QUANTIFYING LONG RUN AGRICULTURAL RISKS AND EVALUATING FARMER RESPONSES TO RISK

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Public Choices and Private Risks: The Role of Economic Analysis

The Research Strategies Subcommittee of EPA's Science Advisory Board recently described the Agency's mission as reducing the level of risk to health and the environment posed by wastes, residues, and contaminants.[1] There is a general recognition that this goal cannot be met for all risks with existing sources. Many policy analysts avoid explicit consideration of tradeoffs that necessarily follow in evaluating which risks will be reduced. Instead they defer the (implicit) valuations to the "final" decisions of the agencies involved or the courts for each source of risk.[2] This situation seems to offer a clear opportunity for using economic analysis to help decide which risks to address and how much each should be reduced.

This paper argues that an important reason for the current state of affairs lies with limitations in economic theory.[3] That is, conventional economic descriptions of individual behavior under uncertainty have failed to reliably estimate the values of reductions in the risks that accompany exposure to pollutants. Moreover, based on people's behavior in laboratory situations involving risk, an increasing number of psychologists and economists have come to question the expected utility framework.[4] In addition, psychologists have identified shortcomings in the way most people actually use information to form risk perceptions.[5]

Taken together these findings have led to a variety of different responses. Many economists have argued that economic theory is primarily relevant in situations where a person:

> ...can be expected to 'know' or to have learned the consequences of different actions so observed choices reveal stables features of his underlying preferences. We use economic theory to calculate how certain variations in the situation are predicted to affect behavior, but these calculations obviously do not reflect or usefully model the adaptive process by which subjects themselves arrived at the decision rules they use (Lucas [1986], p. S402).

In contrast to these economists, we find that most psychologists are more willing to accept diverse responses to risk. These psychologists see the diversity as a reflection of different people's risk-assessment heuristics, limitations in the cognitive efforts devoted to the tasks involved, or as resulting from personality and attitude differences.

This paper aims to describe what the elements of a reformulated model of individual behavior will need to be so that it will be possible to incorporate within our behavioral framework a description of how individuals learn to deal with environmental risks. This learning and risk-perception process should be treated as an integral component of the plans people make in responding to uncertainty. By comparing this approach with conventional models and corresponding empirical analyses, I argue that a composite framework may ultimately provide the valuation information needed to effectively respond to EPA's risk-management objectives.

Following the discussion presented in Section I of this paper, Section II summarizes some recent empirical evidence supporting elements of this approach. The last Section considers how a more general view of individuals' learning, risk perception, and behavior may affect any evaluation of the relative merits of current policies designed to reduce specific sources of environmental risks.

I. The Expected-Utility Model and the Value of Reducing Environmental Risks

The expected-utility model is arguably one of the most important contributions economists have developed in this century. It assumes that behavior under uncertainty can be described with a simple modification to the framework for constrained utility maximization. People usually maximize the expected value of the utilities they would realize under all of the uncertain outcomes, implying that their objective functions are linear in the probabilities characterizing the chances that these outcomes will take place. Most recent critiques of the expected-utility model have focused on this linearity, often referred to as the independence axiom. Although an important restriction, there are nonetheless much simpler features that most applications using this model imposed on the analysis. Thus I begin with them first because they are relevant to environmental problems. Consequently, I discuss each of these smaller issues first before finally describing the more general issues and what they imply for the required amendments to the model.

A. State Independent Utility and the Events at Risk

Economic research that measures individuals' (and firms') behavior under uncertainty, defines measures of risk aversion. Indeed, even in developing alternatives to the expected utility framework it has customarily focused on situations where individuals' utility functions are assumed to be state-independent.[6] Reasons for this assumption appear to relate to their exclusive focus on behavioral responses to uncertainty involving monetary losses.

In these exercises a conventional indirect utility function is implemented wherein income or commodity price variations defined all potential outcomes that were uncertain during an individual's planning horizon.[7] The first important source of change in this area arises with Cook and Graham's [1977] important paper on insurance and the valuation of changes in mortality risks. This work fostered a reorientation in this literature to consider state-dependent preferences. Arrow [1974] anticipated the importance of the state dependency issue, observing that differences in the marginal utility of income across states gave this formulation its behavioral significance.[8] His argument and much of the subsequent discussion of risk-aversion measures (see Karni [1983]) illustrate why a changed and evolved problem description is so important.

By altering the outcome at risk from actual money to something else, we find the question of how that outcome affects an individual's marginal value of money of emerging importance to the ex ante valuation of risk changes. In the state-preference approach to modeling consumer decisions, this is generally not described in specific analytical forms.[9] Indeed, we have been more willing to specify how utility changes with income instead of with events affecting other nonmarketed resources. With monetary losses, these specifications have often

linked utility changes to the Arrow-Pratt measures of risk aversion for state-independent utility specifications. However, it is important to recognize that this work, as well as most other subsequent research, has been notably stimulated by early discussion of the issues associated with defining valuation measures under uncertainty. More specifically, Weisbrod's [1965] concept of option price has been linked to questions of valuing environmental resources by Krutilla [1967] and has profoundly affected current issues associated with valuing environmental risk reductions. The option price concept was defined for those cases where there was some chance of losing a natural asset. The early debates in this literature over the sign of option value simply reflected the fact that we had little to guide the specification of how marginal values of income would change with uncertain outcomes. In simple cases it has been possible to use differences in the marginal value of income across states as a direct measure of the uniqueness of the outcomes at risk (see Smith [1984]). For more complex situations, comparable indexes are difficult to define and even more difficult to measure.

Another important influence on the marginal values placed on risk reductions is the opportunity a person has to adjust to risk through markets. The market reduces discrepancies in these marginal values, provided an individual uses adjustment opportunities they provide to mitigate risks he or she faces. In formal terms, these are described as markets for contingent claims. While this is an abstract conception of how people adjust to risk, we can find real world examples in the insurance markets available for many types of uncertain outcomes. In the resource context, the federal flood insurance program offers one example.

Thus, even within a conventional expected-utility context, it has been important when valuing risk reductions to recognize that most environmental policies involve outcomes that do not routinely "convert" to income. However, this modification alone does not explain the departures from expected-utility behavior observed in recent laboratory experiments and survey research. It is straightforward to show that the conventional state-independent as well as state-dependent specifications have the same implications for the <u>direction</u> of changes in individual value/risk tradeoff with changes in the risk experienced. Indeed, the primary distinction between the two specifications lies in the <u>magnitude</u> of these changes.[10] Thus we must look to other questions with the framework for a more complete explanation of the failings.

B. <u>Entitlements and Risk Valuation</u>

Behind legislation concerning most current environmental regulations is the rationale that the public is entitled to a clean, healthful environment. Nearly a decade-and-a-half ago, Okun [1975] discussed the efficiency/equity tradeoff inherent in most government policy. Meanwhile, he described the economist's concern with legislating rights (i.e. freely distributing them to specific groups or to the public at large) by observing that "...the domain of rights is full of infringements on the calculus of economic efficiency" (p. 10). Okun's intent was not to question the legitimacy of some entitlements, but rather to recognize their costs (in efficiency terms) and argue for more balanced policies.[11] These issues have been a major element in the various questions raised with proposals to use valuation information in evaluating

policies intended to save lives. (See Viscusi [1983], Graham and Vaupel [1981], and Asch [1988] for overviews.)

My concern with the role of entitlements is different, but equally important to any attempts to address Okun's question on risk-related policies. Very simply put -- people perceive certain entitlements to resources, including levels of safety, regardless of whether specific legislation and regulatory policies have established these as actual entitlements. Moreover, these perceived rights of citizens outside some proximity to a landfill containing hazardous wastes or to an incinerator burning them definitely influence their subsequent behavior when changes in the status quo are proposed. Perceived rights are openly reflected in citizens' valuations (or contingent behavior) when proposed policies involving risk increases are presented.

An example from contingent-valuation studies illustrates this citizen response. In a recent study, Bill Desvousges and I (Smith and Desvousges [1986a]) surveyed a sample of households in suburban Boston. We found that marginal values for the same size risk reduction differed by a factor of ten, depending on whether it was presented as a risk reduction (from an existing hazardous waste site) or as avoiding a risk increase. Moreover, this effect is opposite to that which the Kahneman and Tvesky [1977] framework would imply. Indeed, their framework implies that individuals should be willing to pay more to retain a low level of risk than to actually purchase a lowering of risk (to the same point) from some higher level. Our empirical results supported just the opposite outcome. However, focus groups contacted prior to the survey made it clear that reactions to the risk-avoidance question were directly affected by what respondents felt they deserved. (In this case, they felt entitled to lower levels of risk initially described to them.)

Empirical findings illustrating these effects have been interpreted as yet further support for rejecting the expected-utility framework in favor of one that incorporates the actual role of framing.[12] Alternatively, we could use these same findings to argue that we have too narrowly defined individual endowments and their effects on behavior. In defining the perceived constraints to individuals' choices, the focus has customarily been on monetary measures of income and wealth because the existing economic models were only intended to describe behavior in markets. While the orientation has been expanded to nonmarket decisions, our descriptions of behavioral constraints have been slower to respond.

Okun's question cannot be addressed until we understand how values of risk-related policies are affected by individual endowments, including both perceived citizen rights (whether arising from historical precedent or existing statutes) and monetary resources.

C. Environmental Risk and the Sanctity of the Lottery

Most economists make remarkably simple adaptations to their models when facing new circumstances. They maintain that households (or firms) customarily optimize a predefined objective function, often redefining the goods or constraints to fit the problem. Examples of this modeling strategy abound in the literature. To convert the conventional economic description of an

elementary choice problem to one that involves risk, simply replace the term "commodity" with "lottery" and the process will be nearly completed. Lotteries have probabilities and payoffs (or losses). This is especially true for decisions associated with environmental risks. When lotteries are treated as the objects of choice and the rule for selecting among them is the Von-Neumann Morgenstern utility function, we have a framework that has a wide range of behavioral implications. Unfortunately, as some psychologists have observed, real-world uncertainties are inherently different from those circumstances conveyed by the gambling metaphor. The probabilities associated with rolling dice, drawing balls from an urn, or picking numbers from a bingo cage are reasonably easy to understand (or learned quickly). Participants treat them as clear cut because the processes are familiar or easy to replicate. Once the structure becomes more complicated, as appears to be associated with compound lotteries, subjects' varied experiences weigh upon their subsequent behavior. For example, Grether's [1980] study seems to indicate that behavioral departures from a simple Bayesian learning process are reduced with increased experience and financial incentives. More recently, Camerer [1987] has found that differences in the predicted valuation for the payoffs (as implied by a Bayesian expected utility framework) were smaller with experience.[13]

In the real world, the numerous processes giving rise to environmental risks are complex and extend over multiple time periods. In addition, information describing these risks can be vague or even conflicting. Indeed, it is sometimes difficult for people to understand or accept an economist's description of an environmental risk. This point can be illustrated by the difficulties we experienced in designing the questionnaire and supporting materials for the contingent-valuation study involving risks associated with hazardous wastes (discussed earlier). Our objective was to estimate an individual's valuation of reducing the risk of premature death from exposure to hazardous wastes. This estimation required describing this risk change as a "commodity," illustrating the method used for making payments to obtain the risk reduction, as well as the framework and timing for that provision and payment.

Our survey was undertaken in late spring and early summer of 1984. Following the evidence from the early laboratory experiments, it was reasonable to assume that explaining risk as the probability of exposure and premature death would have been more easily understood than one that distinguished the components of the compound event (i.e. the exposure and then the health outcome conditional on this exposure). This was not the case. (For details, see Smith et al. [1985].) In focus group evaluations of alternative approaches for explaining the risk, the participants could not fathom how the "government" could actually reduce the likelihood of an individual's premature death from hazardous waste. In contrast, respondents more easily understood how exposure probabilities could be directly controlled through government policies.

By describing the process in compound terms, we introduced a more complex probability process. While this should have been an equivalent "lottery," it was not! Yet, to do otherwise, we faced the prospect that respondents would not have understood or accepted a key premise to the valuation question -- that government policy-makers could actually take direct action to reduce risks.

Thus, in contrast to the Lucas quote cited earlier, an economic model of individual behavior in these circumstances must describe the learning process customarily part of most decisions. That description should reflect how imprecise the information about risk is. Einhorn and Hogarth [1986] have highlighted the importance of this imprecision and directly refer to it as ambiguity. In their terms it is "...an intermediate state between ignorance (no [probability] distributions are ruled out) and risk (all distributions but one are ruled out)" (p. S229, bracketed term added).

Economic models of behavior under uncertainty don't always ignore the learning variable. However, Arrow's [1971] early characterization of how they incorporate learning remains an apt description of the way learning is assumed to enter economic models. He observed that:

> When beliefs are represented by probabilities, then the observation of an event causes the agent to act in accordance with the conditional probabilities given that event rather than with the probabilities held before the observation (p. 46).

This description makes an important implication -- the learning process describing how people form risk perceptions remains separate from their valuations for the actual events at risk. Consequently, the structure of the expected-utility model is largely unchanged. A new set of probabilities can reflect the "exogenous" learning and any corresponding updating. Behavioral choices contributing to the utilities an individual experiences are separate from this process. In some situations we might expect that process of updating one's conception of the probabilities would depend on what is at risk. The consequences of gauging the prospects for rain versus the outcome of surgery are quite different. One would expect these types of differences to influence the risk perception process.

D. Reformulating Economic Models of Behavior Under Uncertainty

It will not be easy to replace the conventional expected utility model of behavior under uncertainty with one more relevant to the actual decisions people make in dealing with environmental risks. This section does not claim to make this substitution. Rather, it sketches some of the elements of a basic model from decision theory that seems quite capable of beginning the actual process. An individual's risk-perception and behavioral-choice problems are treated as the direct outcome of a joint optimization process. A loss function designated by ℓ is used to characterize the implications of these decisions for each individual.

This function can be derived from a utility function. However, this is often not done explicitly in decision theory treatments of this process. Instead they often begin with a specification of the loss function's properties. Two arguments are identified - the parameter to be estimated (in my case the individual's risk perception, designated here as p) and the true value of the parameter (π). A feature similar in its implications to Einhorn and Hogarth's ambiguity is introduced by specifying that the true value of the

probability is unknown to an individual and that his beliefs about π can be described by some probability distribution (a second-order uncertainty).

This formulation of risk perceptions requires that individuals expend resources to learn about this distribution. A separate function describes these costs. Risk perceptions are then defined as the estimate that minimizes the expected value (over the second-order uncertainty) of this loss function.

The central issues in this framework can be identified without detailed derivations by simply relating the results of these exercises to the specific elements of the risk-perception process. The most common specification for $\ell(.)$ is a quadratic in terms of the parameter to be estimated. While there are numerous reasons for this choice, an important one is that it maintains the separation of risk perception and valuation. π is estimated by minimizing the expected loss function subject to budget constraints, including the cost of acquiring information. The best estimate of π is the expected value using whatever probability distribution characterizes the individual's judgments about π. Thus, before any information is acquired, this estimate will be the expected values based on the individual's prior distribution decisions. After gathering information, the individual's best estimate of risk uses the posterior distribution.

When examining the implications of these results, it is important to ask whether the assumptions required are plausible. There have been few attempts to connect the model to the issues arising when describing individual behavior. To implement this type of model, we might assume that individuals allocate resources to acquire information and minimize losses in expected utility resulting from errors because their plans may not be consistent with the actual features of the uncertainties they face. With this assumption in mind, ℓ could then be specified as a linear function of p with weights corresponding (for the simplest two-outcome case) to the utility functions under each outcome. These utility functions would necessarily include some specification of how any costs of acquiring information affect the utilities they realize. The separation of risk perception and valuation is not maintained with a linear loss function. Instead, the specific features of the utility functions and of the second-order uncertainty ultimately determine the updating rules for risk perceptions.

Both the quadratic and the linear loss function assume that information is optimally utilized. Reflecting psychologists' concerns about individuals use of information would require a respecification in this loss function. This in turn will alter the form implied for individuals' risk perceptions and subsequent behavior.

Two issues directly follow from this brief sketch of an alternative framework for describing risk perceptions. First, as we try to develop an alternative model of individual behavior under uncertainty and if we assume people recognize that they will never know the true likelihood of most uncertain events, then we need to consider what the relevant characterization is of the losses resulting from mistaken risk perceptions. My proposed description would compare the <u>ex ante</u> expected utility realized with the unknown risk versus the expected utility derived from an individual's estimate. In this formulation, learning over time enters the framework because this is a

fundamentally sequential process. We assume each person's characterization of the second-order probability distribution for π reflects his ex post experience with similar risky situations. This process maintains that individuals conceptualize ambiguity with the equivalent of second-order probability functions.

The key question in any more general framework in decision theory is the consequences of mistaken risk perceptions. How do they influence the acquisition and subsequent use of information? With the quadratic loss function, learning and risk perception can be consistent with the conventional separation of probability and valuation. In many other models, this consistency will not exist. This inconsistency implies that characterization of these losses and the learning they motivate are central to an explanation of both people's risk perception and their eventual behavior in the presence of uncertainty.

In addition, the connection between monetary values for a risk change and some measure of individual well-being is now less clear cut. We could maintain that values holding expected utility constant with a given information set are relevant, but other alternatives seem equally plausible. Moreover, even when expected utility is used to measure of well-being, each individual's reference level will still depend upon how the analysis treats learning.

II. The Prospects for Implementing a New Framework

Implementing a model that treats both risk perceptions and behavioral actions as joint outcomes of the consumer's choice process is far from our grasp given our current understanding of people's behavior. It requires a substantial reorientation -- the profession must be willing to directly use information derived from surveys encoding individuals' responses to hypothetical risk situations.

We are not yet close to a practical alternative to the expected utility model where probabilities are assumed exogenous (or at least completely separate) from behavioral decisions. Nonetheless, recent evidence from three sources -- (1) contingent valuation studies (see Gerking et al. [1988]); (2) analyses of behavioral intentions (Viscusi, Magat and Huber [1986, 1987]); and (3) social experiments involving risk communication policies (Smith, Desvousges, Johnson and Fisher [1987, 1988a, 1988b]) -- all support research strategies involving a wider range of joint research efforts between psychology and economics. To gain some insight into what next steps are warranted, consider first the empirical results underlying these general conclusions. After this section, I discuss the recent contributions of models and surveys focused on behavioral intentions in situations involving risk. Finally, I provide a status report on that part of my own research which is associated with communicating the risks directly associated with exposure to radon.[14]

A. Traditional Methods

Wage hedonic models provide the most widely used source of information about how people value risk changes.[15] Repeated applications of this model with different surveys of wages and working conditions (in the United States

and other countries) have supported the model's basic premise. This assumption, in brief, says that individuals recognize the risks of accidents in the work place and may be willing to accept higher risks, provided they receive increased compensation. However, support for this premise remains fairly general and indicates a positive, statistically significant relationship between wages and risks of fatal accidents in the work place. Estimated incremental values for risk span a wide range and are usually reported in terms of the implied values for "statistical lives." These values range from about one-half million dollars to over $8 million in 1986 dollars (see Fisher, Chestnut and Violette [forthcoming]).[16]

Differing measures of the risk of fatal work place accidents account for many of the differences in results. Those studies with estimates at the low end of the range have typically involved samples with higher average risk levels (usually actuarial estimates by occupation), while those at the higher end of the range have generally been Bureau of Labor Statistics (BLS) industry risk estimates. The recent Moore-Viscusi [1988] study is an important exception and is based on a complete census of all occupational fatalities. This study has both higher levels for mean risk and among the highest values for risk increments (a finding consistent with EU theory implications).[17]

Several important qualifications to these findings bear directly on the relevance of estimated values for environmental risks. The models assume that individual workers are aware of the technical measures of job risks. This is sometimes a reasonable expectation, especially for blue-collar workers who may directly observe accidents or be provided with information on industrial accidents. The available empirical evidence generally supports a consistent association between risk perceptions and technical risk estimates for job-related risks. Among the strongest evidence are Viscusi's [1979] early study using a discrete (0, 1) index of workers' perceptions of dangerous conditions, as well as his more recent work (Viscusi and O'Connor [1984]).[18]

Unfortunately, as we move to discussions of environmental risks, the relationship between subjective risk perceptions and technical risks is less clear. Some examples help illustrate the problems involved. In a wage-hedonic model that includes both job and environmental sources for risk, Carol Gilbert and I (Smith and Gilbert [1985]) compared the incremental values for risk reductions associated with job-related fatalities to those estimated for the increased mortality risk due to exposure to air pollution. The analysis suggested that both variables were significant and positive influences on real wages (as theory would imply). Yet the estimated incremental values for health risks from pollution could be quite different from those associated with job accidents. The size of the differences depended on how people's exposure to pollution related to their corresponding health risks.

Similar problems arise with most other sources of environmental risk. In an example of risks of hazardous wastes exposure, for example, most people would consider increased distance from landfills containing these wastes as a way to avoid or reduce exposure. Mitchell's [1980] early proposal to use distance as a gauge of the relative desirability of land uses is consistent with this intuition. In addition, several studies have attempted to use this same approach with hedonic property-value models to estimate the incremental

value of avoiding these facilities.[19] The record remains mixed.[20] A few problems arise when using these approaches to understand how households learn about risk and then act based on these risk perceptions. The most troublesome aspect is the fact that the results reveal nothing about the actual risk perception process.

As part of a larger study (developing a contingent valuation analysis of households' values for reducing hazardous waste risks), Bill Desvousges and I considered whether individual measures of risk changed consistently in relation to increased distances between homes and landfills. This is the implicit assumption underlying the use of distance as a direct proxy for risk. (See McConnell [1988] for a complete development of the theoretical issues involved.) The responses indicated that there was no reliable relationship. (See Smith et al. [1985] for specific findings.)

Comparable findings were also recently reported by Gerking, de Haan and Schulze [1988] in their application of a contingent valuation survey to estimate the individuals' values for job risk reductions. Their study elicited risk perceptions in two ways. The first used a Likert 1-to-5 scale, with 1 labeled "Could Never Happen" and 5 labeled "Most Likely to Happen." Each respondent used the scale to evaluate each of 13 major causes of death at work and to appraise their own job, determining whether it posed any credible threat. The second approach used a ladder with increasing risk designated by ten equally-spaced steps. The risk levels were described using the annual number of job-related fatal accidents per 4,000 workers. Seven example occupations were indicated as steps on the ladder, and respondents specified the step number that most closely corresponded to their own job-related risk of death. The responses indicate that risk perceptions elicited using this format had no significant impact on the stated contingent valuation bids for job-related risk reductions. Moreover, risk perceptions using the ladder actually seemed to overstate technical estimates of job risks. In contrast, risk perceptions elicited in a format linking them to the sources of risk and then using a simple scale to elicit risk perceptions significantly influenced the contingent values for risk reductions.[21]

B. Studies Involving Contingent Behavior and Risk

Over the past four years, Viscusi has considered the implications of product labeling for risk perceptions, precautionary behavior, and learning. Viscusi used hypothetical situations involving risk sources for both workers and households. The research pioneered in integrating concepts of psychology and economics to understand how individuals use information displayed on labels. As we shall see, an interesting pattern emerges from the body of work completed to date.

The first experiments (Viscusi and O'Connor [1984]) considered workers and the job risks arising from handling chemicals in the work place. Hypothetical labels described the risks of these products. Workers were read the labels and were asked about their corresponding risk perceptions and wage requirements, as well as their willingness to remain after new products with different risks were introduced. The results strongly supported a rational risk perception process, as well as the behavioral adjustments implied by conventional theory.

This optimism was reinforced in the second set of results (Viscusi, Magat and Huber [1986]) which involved a single source of risk and structured interviews discussing precautionary behavior. The study considered two household products as separate sources of risk -- a liquid bleach and a liquid drain opener. Three different labels were designed for the bleach and two for the drain opener. The labels varied levels of stated risk information and, in the case of the bleach, one label's content made risk information more prominent. Each respondent (in a shopping mall intercept survey) was shown one product label and then interviewed to evaluate precautionary behavior. Most of the interview focused on product usage issues to avoid prompting respondents to focus on risk-related questions. This helped insure more honest responses.

The third study (Viscusi, Magat and Huber [1987]) was concerned with individuals' values for reducing multiple risk sources and provides the first indication of the authors' concerns with the predictions corresponding to conventional economic framework. Their paper concluded that "...the nature of individuals' processing of risk information is of considerable consequence and perhaps even of dominant concern" (p. 478). This study also used product labels to describe the two risk sources -- an insecticide and a toilet cleaner. Individuals were asked about the price increases they would pay to reduce each source of risk for individual as well as joint reductions in the two products. Risks were expressed as injuries per 10,000 bottles used of each product. The events at risk were varied for households with and without children. While the results still supported a rational behavioral model in the presence of risk, there were "...substantial departures from the model's predictions that appear attributable to the influence of cognitive factors lying outside economists' traditional concerns" (p. 478).

These concerns are elaborated in the most recent study (Magat et al. [1988]), which used a framework based on an open-ended memory task to evaluate how individuals recalled information from product labels. After reading a product's labels, respondents were asked what directions they would give to a friend who had never used the product. Each individual received one of five possible labels. Each label varied in the amount of risk and precautionary information presented, with one format having a cluttered presentation of the information. In coding the respondents' unstructured answers, five categories of responses were identified: Direction for Uses; How Can it Hurt You?; Actions to Take; Actions to Avoid; and Antidotes.

The last four response types involve risk-related uses. They were the primary focus of the Magat et al. evaluation of how labels affected individuals' recall of information from the product labels. The authors examined how labels influenced these responses and found that:

> ...There is an upper bound on individuals' ability to process risk information....The difficulty is not simply that individuals process only a small number of pieces of information on a product label and then stop. Rather, the types and quantities of information that are recalled may be affected by the amount of information presented, possible in an adverse manner (p. 230).

This progressive change in the nature of conclusions drawn from this line of research parallels a similar recognition from previous laboratory experiments. Of course, there is inevitable criticism of both types of research. Skeptics say the research involves circumstances that are either greatly simplified for laboratory experiments or hypothetical for the contingent behavior and contingent valuation surveys. To answer these concerns and provide support for the conclusions drawn in this research, in the next section I summarize some of the results from two social experiments that avoid these limitations but lead to similar conclusions.

C. Radon Risk Communication Studies

Naturally occurring risk sources provide examples of risk variation experienced by individuals. In this section, I describe the results of my ongoing research into households' responses to a naturally occurring pollutant, radon. The EPA has sponsored a number of risk communication efforts in response to the recent growing awareness of the high risks involved. My summary relates to joint research with Bill Desvousges in which we use evaluations of the effectiveness of two of these communication efforts in our attempts to learn more about how people form risk perceptions.

Our first experiment investigated the risks of premature mortality from radon exposure. We used a panel of households that agreed to participate in a radon-monitoring project. The second experiment evaluated a public information program intended to increase private monitoring for radon. Each study combined research and policy objectives. Thus there were limitations on both number and type of research issues that each could consider. Nonetheless, it was possible to use these studies to address issues raised by both the conventional wage hedonic models and the contingent behavior surveys. This summary describes our analysis and conclusions of how households learned about risk, updated their risk perceptions, and acquired more information about radon risks.

About three years ago, Bill Desvousges and I participated in an ongoing project designed by the New York State Energy Research and Development Authority (NYSERDA). We worked with economists at EPA to measure the indoor concentrations of radon in approximately 2,300 detached, single-family homes in New York state.[22] NYSERDA's aimed to estimate average radon concentrations around the state. On the other hand, Bill and I aimed to evaluate how the information used to explain radon's risks eventually influenced households' risk perceptions and subsequent behavior.

The NYSERDA study design called for short-term and annual measurements at two different locations in each home. The readings from one monitor, with approximately two months of home living area exposure, were sent to participating households in December 1986. About a year later, the annual reading from two monitors (living area and basement) were sent to each participant. Prior to receiving any of this information, we interviewed a randomly selected adult decision-maker in each household and conducted follow-up interviews with that person after sending each set of readings. All but the last were telephone interviews. Budget limitations forced the use of a mail survey for the second follow-up. The second follow-up was completed in spring 1988. Households were advised to wait for the annual results before

undertaking mitigation. Thus, this study is still underway. We anticipate a final interview early in 1989 to collect information on households' eventual mitigation actions.

To evaluate the effects of risk information, we randomly assigned each household one of six different information packets.[23] These included the EPA Citizen's Guide to Radon, a one-page fact sheet similar to those which some states currently used in testing firms' abilities to explain radon and four booklets with systematically varied amounts of quantitative information about radon's risk and the extent of direction given for using personal circumstances to adjust risk perceptions.[24] To illustrate what we learned from the results thus far, I will summarize the observed effects of the information materials on households' learning and updating of their risk perceptions.

To evaluate learning, each individual answered a set of multiple-choice questions (12 in the baseline interview and 6 in the first follow-up). Four questions were repeated between the two interviews. Our measurements were based two gauges of information transfer. The first used the total number of correct answers for all questions and subsets of the questions classified by the type of information elicited (e.g. risk, measurement, or mitigation). The second focused on whether performance improved with only the repeated questions. We found the level of the two-month radon reading was a positive, statistically significant determinant of performance in the follow-up quiz. Moreover, it was significant (at least at the ten-percent level) in determining desirable changes in performance (i.e. going from incorrect to correct responses) between the two quizzes for two of the four repeated questions. As we expected, the radon reading was an important motivation to acquire more information about radon's risk.

All models also indicated the type of information brochure received influenced learning. Overall, the fact sheet was found distinctly inferior to all other alternatives, while the relative performance of the remaining information brochures depended on the subject matter of the questions. As one might expect, brochures emphasizing quantitative risk information enhanced performance on radon measurement-related questions.

Perhaps the most surprising result concerned the five brochures. We had regarded all five as containing comparable factual content. Yet each had a had a distinguishably different effect on learning, as measured by numerous questions, including questions asking for advise they would offer a neighbor. (See Smith et al. [1987].) For some learning tasks, the information booklet was a more important explanatory factor than was the household's radon level.

The second aspect of the work involved the formation of risk perceptions in response to new information. We developed a simple risk-updating model based on a hypothesis that current risk perception was a direct function of the individual's prior reported risk perception, in addition to any newly acquired information. This format can be derived from the model I sketched earlier, assuming the loss function was a quadratic in a person's perceived risk. In all three interviews, we elicited subjective risk perceptions using a 1-to-10 scale. Each respondent described how serious the risk of radon exposure was for himself as well as his household.

Table 1 presents selected coefficients from two models - one based on the first risk update (after receiving the two-month reading) and one using the risk perceptions after the annual readings were sent (labeled second update). Three conclusions follow from these results. First, risk perceptions are updated systematically and do respond to the radon information. Second, the format used to explain radon's risk was important for both risk updates but impacted each differently. When individuals updated their perceptions after the two-month reading, they were revising perceptions formed before readings for their homes. In these first updates, the lengthier materials effectively reduced individuals' subjective risk perceptions (for a given radon level) relative to their perceptions with only the single-page fact sheet. The nature of the information materials' effects changed with the second update. In this case, only those receiving the command/qualitative brochures (formats are explained in Table 2) exhibited significant differences from those receiving any other types of materials. This difference may reflect the new radon readings and/or the type of booklet. Because readings in the living area were very similar for the two-month and annual monitors, they did not represent new information.

The annual basement radon readings were substantially higher than were the living area readings. Taken together with a booklet (command/ qualitative) that encouraged individuals to think in terms of thresholds (with readings below the EPA guideline regarded as safe and those above as implying a household faced serious risk), these increases apparently caused some households to increase their risk perceptions more than warranted.

Finally, the pattern of effects of the radon readings on each risk update and the relative size of the estimated coefficient for the prior risk perception are all consistent with a rational updating process. More specifically, only new information -- the basement readings -- affected the risk perceptions stated at the time of the second update. The other readings did not have this effect. Equally important, the size of the estimated coefficient for prior risk perceptions conforms with those expected in a rational learning framework. Before the first update, a household's risk perceptions were largely "guesses" based on popular media presentations. We would expect, therefore, that they would be given small weight in comparison with that given to new information (the radon readings and the information materials). This is precisely what the estimates indicate. With the second update, prior beliefs were based on factual information, and the new information simply refined a household's knowledge. The weights reflect this interpretation with about equal weight implicitly given to both information sources.

Results from the second risk-communication program in three Maryland towns further enhance our understanding of information's role in risk perception and behavior. First, the results indicate that information conveyed through public media can directly affect people's knowledge of radon, corresponding to the program's targeted subjects. Second, these programs appear to affect viewers' decisions to acquire more specific information through radon testing. Thus, these results provide the first evidence linking risk information to subsequent behavior.

This second program aimed to develop and evaluate practical information programs that could eventually be used to promote radon testing.[25] Three Maryland towns were selected for analysis -- Hagerstown, Frederick, and Randallstown. The first two communities received different public information programs developed jointly by EPA's Program Evaluation Division and the Research Triangle Institute. The third community served as a control. Table 2 describes the two programs. For program evaluation, three sets of telephone interviews were conducted in each community. These included baseline surveys of random samples of approximately 500 individuals in each community in December 1987 (before the program) and then two follow-up surveys conducted concurrently in April 1988 (after the program). These follow-up interviews involved repeat contacts with those originally interviewed, along with independent samples of another 500 individuals in each town.

Our analysis focuses on two aspects of the panel sample's responses: (1) evaluating how well they learned the key elements of the program's intended messages, and (2) examining the factors that explain respondents' radon testing decisions. Table 3 reports some of the estimated parameters from multinomial logit models. These models were used to describe how the EPA communications program affected answers to each of two repeated questions (from the baseline and follow-up radon quiz). These questions related to the EPA program's two primary messages:

- Radon is a serious health risk and anyone can be at risk.
- Radon testing is inexpensive and easy to do.

By classifying the two answers for each question, four mutually exclusive categories were defined. These were classified by baseline quiz answers and by the answers to the same question on the follow-up: no knowledge = incorrect, incorrect; unlearn = correct, incorrect; learn = incorrect, correct; and both correct - correct, correct. The table reports selected parameter estimates for the two outcomes of primary interest -- learn and both correct. The parameters reflect each variable's differential effect for the likelihood of the states defined as learn or both correct, in comparison to the no-knowledge outcome.

Three aspects of these findings are relevant to my overall argument. First, the most extensive information program (in Frederick) had a consistently significant, positive effect (at least at the 10% level) on learning for both of the targeted questions. Moreover, this effect can be distinguished from any prior knowledge.

Second, other independent information programs effected respondents' knowledge. These effects are reflected by the qualitative variables in Rows 3 and 4 of Table 3. They examine whether an independent radon information program (a week-long public service television special on radon initiated by WJLA, a Washington, D.C. television network) had a separate effect on learning. Two of our towns were in this station's viewing area. Since the EPA public service announcements were not televised, both types of recall statements could be considered as reflecting WJLA's program. Finally, Hagerstown's smaller-scale program apparently did not transfer sufficient information to improve respondents' knowledge on these issues.

These findings reinforce the New York study results. In sum, people do respond to risk-related information. Moreover, the Maryland study indicates that this response will hold true even when respondents have not expressed direct interest in the subject (by participating in a radon monitoring project).

The estimates in Table 4 provide a behavioral response to a public information program. This response measured whether households which had not previously monitored their homes for radon later decided to do so in response to the public information program. Column 1 in the table reports a probit model describing those households which were tested prior to the baseline survey. Column 2 reports a comparable analysis of the nontesters at the time of the baseline interview who appear by monitoring to have responded to the program.

The positive and significant coefficient for the qualitative variable used to designate the Frederick program suggests a direct connection between the information program and new testing decisions. This implies an increase of nearly five percentage points in the probability of testing as a result of the program in Frederick (.03 to .076). Only a few other factors appear to influence these decisions, including (1) prior knowledge of radon (reflected by the qualitative variable for discussing radon); and (2) the inverse Mills ratio to account for the selection effects associated with the nontesters at the time of the baseline interview (see Heckman [1979]). The model in Column 1 was used to estimate this term.

These results indicate that it is possible to accurately describe individuals' learning and risk perception processes. Our models are largely reduced-form empirical summaries. Yet the risk updating models are consistent with the framework sketched for describing how risk perceptions and behavior might be jointly determined. Our evidence on learning is largely empirical. Nonetheless, it does indicate that information conveyed through the general media definitely affects learning. Moreover, it indicates that information programs can induce some modest increases in the number of individuals who monitor their homes for radon.

A more specific empirical analysis of the theoretical framework to describe learning, risk perception, and behavior must await further observation. It should be possible to use this information along with the updated risk perceptions to evaluate whether responses were formed from separate processes or as a result of integrated decisions.

III. Implications for Environmental Policy

This paper began by arguing that risk management is likely to be the focus of future environmental policies. While this focus should offer opportunities for economic analysis, they have not yet materialized. The existing environmental statutes have clearly contributed to this omission. Nonetheless, a part of the blame directly lies within economics itself. Indeed, the conventional economic model of individual behavior in the presence of uncertainty places the lottery as the dominant characterization of risk. In

such a setting, concern over learning about risk or in understanding the odds associated with the process largely disappears. Moreover, these models routinely assume markets actually discipline behavior, reducing the influence of economic agents who do not learn from observed economic responses.

Unfortunately, neither of these features is present with environmental risks, and the processes at risk are not often repeated. Information about them is often diffuse, contradictory, or ambiguous. Personal experiences, judgments, and interpretations then become key elements in characterizing environmental risks. Equally important, markets cannot be relied upon to discipline "slow learners."

A new framework is needed under these conditions, which I believe characterize many important real-world sources of risk. The framework I sketched at the end of Section I treats risk perception and behavioral decisions as joint outcomes of consumption plans. This approach would require a more specific treatment of the cognitive processes which individuals customarily use to interpret information about risk. Testing and evaluation would require greater acceptance of surveys of individual responses to hypothetical situations, along with the use of existing risk sources to develop real-world counterparts to social experiments.

The available empirical evidence from both sources (summarized in Section II) supports the directions implied by this general framework. However, neither source tests an alternative structural model. At this stage the findings are barely beyond suggestive anecdotes. With this summary, then, it must be clear that advice one valuating current policies cannot as yet be very specific.

I believe the first implication of both the conceptual and empirical problems associated with the expected utility model is that risk communication programs must be treated as integral components of all environmental policies. Enhancing public understanding of existing environmental risks is at least as important as any of the currently proposed risk-reducing policies. There is a wide discrepancy between the risks identified by the general public and those recently identified as important by EPA technical experts (in their report Rating the Risks. See U. S. Environmental Protection Agency [1987].) This discrepancy is one recent reflection of the failures in risk communication.

Moreover, the costs of inadequate risk communication may well increase dramatically, given recent policy initiatives. Two examples illustrate this general problem. The first illustration concerns the valuation of reducing risks of chronic and acute health effects, the pending reauthorization of the Clear Air Act, and the record ozone pollution the summer of 1988. Indeed, a recent comparison of ozone concentrations in 1983, 1987, and 1988 indicated increased violations of the current standard. Some preliminary evidence has found that long-term exposures to low ozone levels may permanently effect on the respiratory system, this has rekindled interest in more stringent uniform standards.

Such controls are potentially costly, ranging to as high as $100 billion over the next ten years, as Krupnick [1988] has recently observed. Yet the

quality of our estimates of the value of risk reductions is so inadequate that the annual benefits (based on clinical studies) ranged from $51 million to $4.7 billion. This difference amounts to a variation of two orders of magnitude, from $.46 to $43 per person. Such lack of resolution arises from our lack of successfully communicating risk and correctly evaluating how households would value risk reductions of morbidity effects.

A comparable problem arises with groundwater contamination. This pollution affects the definition of cleanup at Superfund sites, as well as the design of policies to manage underground storage tanks. In all these cases, the failure to effectively communicate the meaning of the risks involved has led many policy makers to abandon economic methods altogether as effective sources of valuation information. The latency period, cause of death, and indeed, level of risks involved are usually quite different (generally smaller) than on-the-job risks of fatal accidents. Thus, we expect that incremental values will be different also.

We must resolve the risk communication problems and also develop integrated models of the cognitive and economic factors involved in just how individuals learn about risks and respond to them. Until that happens, economists are unlikely to be able to offer constructive contributions to the emerging policy issues involving environmental risk.

Table 1. RISK UPDATING MODELS FOR NYSERDA RADON MEASUREMENT PROJECT[a]

Selected Independent Variables	Risk Updating Models[b]	
	First	Second
Two-Month Radon Reading[c] (Living Area)	.024 (2.927)	-.031 (-0.760)
Annual Radon Reading[c] (Living Area)		.013 (1.004)
Annual Radon Reading[c] (Basement)		.006 (2.355)
Prior Risk Perception	.063 (3.228)	.458 (10.897)
Information Materials[d]		
Command/ Quantitative	-.084 (-2.048)	-.021 (0.583)
Command/ Qualitative	(-.030 (-0.721)	.088 (2.488)
Cajole/ Quantitative	(-.122) (-2.960)	(-.002) (-0.070)
Cajole/ Qualitative	-.059 (-1.486)	-.020 (-0.585)
EPA Citizens Guide	-.027 (-0.405)	-.001 (-0.031)

[a]These results are taken from Smith, Desvousges, Johnson and Fisher [1988]. The complete models are reported in Table 1 of that paper and are estimated using a two-limit tobit estimator with adjustments for attrition and selection effects on each sample. The coefficients can be interpreted as measuring the marginal contribution of each variable to the rescaled (to the 0-to-1 interval) risk index. The first update model relates to only the sample of individuals with complete information for the second update. The numbers in parentheses are the ratios of coefficients to their estimated asymptotic standard errors. The risk perception indexes have been rescaled to the 0-to-1 interval.

Table 1. (continued)

[b]The basic model specifies that $R_t = \alpha_0 + A_1 R_{t-1} + \Sigma \beta_j I_j$, where I_j designates the variables describing the new information and the individual's characteristics if they are hypothesized to influence how individuals interpret new information.

[c]Measured in picocouries per liter.

[d]These are qualitative variables describing the information material each individual received with their two-month readings. As Footnote 23 explains, ethical considerations required that we replace the materials given to people who received the fact sheet with their two-month reading. The fact sheet is the omitted category.

The four project design information booklets are identified by the two criteria underlying their definitions - extent of quantitative information provided about risk and the extent of encouragement given to adjust EPA's guide and to fit each person's circumstances (Cajole = personal adjustment encouraged; Command = adjustment discouraged).

Table 2. DESIGN FEATURES OF MARYLAND PUBLIC INFORMATION PROGRAM

Community	Role in EPA Test	Elements of Treatment[a]			Impact of Independent WJLA Program[b]
		Media	Mailings	Outreach	
Randallstown	Control	None[c]	None[c]	None[c]	10 kits
Hagerstown	Treatment #1	PSA to 3 radio stations every two weeks; project-designed posters ran in newspaper one week in February; four additional articles in paper	Pamphlet inserted in utility bills during February/March billing cycle	None	93 kits
Frederick	Treatment #2	PSA to 2 radio stations every two weeks; five of eight articles in local newspaper project-related	Pamphlet inserted in utility bills during February/March billing cycle	Posters (4) in locations around town; nine presenta- to community groups between January and March 1988; organized Radon Awareness Week; arranged for Mayor and Aldermen to monitor their homes	669 kits

[a]The primary messages emphasized in the public service announcements (PSA), posters, public meetings, etc. were:

- Radon is a serious health risk. You may be at risk. The only way to find out is to test.
- Testing is easy and inexpensive.
- Radon problems can be fixed.

[b]Independent of the EPA project, a Washington, D.C. television station, WJLA, conducted a month-long campaign to encourage people to test their homes for radon during January/February of our study period. The campaign had multiple components, with coordination by television and newspapers, and availability of radon test kits at a reduced price at Safeway Supermarkets. The campaign began on January 12, included a three-part news series during the week of January 18, and ended with another three-part series during

Table 2. (continued)

the week of February 15-19. Advertisements for the effort appeared in the Washington Post and on television. 100,000 radon test kits were purchased, with 70,000 returned for analysis. Television ratings indicated an audience of 76,000 viewers. The television programs targeted the Washington, D.C. viewing area. Residents of Frederick were most likely to watch the station airing the programs. Hagerstown residents could view WJLA, but reception is poor without cable. Randallstown is outside the viewing area, but reception is good. Numbers refer to the radon test kits returned from each community.

[c]None refers to the fact that there were no project-initiated information materials presented in public media mailings or meetings. Some independent newspaper articles did appear in a local paper.

Table 3. LEARNING MODELS FOR MARYLAND PANEL SAMPLE[a]

	Questions[b]			
	How can you test for radon?		What kind of health problems does radon cause?	
	Learn	Both Correct	Learn	Both Correct
Qualitative Variables[c] for Program Effects				
Frederick	.451 (2.522)	.280 (1.260)	.378 (1.846)	.706 (3.733)
Hagerstown	-.032 (-0.181)	-.166 (-0.735)	.139 (0.681)	.457 (2.421)
Heard about Radon on TV	1.526 (10.624)	1.464 (8.095)	1.474 (8.736)	1.497 (9.547)
Recall WJLA Program	.477 (1.644)	.572 (1.741)	.682 (1.804)	.823 (2.313)
Other Factors				
Education	.068 (2.445)	.197 (5.527)	.030 (0.920)	.138 (4.705)
Talked about Radon before Program	.234 (1.524)	1.059 (6.014)	.368 (2.006)	.854 (5.437)

[a]Source: Desvousges, Smith and Rink [1988, Table 4A]. Numbers in parentheses are ratios of the estimated coefficients to their asymptotic standard errors.

[b]The models are estimated in multinomial logit framework where the probability of each outcome, Prob (Outcome 1), is described as follows:

$$\text{Prob (Outcome = 1)} = \frac{e^{x^T\beta_1}}{\sum_{j=1}^{4} e^{x^T\beta_j}}$$

Table 3. (continued)

where: x = a Kx1 vector of values for the independent variables hypothesized to influence the four states defined by a respondent's answers to the radon quiz questions.

β = a Kx1 parameter vector

[c]The variables are defined as follows:

Frederick, Hagerstown	= qualitative variables (0, 1) designating town of residence. (Randallstown is the omitted category.)
Heard about Radon on TV	= qualitative variables (0, 1) indicating the respondent heard about radon on television after the information program.
Recall WJLA Program	= qualitative variable (0, 1) indicating the individual recalled the special unrelated information program about radon on a local Washington, D.C. station about radon during a public information program.
Education	= years of education.
Talked about Radon	= qualitative variable (0, 1) indicating individuals had discussed radon with relatives, friends, or neighbors prior to the information program.

Table 4. DETERMINANTS OF RADON TESTING: MARYLAND PANEL SAMPLE[a]

Independent Variables	Before Information Programs	After Information Programs
Constant	-3.020 -5.843	-1.651 (-2.883)
Family Income (in Dollars)	$.26x10^{-5}$ (0.648)	$.29x10^{-5}$ (0.661)
Years of Education	.052 (1.668)	-.062 (-1.765)
Age	-.005 (-0.774)	.002 (0.473)
Sex (1 = Male)	-.059 (-0.414)	---
Health Attitude (Concerned About Health = 1)	.328 (2.333)	-.007 (-0.042)
Number of Years at Address	$.36x10^{-3}$ (0.052)	---
Have Basement and Use It for Living Space (=1)	-1.59 (-1.075)	.057 (0.366)
Total Correct Answers Baseline Radon Quiz	.202 (5.480)	---
Hagerstown (=1)	---	.078 (0.368)
Frederick (=1)	---	.437 (2.243)
Talk about Radon Prior to Baseline (=1)	---	.345 (2.232)
Saw WJLA Program (=1)	---	.091 (0.427)
Inverse Mills for Baseline Testing	---	-2.168 (-2.466)

Table 4. (continued)

[a]These models are probit estimates. The numbers in parentheses below the estimated coefficients are rations of the coefficient to the estimated asymptotic t-ratio.

[b]An inverse Mills ratio is included in the probit model for the new testing decisions to reflect the selection effects of losing those who tested at the baseline. Bivariate probit models for both testing decisions did not converge.

NOTES

*University Distinguished Professor, Department of Economics and Business, North Carolina State University, and University Fellow, Resources for the Future. This paper draws on research conducted in collaboration with Bill Desvousges over the past five years. It was originally presented as the Benjamin H. Hibbard Memorial Lecture at the Department of Agricultural Economics, University of Wisconsin, Madison, and will be published as part of that lecture series. Thanks are also due Richard Bishop for constructive comments on an earlier draft of this paper and to Dawn Danz-Hale for substantially improving the exposition. Partial support for the research was provided by cooperative agreements from the U. S. Environmental Protection Agency.

1. The Science Advisory Board's report (EPA [1982]) makes this point in quite specific terms, noting that:

> EPA's basic mission is to reduce the level of risk to health and to the environment posed by wastes, residues and contaminants....In the past, EPA has largely focused on specific programs mandated by Congress....The EPA research and development strategy should focus on problems and areas where there is the greatest potential for reducing risk to human health and the environment" (p. 4).

2. In a series of papers, Huber [1983a, 1983b, and 1986] has emphatically developed this theme, noting a bias in the way legislators, administrative rule makers, and judges deal with risk. Each tends to favor accepting old risk (in many cases by default) and rejecting any new ones. Graham and Vaupel [1981] offer specific examples of how decisions can imply widely disparate values for risk reductions, from 0 for a group of transportation safety policies, such as mandatory airbags, to $169 million (per statistical life) in OSHA's analyses of work place concentrations of acrytonctride.

3. Of course, it is important to acknowledge that the statutes governing EPA's regulatory programs also limit the role economics can play in defining regulatory standards. This is most stringent in the case of the primary standards for criteria air pollutants, because the Clean Air Act prohibits any consideration of the costs of control. (It does not preclude consideration of the benefits.) Moreover, since Executive Order 12291, OMB has required that benefit-cost analyses be prepared and submitted as part of the regulatory impact analyses, even though the benefit-cost information must not play a role in defining the standards involved.

4. See Shoemaker [1982] for a fairly complete summary of most of the early literature. See Hogarth and Reder [1986] for a more recent discussion of the contrasts between economists' and psychologists' interpretations of and responses to the failures of the expected-utility framework.

5. Usually referred to as risk assessment heuristics, these rules have been extensively discussed by Kahneman and Tversky [1979] and Slovic et al. [1985].

6. Examples of these rejections of state-dependent specifications include Malinvaud [1972] and Hirschleifer [1970]. See also Hirschleifer and Riley [1979] for an early overview of the contrasting views of the theoretical plausibility of a state-dependent utility specification.

7. An alternative treatment assumes that the arguments in an indirect utility function are random variables, because of stochastic influences outside an individual's control. This format has two implications. First it implicitly restricts the way in which uncertainty can influence behavior by the variables (e.g. prices versus income) that are treated as random. Second, it is a continuous analog of the state-preference approach, focusing on the distributions used to characterize the relevant random variables, rather than probabilities of "events."

8. Arrow's [1974] justification for state-dependent preferences in a health context observed that "...income is not the only uncertainty, especially in the context of health insurance, and only under special and unrealistic circumstances can it be held that the other uncertainties have income equivalents. Put loosely, the marginal utility of income will in general depend not only on the amount of income but also on the state of the individual or, more generally, on the state of the world" (p. 2, emphasis added).

9. The best example of this same point in the environmental literature can be found in the early discussions of the sign of option value. The assumptions made about differences in the marginal utility of income across states distinguished the positions of those involved in these debates. See Schmalansee [1972] for an early discussion that treated this issues by assumption. Bishop [1982], Graham [1981], and Smith [1983] discussed in more detail the implications of these types of assumptions.

10. For the most part, the efforts by economists to develop alternatives have not changed the basic predictions of the model. That is, the marginal rate of substitution between money and risk moves in the same direction with a change in probability for a wide range of the proposed alternatives. See Smith and Desvousges [forthcoming] for further discussion.

11. Asch [1988] was the first to use this argument in discussing the implications of health and safety regulations.

12. Kahneman and Tversky [1979] have argued that reference effects (e.g. the direction of the effect in relationship to the status quo) help to explain many seemingly irrational responses. However, their argument presupposes that

individuals' valuation functions have a specific shape, without ever explaining why this pattern arises.

13. Schulze et al. [1986] found qualifications to this conclusion. Their experiments indicate that at low probabilities (around .01), simple replication of insurance markets may not lead to behavior that conforms with an EU framework for a large number of subjects.

14. This research is a joint effort. The New York experiment is joint with Bill Desvousges, Ann Fisher, and Reed Johnson. The Maryland analyses were conducted with Bill Desvousges and Hillery Rink.

15. Thaler and Rosen [1976] offer the first empirical analysis of this type. Viscusi [1986] provides a good summary of the method and its role in policy analyses. Fisher et al. [forthcoming] have recently summarized the estimates of the values for statistical lives implied by these estimates.

16. The hedonic wage model provides estimates of the wage increment an individual would expect to realize from a small reduction in risk of a fatal accident on-the-job. These measures are often reported as the total payments a group would pay for these risk changes, so that the expected number of fatal accidents would be reduced by one. Thus, if Δr is the risk reduction and we require than n individuals experience this change, then the n sufficient to reduce expected fatalities by one is:

$$n = \frac{1}{\Delta r}$$

If the wage reduction an individual would agree to accept to realize the risk reduction of Δr is Δw, then the value of a statistical life is $-n\Delta w$ or $\underline{\Delta w/\Delta r}$ <u>(recognizing that both Δw and Δr are negative values in this explanation.</u>

17. We expect that the marginal value of a risk reduction would be higher when risk level is higher. See Jones-Lee [1974] for a discussion.

18. In published research associated with the Boston hazardous waste contingent valuation survey, Bill Desvousges and I investigated the relationship between a stated risk perception using a ladder with a scale that distinguished segments according to the magnitude of the risk (see Smith et al. [1985]). The contingent valuation questions asking about the compensation an individual required to accept a new job with higher risks were not related to stated risk perceptions. Yet, as Gerking et al. [1988] found the subject risk perceptions were consistent with the BLS industry risk data for their industries. A simple OLS model yielded the following results:

$$\text{Subjective Risk} = -.0002 + 7.287\ (\text{BLS Fatality Risk})$$
$$(-.1476)\ (3.598)$$

$$R^2 = .031$$
$$n = 413$$

Attempts to distinguish the effects of occupation and other personal characteristics were not successful.

19. Examples of the early work focusing on situations involving one site are reported in Adler et al. [1982]. More recently, Schulze et al. [1986] have adopted a different approach to estimating hedonic models by considering only sales that are within some close proximity to a site with hazardous waste. There is some question as to whether models developed using this strategy should be treated as reflecting an equilibrium price vector.

20. Part of the problem was due to the timing of households' knowledge of the presence of the wastes at any particular location in relation to the timing of housing sales. The findings of both Kolhase [1988] and Michaels et al. [1988] confirm these difficulties.

21. This finding was confirmed by the most recent follow-up survey in the NYSERDA radon study. Because it was a mail survey, we were able to evaluate the performance of different questions for eliciting risk perceptions in comparison with the 1-to-10 scale. Other indexes more closely linked with probabilities were not associated with the radon measurements. However, they were consistent in overall direction with the 1-to-10 risk scale. (See the appendix to Smith et al. [1988b] for details.)

22. This project required cooperation from NYSERDA, EPA, the New York Department of Health, the seven investor-owned electric utilities in the state, and the Office of Management and Budget. A detailed description of the design, involvement of advisory groups, and other experts is available in Smith et al. [1987].

23. Ethical considerations imposed an important qualification on this assignment process. Because the single-page fact sheet had less information that the other information booklets, we did not allow anyone whose two-month reading was 1 picocuries or more to receive it. This group was randomly assigned one of the five information booklets. Those with readings below 1 picocurie received either the fact sheet or one of the other five information materials. This feature had important implications because our results indicate that those receiving the fact sheet were concerned about the radon, despite their low levels.

24. All of the project designed booklets were subjected to a word analysis for their reading levels and were found to correspond to about the 11th-grade level. (See Smith et al. [1987] for more details.)

25. For more detailed discussion of the program, see Desvousges, Smith and Rink [1988].

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