77-107.

Freeman, A.M. III, The Benefits of Environmental Improvement, Baltimore, MD: The Johns Hopkins Univ. Press (1979).