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Environmental Risk Perception and Valuation:
Conventional versus Prospective Reference Theory

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I. Introduction

The definition of the commodity is a central issue in modeling people's choices in the presence of uncertainty. To appreciate why this is so, we need to consider the modeling strategy inherent in virtually all microeconomic descriptions of people's values for commodities. Using tradeoffs to infer values is usually the first idea introduced in describing individual behavior with microeconomics. A commodity's value is measured by how much of some other good a person will give up to get more of the defined commodity. This concept is, of course, the essence of a marginal rate of substitution.¹

The conventional economic model for individual behavior in the presence of risk assumes that people choose lotteries and the rule for selecting them involves optimizing a Von Neumann-Morgenstern (VNM) utility function. While this function has specific properties that are important to its predictive power, the model is basically the same as that for behavior under conditions of certainty. VNM restructured their description of preferences to allow a lottery to play the same role as a commodity. The value the model implies for a lottery is described in terms of other goods people would trade for an increment to the lottery. Two aspects of this approach to describing people's behavior cause problems in applying it to real situations involving environmental risks. First, there is

no natural way to define and measure increments to a lottery. As a result, the economic models used to value changes in lotteries have focused on changes in either the probabilities or the outcomes that define each lottery. Much of the literature on private decisions involving lotteries concerns choices about insurance or about financial assets. With the exception of life insurance choices, the outcomes at risk are usually well-defined monetary values. Often people have the opportunity to gain experience through repeated transactions. Markets provide incentives that discipline incorrect perceptions of the probabilities inherent in such lotteries.

These mechanisms are not available for environmental lotteries. Both the probabilities and the outcomes are different. Environmental lotteries are usually described in terms of exposures to substances that involve serious, often life-threatening, health effects. A partial list of sources includes hazardous and nuclear waste, air pollutants, and pesticide residues on food. There are numerous others. Both the exposure probabilities and the conditional probability of a health outcome given exposure are not widely understood by people.¹ Because the outcomes often involve death, no opportunities exist to gain experience. And, in many of these examples, a different type of "time" compounds the problems people have in conceptualizing environmental lotteries as commodities. They never seem to end. Once hazardous substances are released into the environment or a person is exposed to a potentially harmful pollutant, the outcome is not resolved until the individual dies.²

The second problem with treating environmental lotteries as commodities arises from the ex ante nature of the tradeoff inherent in determining values for them. Exchanges are between some numeraire and attributes of a process that is not resolved when the tradeoff is defined. Of course, this is less important if

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people have prior experience with the outcomes at risk. But as I noted earlier, this is unlikely for environmental risks.

With this background, it is hardly surprising that economic analyses of efficient policies for dealing with environmental risks seem to be at odds with what people want. The Environmental Protection Agency's report, Unfinished Business [see U. S. Environmental Protection Agency (1987)], sought to rate environmental risks and found wide discrepancies between the public's identification of important environmental risks and those selected by EPA's technical experts. Motivated by such concerns about using economics to evaluate policies involving environmental risk, Machina [1990] recently recommended that we treat departures from the "strictures of probability theory" arising from the formation of risk perceptions differently from systematic departures from the predictions of expected utility theory. In his view, the former should be corrected, and the latter should not. Because this paper is about the connections between risk perceptions and valuation, it seemed appropriate to introduce it with this background and Machina's conclusion.

Environmental risks do not arrive as "neat," well-defined lotteries. They require that people acquire information and learn about the events at risk, including the processes underlying them. However, we know very little about how people perform these tasks. In the next section, I summarize some findings from the available research. Overall, they suggest that the framing of information about the process causing the risk can influence both perceptions and behavior. Moreover, people's preferences influence how they acquire this information, form risk perceptions, and value actions intended to reduce the perceived risk.³ Unfortunately, attempts to replace the conventional expected utility framework have not been successful in describing this multifaceted process as a complete

unit. Nonetheless, it is possible to illustrate how risk perceptions and values are connected. Section III develops this connection by comparing how the value of a change in risk can be described using a conventional expected utility model versus Viscusi's [1989, 1990] recently proposed prospective reference theory (PRT). PRT recognizes an individual's risk perceptions as distinct from the technical estimates of experts. Instead, they are a composite reflecting an individual's prior beliefs, the information they receive about the process, and the relative degree of confidence they assign to each. To demonstrate the links between perceptions and values, I use the PRT model to define a locus that describes how the values of a policy change would vary with the weights involved in defining subjective risk perceptions.

Drawing implications for environmental risk policy is certainly dangerous, especially after arguing that the conventional theory used to evaluate policy is incompatible with what people do and the empirical evidence is incomplete. Nonetheless, the last section describes how coordinating the available instruments might improve the efficiency of environmental risk policies.

II. Economic Research on the Risk Perception Process

Despite the wide acceptance of the expected utility model for describing individual behavior under uncertainty and the general recognition that experience must condition each person's beliefs about uncertain events, remarkably little economic research has been undertaken to describe how people form risk perceptions. Viscusi and O'Connor's [1984] evaluation of how chemical workers updated their risk perceptions and wage requirements in response to hypothetical product labels appears to be the first such study. Psychologists have expressed long-standing interest in these problems and have often criticized the expected

utility (EU) framework.⁴ Nonetheless, the recent research on risk perception is different from their experiments, which have been designed to explore the limits of people's ability to process information.

Two types of studies characterize the recent work. The first type involves hypothetical behavior and follows the general format of contingent valuation (CV) studies. (See Mitchell and Carson [1989] for a general overview of the CV method.) But in this case, the surveys seek to elicit how risk perceptions and/or contingent behavior respond to different hypothetical information treatments. The second type of research involves actual risks and the effects of different information programs. Because the risks are real, these studies have usually been conducted as part of evaluating the effectiveness of risk communication programs.

Both types of research suggest that people's risk perceptions systematically respond to information. The content and framing of the information can influence respondents' risk perceptions, stated behavior, and actual behavior.

A. Studies Using Contingent Behavior

Most current research that uses hypothetical situations to study how people's risk perceptions respond to information is associated with Viscusi's experiments. As noted earlier, the first of these (Viscusi and O'Connor [1984]) considered chemical workers and their perceptions of job risks from handling chemicals in the workplace. To evaluate how workers' risk perceptions responded to information, the study elicited each respondent's perception of his/her job risk using a simple scale with the average risk to manufacturing workers identified as an anchor on the scale. Each respondent was interviewed before and

after they read hypothetical labels describing new products. Respondents were asked their wage requirements and whether they would remain at their jobs if the hypothetical product they read about replaced the chemicals currently involved in their workplace. Viscusi and O'Connor's analysis of the risk updating process, as well as of the other behavioral responses asked of these respondents, strongly supports a rational response (and therefore conventional EU theory where learning and perception are treated as exogenous or predetermined to the specific behavioral response asked).

Viscusi's continuing research in this area reveals a subtle but systematic change in this conclusion. With each progressive reduction in the way the information presented to respondents connected risks to precautionary behavior as well as in the structure of the behavioral questions asked of them, support for the conventional framework with its separation of risk perception and behavior lessened.

Viscusi, Magat, and Huber's [1986] study reinforced Viscusi and O'Connor's analysis, however it was a highly structured evaluation of responses to a single source of risk. These authors interviewed respondents about precautionary behavior for using two hypothetical household products. Labels for each product varied the amount of risk information and its prominence on the label. Each respondent in a shopping mall intercept survey was shown one product label and asked about product use patterns to avoid prompting them to focus on the risk-related questions. While specific risk perceptions were not elicited, questions about general risk attitudes and precautionary behavior were asked. Both sets of responses supported the conclusions drawn in Viscusi and O'Connor's earlier study of chemical workers' risk perceptions. However, when the experimental situations introduced multiple risk sources (see Viscusi, Magat and Huber [1987])

or used questions relying on open-ended memory tasks related to the information from hypothetical product labels (see Magat, Viscusi and Huber [1988]), the cognitive factors frequently identified by psychologists as important to how people process risk information were found to influence both experiments' findings. With multiple risks, departures from a rational model's predicted behavior seemed to be related to cognitive factors in a respondent's understanding of risk information. This was reinforced in the last study. Magat, Viscusi, and Huber [1988] concluded that the experiments indicate "...an upper bound on individuals' ability to process risk information" that may well interfere with their overall ability to use that information.

The most recent study investigating the influence of information on risk perceptions and behavioral intentions (Weinstein, Sandman and Roberts [1989]) follows the overall design of the Smith et al. [1990] New York radon study (discussed below) but asks people about their risk perceptions and behavioral intentions in response to hypothetical radon and asbestos readings, different types of information about the risks they produce, and mitigation responses. The sample consisted of New Jersey homeowners with telephone listings who agreed to receive one of 56 different information treatments designed for the study along with a questionnaire. Thirty-four percent of the 8,500 households contacted agreed to participate. About two-thirds of them (1,948) returned questionnaires.

Table 1 describes the differences in the seven information treatments used in the study. Each treatment involved a four-page brochure--one for radon and one for asbestos. The last page in each type of brochure was altered to incorporate information identified as the design feature. Each respondent was asked to evaluate their circumstances using one of four hypothetical exposure levels for the substance serving as the source of risk for their treatment.

Thus, 56 different possibilities arise from the source of risk (2) x level of exposure (4) x information attributes (7).

Respondents were asked to evaluate the brochures, including their perceptions of risk seriousness, the likelihood of illness, and their intentions to take action if they were to receive the hypothetical radon or asbestos readings (described in the questionnaire as "imaginary"). The authors draw rather strong conclusions from their analysis of the responses to these information treatments. Those most relevant to this paper are:

- (1) People respond differently when an action level is presented based on variables likely to be related both to risk perception and remediation plans.
- (2) People receiving probability information did "a better job of estimating illness probabilities." However, comparisons of the risks assigned by respondents with radon versus asbestos as the hypothetical source indicated that the risk levels were not correctly scaled in terms of their absolute levels by either group.
- (3) Respondents receiving comparative risk information reduced their risk averse reactions to the materials.

While these conclusions support the argument that preferences, information, and perception are linked, they should not be taken as the result of conventional statistical tests with the survey data collected. Instead, they are the authors' interpretive judgments, based largely on bar graphs comparing the answers to categorical variables across information treatments. While the authors report some statistical analyses, these tests generally used measures of each response derived from recoding categorical variables in forms that imply specific

quantitative differences in the responses to questions posed as qualitative judgments. For example, the remediation question for radon was:

"Given your test results and the information in the brochure, do you think you need to reduce the radon level?

- should take action even if it is hard to reduce the radon level.
- should take action only if it is relatively easy to reduce the radon level.
- do not feel action is needed at my level.
- undecided.
 - Which way would you be leaning?
 - reduce the radon level
 - do not reduce the radon level

These responses were recoded on a 1-to-4 scale. Regardless of which end of the possibilities from "definitely taking action" to "undecided" was coded as 4, the relative magnitude of the effects is completely arbitrary. Most of the authors' statistical analyses treated these types of variables as if they were continuous quantitative indexes of each type of response.

Thus, the most appropriate conclusion to be drawn from their analysis is that the findings are the qualitative judgments of the researchers based on simple statistical summaries of the response distributions. They may not be as conclusive as the authors imply. Nonetheless, when their findings are combined with the work of Viscusi and his co-authors, which was based on fewer information alternatives but more rigorous testing, the record from contingent behavior studies clearly supports the link between risk perceptions and behavior.

B. Studies Using Risk Communication Programs

Research findings that rely on responses to hypothetical situations inevitably face the criticism that reports based on people's interpretations of

hypothetical situations and their contingent responses may not be reliable guides to their actual responses to risk information.¹ Policy interest in using information programs over the last five years has spawned several studies of their effectiveness. These studies can be distinguished by two design features: (a) the ability to observe a sample of people update their risk perceptions and undertake activities in response to information about specific types of risks; and (b) the experimental control over the information provided to the sample. In what follows, I will summarize the results of four studies--all associated with radon risk--that investigated the influence of information on risk perceptions.²

Reed Johnson and I (see Smith and Johnson [1988] conducted one of the first efforts to evaluate how people respond to information about a real risk. Staff at the Maine Medical Center interviewed a sample of individuals who had participated in an epidemiological study they had designed relating lung cancer to radon exposure as well as a control sample of households who requested tests of air or water as part of the Radiological Health Program offered by the Maine Department of Human Services.³ All of the 230 households agreeing to telephone interviews about their risk perceptions, mitigating activities, and socioeconomic activities were monitored for radon in both indoor air and water. Interviews were conducted after each household received their radon readings along with the same eleven-page information booklet (describing the sources of radon, its health risks, and possible mitigation strategies). Respondents were asked their perceptions of radon's risks at the time of the interview and what their perceptions of radon's risk were prior to receiving the monitoring results and pamphlet. The results supported Viscusi and O'Connor's updating model and indicated that information and mitigation actions affected risk perceptions.

Respondents' radon readings were positive and significant influences on current risk perceptions. Experience with a cancer patient in the household also increased the weight respondents assigned to their perceptions prior to receiving the monitoring results and pamphlet. Unfortunately, the retrospective nature of the risk perception question and the inability to observe how different types of information affected these respondents limits the usefulness of this study as support for my overall argument that environmental risks often are not well-defined and, therefore, risk perception must be treated as an important component of behavior.

The last three studies do allow this issue to be investigated more directly. Two of them involve my joint research with Bill Desvousges initiated in 1985 to investigate the performance of different types of risk communication programs in New York and Maryland. Because the New York study is still underway (the surveying of participating households is finished but empirical analysis of the panel data describing their responses continues), I will review those findings last.

The Maryland risk communication program was initiated after some preliminary results were available from the New York study (see Smith et al. [1987]). The Maryland program sought to develop and evaluate practical information programs that could eventually be distributed to individual states in an effort to promote radon testing (see Desvousges, Smith, and Rink [1989]). 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). Then two follow-up surveys were 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.

The analysis I will summarize here 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. Three aspects of these findings relate to my overall argument about the connections between preferences, risk perception, and behavior for environmental risks. 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. (Information questions were asked during a baseline survey and then again after the program to promote testing.) Moreover, this effect can be distinguished from any prior knowledge. Second, other uncoordinated information programs affected respondents' knowledge.

Our study examined whether an independent radon information program had a separate effect on learning. A week-long public service television special on radon was initiated by WJLA, a Washington, D.C. television network. Two of our towns were in this station's viewing area. To attempt to account for this influence, we asked respondents during the second interview if and how they heard about radon. If they identified the WJLA program or simply stated "the television," both answers could be considered as reflecting WJLA's program. (The EPA public service announcements were not televised.)

Hagerstown's smaller-scale program apparently did not transfer sufficient information to improve respondents' knowledge on these issues. Table 3 reports our findings on whether the information programs affected behavior. This response measured whether respondents who had not previously monitored their homes for radon later decided to do so because of the public information program. Column 1 in the table reports a probit model describing the determinants of decisions to test for radon prior to the baseline survey. Column 2 reports a comparable analysis of the untested households at the time of the baseline interview who appeared to respond to the program by undertaking some type of monitoring for radon.

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 because 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 used to account for the selection effects associated with the untested households at the time of the baseline interview (see Heckman [1979]). The model in Column 1 was used to estimate this term. While these models are best interpreted as reduced form relationships, they do indicate a behavioral link between the decision to monitor a home for radon and the type of public information program used to describe radon's risk. Moreover, this impact could well be understated because information programs do appear to raise a household's level of awareness about the focus of those programs, and this appears to increase the likelihood of monitoring at a later time.⁸

Golding, Krinsky and Plough [1990] adopted a similar design in their study of the effects of information programs in three towns in Massachusetts--Clinton, Fitchburg, and Worcester. Worcester served as the control community. The other two received two different information programs about radon through their local newspapers. Each town was assumed to be served exclusively by its local newspaper. In Clinton, four technical articles appeared in the local newspaper, each covering a different aspect of radon: its source and nature, monitoring, health effects from exposure, and finally, mitigation. In Fitchburg, four articles covered the same concepts but used a dramatized account of one person's attempt to understand and cope with these aspects of radon.

Baseline and follow-up telephone interviews were conducted before and after the newspaper articles appeared in the two towns receiving the information and in the control community. Both panel and independent samples were composed to evaluate the effects of the programs. Unfortunately, the sample sizes for the follow-up interviews (both the panel and the independent groups) were small.⁹ The authors did not find differences in the effects of the two types of programs on respondents' decisions to test for radon. Indeed, the information programs did not appear to have a significant effect on testing decisions. As with the Weinstein et al. [1989] analysis, these conclusions are difficult to evaluate. The authors did not appear to consider multivariate analysis in evaluating the programs and relied instead on simple univariate tests and graphical descriptions of the data. With these small samples and rather small differences in the responses to questions about intentions to test or mitigate, their conclusions are likely to be correct. That is, it is unlikely that statistical tests with such small samples will uncover an effect that is not apparent from the summary data. The converse is, of course, not necessarily true. Effects that seem to

be present in simply descriptive summaries may not be associated with information treatments. Moreover, the criticism that is relevant to this study arises from the conclusion of "no effect" when the samples are too small to detect one. The differences between the information treatments may be small enough to require larger samples to be estimated accurately. This is especially true when individuals' demographic and economic characteristics influence how they respond to information programs. Thus, we cannot conclude that Golding et al.'s method for framing is not important. Instead, it may have such small effects that it requires a more discriminating test.

The last study to be reviewed is the most extensive and, in some respects, nearly as specialized as the evaluation of the Maine sample I described earlier.⁴ The NYSDERDA/EPA study of the influence of information materials on people's perceptions of radon risks and their mitigation decisions began before much of the risk communication research summarized above. Because aspects of this study's results have been summarized in several earlier papers (see Smith, et al. [1988, 1990] and Smith and Desvousges [1990]), I will focus this summary and overview on three aspects of the study: (1) a brief description of the design; (2) a summary of the influence of information on risk perceptions, including new evidence not previously reported in other papers that has been taken from the last interview after mitigation decisions; and (3) some highlights of the evidence on the influence of information on respondents' mitigation decisions.

In 1985, the New York State Energy Research and Development Authority (NYSDERDA) initiated a monitoring project to measure indoor concentrations of radon in detached single-family homes in seven geologic zones in the state. The study design selected a random sample of 2,300 New York homeowners who had no

plans to move in the next year and placed three radon monitors in each home--two in the living area and one in the basement. One of the living area monitors was removed after about two months, and the other monitors were returned after one year.

With EPA support and NYSDERDA cooperation, this monitoring project was used as an opportunity to evaluate the effectiveness of risk communication materials.⁵ The design was adjusted to conform to the NYSDERDA protocol for providing the participating households information about their radon readings. To meet this objective, four information brochures were designed, each varying the mode of presentation of risk information. They can be distinguished by two design attributes: the extent of quantitative information (i.e., quantitative versus qualitative) and the degree of encouragement given to respondents to evaluate how their personal circumstances might affect the risks they experience from radon (i.e., command versus cajole). Four different variants were composed by pairing the design alternatives from each attribute. In addition, the EPA booklet entitled A Citizen's Guide to Radon and a one-page fact sheet were also considered as alternative information treatments.

Each household received their radon readings in two steps--first the two-month readings from the living area monitor and then the annual readings for the remaining living area and basement monitors. In addition, they received one of the six information treatments. This treatment was randomly assigned with an important constraint--households with two-month radon readings higher than one picocurie per liter were not allowed to receive the one-page fact sheet and were randomly assigned one of the five remaining alternatives. Those with readings below one picocurie were randomly assigned to the six treatments, with about half

given the fact sheet and the remainder divided randomly among the five other alternatives.¹²

The analysis of the effects of these information materials is based on four interviews of the same adult decision maker in the household who was randomly selected during a baseline interview conducted six months before the results for the two-month readings were sent to each household. The schedule for the information distribution and interviews, along with percentages of households completing each survey, are given in Table 4.

Table 5 summarizes the primary results applying the Viscusi-O'Connor updating model for risk perceptions to each of the three updates. Because of the experimental design, panel nature of the sample, and the application to "real" risks, these findings provide the strongest support to date for a systematic risk updating process that is influenced both by information and how it is conveyed to people. The radon readings were positive and significant determinants of risk perceptions when they were "new" information. The two-month reading was "new" for the first update and a positive, significant influence on stated risk perceptions. Thereafter, we would expect this reading's effect to be incorporated in the prior risk perceptions term (i.e., those formed at the first update), and this is what the model implies. Because the annual living area reading confirms the two-month reading, it is also not "new" information. The annual basement reading was surprising for most households--over twice as large as the living area readings. The second risk update reflects this aspect of the basement reading as "new" information with a positive and significant coefficient.

The information treatments also affect risk perceptions in ways that are consistent with people systematically responding to information. Those households

that received quantitative risk information (i.e., the command/quantitative and cajole/quantitative booklets, both containing risk charts linking radon readings to estimates of the lifetime risk of premature death from lung cancer) reduced their risk perceptions in comparison to households with comparable radon readings that received the one-page fact sheet.

The information materials are generally not influential thereafter. Again their effects are captured in the prior risk perceptions term. However, the second update produced an interesting response that did reflect a new effect from the information materials. Because of the surprising basement reading, households receiving the command/qualitative brochures updated their risk perceptions differently from those receiving other materials. This brochure emphasized the EPA Action Guideline for radon (at four picocuries per liter) and provided no specific risk information. As a result, it established the Action Guideline as a threshold. We (Smith et al. [1990]) conjectured that this treatment probably led respondents to treat the Action Guideline as a "threshold for safety," and therefore led these households to interpret their basement readings differently. This hypothesis was informally confirmed (as I noted earlier) by the Weinstein et al. [1990] independent results evaluating the effects of specific action guidelines for people's behavioral intentions and perceptions of both radon and asbestos risks.

The last two columns in the table report some preliminary results from the last interview. At this point, people had nearly a year to take action and revise their risk perceptions. Overall the average risk perception is lower and somewhat less influenced by the perceptions stated a year earlier. The information materials do not influence perceptions at this point. People have had time to take action and acquire information on their own. Moreover, we expected that

those mitigating would have reduced their risk perceptions. Because each household's annual readings are no longer "new" information, we would not have expected them to influence risk perceptions. The final models, both nonlinear 2SLS and the two-limit Tobit, confirm this hypothesis.

The conclusions drawn on this hypothesis depend on the estimator used to describe how risk perceptions were updated. Using the two-limit Tobit that recognizes the potential for censoring at either end of the risk scale, the qualitative variable for undertaking mitigation is a significant positive influence on risk perceptions stated after mitigation was completed. Our simple hypothesis expected a negative effect as observed with the Maine sample (see Smith and Johnson [1988]). There are several potential explanations. The nonlinear 2SLS explores one of them--namely that risk perceptions and mitigation should be treated as endogenous variables.¹³ When this was done, none of the other findings changed, and the mitigation term had a negative but insignificant influence on current risk perceptions.

It is possible that people reacted to the lifetime nature of the risk and adjusted their response to mitigation based on the amount of time they lived in their homes and were exposed to radon before receiving information about radon's risk. This type of response is consistent with Ippolito's [1981] explanation of the opposing effects of information about cancer-causing hazards on the aggregate patterns of consumption of hazardous goods that nonetheless contribute positively to utility. She argued on theoretical grounds for two opposing influences. People who are ignorant of radon's presence in their home and its risk should act to reduce the risk when informed of the hazard as one that increases with exposure. If the outset of the health effect is delayed after exposure, they also could perceive that their risks of cancer had already increased and choose

(because of shortened life expectancy) to postpone action in favor of other consumption activities. The net effect in Ippolito's life-cycle description of rational behavior with these types of risk could be in either direction.

The last aspect of the NYSERDA experiment concerns the influence of information on risk mitigation. As with the case of risk perceptions, the empirical evidence indicates a clear link between the information respondents received and their mitigation responses. Because most of the sample had low radon readings, we did not expect a large fraction to undertake any form of mitigation. Equally important, the expenditures for mitigation do not seem to imply a smooth continuous relationship. Consequently, mitigation was defined in categorical terms as: taking no action, acquiring information, or modifying the house to reduce radon concentrations. Using a multinomial logit model, both the radon levels and the type of information affected the likelihood of either acquiring more information or taking some action to reduce radon concentrations.

Information that identifies clear thresholds for action increases the likelihood a person will undertake some form of mitigation. This was especially true for respondents who perceived that they crossed the threshold implied by EPA's Action Guidelines. That is, when we considered the responses of households with two-month readings below four picocuries and annual basement readings above the Action Guideline, they had increased likelihood of mitigating in addition to the effect contributed separately by the level of the basement reading. When information materials served to reduce the resolution of the guideline without specific quantitative risk estimates (as in the case of the cajole/qualitative booklet), this response to a threshold was less pronounced.

C. Implications

Empirical analyses of the risk perception process are inherently limited. Controlling the level of serious risk experienced by people and manipulating the information they have to understand that risk is ethically unacceptable in most situations. Only in situations where the risk arises from natural sources and the information alternatives are considered equally effective can we investigate how differences in real risks and the information provided about them might affect people's risk perceptions. As the earlier summary indicates,¹⁴ these requirements limit the issues that can be considered. This is one reason why research on risk perception has posed hypothetical situations.¹⁴ Overall, both of the strategies that have been used to investigate how people organize information about risk situations, conceptualize their perceptions of those risks, and respond to them support an economic model of risk perception and behavior that links the two processes.

III. The Treatment of Risk Perceptions and Ex Ante Valuation

Once we acknowledge that risk perceptions reflect objective information about the events at risk and each individual's own beliefs about the process, then the task of defining ex ante values identifies a fundamental conflict. Are the departures of each person's risk perceptions from the "objective probabilities" a matter properly regarded as inherent in preferences? (This implies that we should accept them as we accept consumer sovereignty in defining ex post measures of people's values.) Or do they reflect mistakes? This is the issue that Machina's [1990] recommendations (cited at the outset) would address. His argument suggests that "incorrect" risk perceptions should be treated as mistakes that should be "corrected" like any other mistake. He contends that:

"...reporting a length, width, and area of a room that are not commensurate implies an internally inconsistent description of the room and is simply wrong; preferring purple polka-dot carpeting, however, is a matter of clients' tastes, to which they have every right if it is their living room. In the case of health or environmental risks, this would correspond to the distinction between measuring the detrimental effects of a drug or a pollutant versus determining the individual patient's or society's attitudes toward hearing these consequences" (p. 174).

Unfortunately, the issues are not as clear-cut as his argument implies.

As Fischhoff [1989] observes, while there are "actual risks" (i.e., probabilities of undesirable outcomes), we will never know what they are.

"All that anyone does know about risks can be classified as perceptions. Those assertions that are typically called actual risks (or facts or objective information) inevitably contain some element of judgment on the part of the scientists who produce them. In this light, what is commonly called the conflict between actual and perceived risk is better thought of as the conflict between two sets of risk perceptions. Those of ranking scientists performing within their field of expertise and those of anybody else" (p. 270, emphasis added).

In the absence of a comprehensive description of individual behavior that explains the connections between preferences, perceptions, and behavior, ex ante benefit measurement has largely been forced to adopt one of two strategies:

- (1) ignore the difference between experts' estimates of risk and peoples' perceptions and use expected utility theory to define ex ante values; or
- (2) postulate an alternative structure to describe preferences that allows experts' estimates of risk to enter preferences in a nonlinear form and derive values from these functions.

For the most part, these approaches have been treated as mutually exclusive alternatives. However, this is not necessary. Indeed, it is possible to extend Viscusi's [1989] recently proposal--integrating a risk updating model with ex ante consumer choice--to provide the basis for comparisons that illustrate how

using either strategy will affect the value assigned to policies, both outcomes and risks.

A. Prospective Reference Theory versus the Conventional Approach

A simple two-state characterization of individual decision making illustrates how Viscusi's PRT framework can be used to compare the implications of different risk perception treatments. Two types of valuation tasks will be considered--valuing changes in some outcome and valuing changes in risk. Following the conventions of most of the literature on ex ante valuation, I assume preferences are state dependent.¹⁵ To avoid another set of issues that are not central to the reasons for comparing Viscusi's framework with the conventional approach, I will focus on the option price measure for valuing each type of change.¹⁶

Individual utility is represented by $U_i(Y_i)$ ($i = A, B$) where the state definitions can be interpreted based on the particular application and Y_i represents income in state i . What is important about the assumption of state dependency is that the marginal utility of income varies with state. As a rule, the U_i are interpreted as indirect utility functions, and the focus is on a change in outcome that is assumed to be outside each person's control but valued. This is represented by adding an argument, Q , to U_i as $U_i(Y_i, Q)$. Option price, OP , for a change in Q will be defined as a change in Q from some reference level. Here I will assume the level is Q_0 and the new level, $\bar{Q}$. The value for this change becomes an ex ante measure because the model assumes a person does not know which state will govern his (or her) preferences.¹⁷ It is determined by random process with P designating the probability for state A and $(1-P)$ for B . The distinction between the conventional and Viscusi models rests with the

representation of the probabilities. For a conventional expected utility model, they are treated as objective information and therefore are exogenous parameters in defining ex ante monetary values for the change in Q .

When each individual is assumed to maximize expected utility, the maximum amount that would be paid (as an option price) for a change from Q_0 to $\bar{Q}$ is defined by the reduction in income (Y) that would be agreed to, regardless of state, with $\bar{Q}$ assumed and lead to the same expected utility as without $\bar{Q}$ but when no payment is made, as given by equation (1).

$$PU_A(Y-OP, \bar{Q}) + (1-P)U_B(Y-OP, \bar{Q}) = PU_A(Y, Q_0) + (1-P)U_B(Y, Q_0) \quad (1)$$

The change from Q_0 to $\bar{Q}$ does not have to be assured. It could be assumed to take place only in one state, say A . Equation (2) defines the option price, $\bar{OP}$, for this situation.

$$PU_A(Y-\bar{OP}, \bar{Q}) + (1-P)U_B(Y-\bar{OP}, Q_0) = PU_A(Y, Q_0) + (1-P)U_B(Y, Q_0) \quad (2)$$

There is still a change in outcome, but it is not assured. In the case described by (1), the outcome change would be assured, but a person's values for it would not. Both possibilities have been discussed in the option price literature (see Bishop [1982], Smith [1983], and Freeman [1985, 1989]). The second case is easier to use in describing the ex ante value of a probability (or risk, if the outcome is undesirable) change. Continuing to assume the change to $\bar{Q}$ is desirable, increasing its probability would be valued. Here the usual case presented in the literature modifies the reference case, so it is not assured Q_0 , but instead $\bar{Q}$ and Q_0 with a different set of probabilities than the new situation, as in (3) and the option price, OP^* , measures the ex ante values for yet another type of event.

$$(P+\theta)U_A(Y-OP^*, \bar{Q}) + (1-P-\theta)U_B(Y-OP^*, Q_0) = PU_A(Y, \bar{Q}) + (1-P)U_B(Y, Q_0) \quad (3)$$

Of course, changes in both P and Q could be envisioned. However, such cases would involve modifying both aspects of the lotteries. Thus, these alternative specifications illustrate the problems in defining an increment to the "commodity" that is valued--the lottery. A marginal change (holding expected utility constant) can be defined from (3) as $\frac{dOP^*}{dP}$ (when θ is allowed to approach zero).

$$\frac{dOP^*}{dP} = \frac{U_A(Y, \bar{Q}) - U_B(Y, Q_0)}{PU_{AY} + (1-P)U_{BY}} \quad (4)$$

$$\text{where } U_{iY} = \frac{\partial U_i}{\partial Y}$$

Marginal changes in Q would also be defined in a similar fashion and compared with ex post values (see Freeman [1989]).

This is the conventional treatment. The difficulties arise in implementing any of these three definitions when people do not accept the "objective" probabilities assessed for them by the "experts." That is, policy offers either a change in Q or in P, and consumers believe the probabilities are different than the experts' evaluations. This situation is most pronounced when the policy involves a change in probability. Increasing P would correspond (because state A has been described as favorable) to policies that reduce risks of exposure to hazardous wastes through drinking water, pesticides on food, or even the likelihood of poor visibility conditions at a national park when the scenic vista is important to the enjoyment of a visit.

Two problems result from these discrepancies. First, to the extent indirect methods can be used to measure $\bar{OP}$ or OP^* , they will be based on what people perceive the probabilities to be, not the experts' estimates (see Freeman [forthcoming]). Second, and equally important, even if we could recover enough information to measure the elements in equations (2), (3), and (4), whose probabilities do we use to measure $\bar{OP}$, OP^* or $\frac{dOP^*}{dP}$ Machina [1990] recommends the experts.⁶

Viscusi's prospective reference theory (PRT) offers one way of evaluating the implications of how we answer the second question. While it may seem simply to restate the weighting function component of prospect theory (Kahneman and Tversky [1979]), PRT does more in its description of subjective probabilities and does not restrict value functions. It replaces P in each of the preceding expressions by a function of P, say $\Pi(P)$, as prospect theory would. However, the distinction arises in how that perceived probability function is interpreted. It is treated as a linear function of a reference risk level, say P_0 , and the P which can be interpreted as the experts' assessment of the risk. Equation (5) provides an example:

$$\Pi(P) = \frac{\gamma P + \alpha P_0}{\gamma + \alpha} \quad (5)$$

γ and α represent weights describing the informational content associated with experts' risk assessments versus each person's reference risk level or prior beliefs. While the model does not explain the source of these weights or how they change in response to different events at risk, it does provide a basis for describing how the ex ante values analysts use are affected by how we resolve problems with the formation of subjective risk perceptions.

B. PRT and the Ex Ante Valuation of Outcomes

PRT treats each individual's objective function as if it were a weighted average of two expected utility functions, and this is why it provides a direct way to illustrate the effects of perceptions on ex ante values. The PRT description of the reference ex ante level of well being, k , for the initial definition of option price (i.e., equation (1)) would be given by equation (6).

$$k = P \left(\frac{\gamma}{\gamma + \alpha} \right) U_A(Y, Q_0) + (1-P) \left(\frac{\gamma}{\gamma + \alpha} \right) U_B(Y, Q_0) + P_0 \left(\frac{\alpha}{\gamma + \alpha} \right) U_A(Y, Q_0) + (1-P_0) \left(\frac{\alpha}{\gamma + \alpha} \right) U_B(Y, Q_0) \quad (6)$$

This is derived by substituting $\Pi(P)$ for P on the right side of equation (1) and regrouping terms so k can be re-expressed as a weighted sum of two expected value (EU) functions--one using P and the other P_0 as in (7).

$$k = \left(\frac{\gamma}{\gamma + \alpha} \right) EU(Y, Q_0, P) + \left(\frac{\alpha}{\gamma + \alpha} \right) EU(Y, Q_0, P_0) \quad (7)$$

The counterpart to the first valuation definition for OP defined for PRT would be:

$$\left(\frac{\gamma}{\gamma + \alpha} \right) EU(Y-OP^V, \bar{Q}, P) + \left(\frac{\alpha}{\gamma + \alpha} \right) EU(Y-OP^V, \bar{Q}, P_0) = k \quad (8)$$

where OP^V corresponds to the PRT definition of OP.

The reason for adopting this reformatting is that it illustrates how assumptions about how to treat perceptions define a locus of valuation concepts.

That is, equation (8) simply restricts the value concept to be the constant that for given weights (i.e., α, γ) holds PRT's value constant at k . We could define separate OP's for each of the two possibilities for the probabilities. As we change the relative weights assigned to experts' assessments versus people's beliefs, a locus of valuation alternatives (each compatible with the same reference level k) is defined. Figure 1 illustrates the idea.

Because the utility functions are well-behaved, this locus looks like a Graham [1981] willingness-to-pay locus. It is not the same concept. Intersections with a 45° line correspond to using Viscusi's PRT to describe people's behavior and assuming that ex ante values for policy changes should correspond to how they would value those policies even if their values are based on "incorrect" perceptions. The vertical intercept $OP(P)$ corresponds to Machina's proposal--accept people's preferences but correct their interpretation of probabilities.

The slope of the schedule reflects the fundamental issue--any intervention in how each person evaluates risk involves separating the components of a lottery in order to define an increment for use in defining an ex ante value, and that separation will be arbitrary because both perceptions and the valuation of outcomes are reflected in changes in $OP(P)$ and $OP(P_0)$.

$$\frac{dOP(P)}{dOP(P_0)} = \frac{\alpha EMUY(P_0)}{\gamma EMUY(P)} \quad (9)$$

where $EMUY(P)$, $EMUY(P_0)$ are the expected marginal utilities of income when P and P_0 are taken as the description of risk respectively.

C. PRT and Ex Ante Valuation of Risk

Equation (8) also allows comparison between the valuation of a risk change by recognizing that the change simply updates one component of an individual's risk perception function. The PRT counterpart to the relationship in (4) can be used to describe how the valuation of risk would differ from the conventional model. Equation (10) provides that description.

$$\frac{dOP^V}{dP} = \frac{\frac{dOP^*}{dP}}{\left[1 + \frac{\alpha EMUY(P_0)}{\gamma EMUY(P)}\right]} \quad (10)$$

Thus, the size of the discrepancy between a perception-based measure of the value of a risk change in comparison to one that assumes people use experts' probability assessments depends on two factors: (1) the differential weight given to experts' versus prior information; and (2) the relative size of the expected marginal utilities of income under the individual's prior perceptions versus the experts' assessments of the risk. Because it is difficult to conceptualize how large these differences can be, I calculated some examples using a variation on one of the specifications proposed by Freeman [1989] in his comparison of ex ante versus ex post values. Table 6 summarizes the results for state dependent utility functions defined so the event corresponds to some undesirable outcome with a loss of Z in state A and nothing lost in state B as given by equation (11).

$$\begin{aligned} U_A &= (Y-Z)^a \\ U_B &= Y^{a+b} \end{aligned} \quad (11)$$

Z corresponds to the ex post consumer surplus. In Table 6 we describe it as a percent of income using 10 and 80 percent. As with any empirical example, the results will depend on the utility function. Nonetheless, the table does convey my general point--risk perceptions matter!

The most important determinant of the relative size of the value of a risk change is the weight a person assigns to experts' versus personal risk assessments. Only one set of parameters for a and b were selected because the magnitude of the differences are insensitive to the specification. While the same general pattern characterizes all the cases when comparing the disparities between prior and experts' assessments of risk, both level and size of the disparity do matter in determining the relative size of the values assigned to risk changes. As with Freeman's [1989] comparison of ex ante and ex post values, different specifications for the utility function will influence the relative importance of the factors judged to be important to values in a PRT framework. My point is simply that the size of the differences based on how we choose to interpret the risk perception process can be substantial.

IV. Policy Implications

By selecting a position on how to deal with divergences between experts' and everyone else's risk perceptions, we also choose a valuation measure. This applies even when we adopt a model that treats risk perception and valuation separately. All that needs to be added is recognition that people have their own perceptions and they weigh experts' assessments along with their initial risk perceptions.

I have used Viscusi's PRT framework to define a locus of possible ex ante values for changes in outcomes. Two correspond to the alternatives posed at the

outset of Section 11--adhering to experts' assessments on the risks (the vertical intercept of the locus, designated R in Figure 1) versus using each person's value, recognizing that it will be influenced by the experts' estimates as well as other information (the intersection of the locus with the 45° line marked as V in Figure 1).

While the shape of the locus will depend on the assumed features of each person's preferences and his (or her) relative weighting of information, it is clear that the treatment of perceptions can make the difference between positive and negative net values for actions under uncertainty. Moreover, to the extent we accept the fact that the presentation (or framing) of information can influence how it is interpreted and used, then we acknowledge an ability of policy to influence on the relative weights assigned to experts' assessments and people's prior beliefs. This influence is certainly not complete. There are limits to how much public information programs can influence the confidence people will place in experts' judgments, and this seems to vary with the type of environmental risk.

This may seem to make the task of developing economic information on the ex ante value people place on policy so complex as to preclude its use in any practical applications. This is not my objective. Rather, it is to suggest that policy design under conditions of uncertainty must be reconsidered to include more than simply estimating the values of policies defined independent of the uncertainties in the processes to be affected by policy initiatives. Instead, the design should encompass concern over:

- (1) delivering information about the sources of risk and the influence of policy actions on either the risk or the outcomes at risk

- (2) designing actions to change the types of outcomes or risks in ways that recognize how people perceive the potential gain;
- (3) providing opportunities for individuals to adjust in ex ante terms (through insurance mechanisms) to the level of "protection" or size of uncertain outcomes provided by the policy process.

To this point, most of the attention in economic analyses of policy design for environmental risks has focused on resolving the middle task, arguing that this is not likely to happen if we separate risk perception and valuation. Equally important, because a realistic response to the second task requires more information than analysts are likely to have about how people form perceptions and value policies, mistakes must be expected. The first two tasks attempt to provide the information and adjustment opportunities for people that markets would offer. Therefore, they require that policy design consider whether it is possible to incorporate opportunities for people to privately "self-correct" to compensate for the excesses or inadequacies they perceive in policies designed to mitigate environmental risks.

TABLE 1. Weinstein Sandman, Roberts Evaluation of Risk Communication Materials

Treatment Number	Key Issue	Description
1	Risk Probabilities	Information about expected lifetime mortality expressed as deaths per thousand people at various levels of exposure.
2	Risk Probabilities and Comparisons	Same information as Treatment 1 with comparative information describing risks from cigarette smoking.
3	Probabilities in Graphic Format	Treatment 1 displayed using a histogram.
4	Standard	Information about the recommended action level for the source of risk.
4	Standard, Risk Probability and Comparisons	Combines Treatment 4 with Treatment 2.
6	Standard and Advice	Treatment 4 with detailed action advice and verbal levels for the four range of exposure levels.
7	Standard, Advice, Risk Probabilities and Comparisons	Combines Treatment 2 with Treatment 6.

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 presentations to community groups between January and March 1988; organized Radon Awareness Week; arranged for Mayor and Aldermen to visit their homes	669 kits

^aThe primary messages emphasized in the public service announcements (PSA), poster 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.

^bIndependent 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 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.

^cNone refers to the fact that there were no project-initiated information materials presented in public media mailings or meetings. Some independent newspaper articles do appear in a local paper.

TABLE 4. Description of Interviews for
NYSERDA Radon Risk Study

Interview/Mailing	Format of Interview	Percent Completion	Date
Baseline	Telephone	97	May/June 1986
Distribute two-month readings and information treatment	---	---	December 1986 /January 1987
First Followup	Telephone	91	December 1986 /January 1987
Distribute annual readings and information treatment ^a	---	---	January 1988 /February 1988
Second Followup	Mail ^b	74	March 1988
Final Followup	Telephone	91 ^c	February 1989

^aOur analysis of the participating households' responses to the one-page fact sheet after the first follow-up interview indicated that they had become overly concerned about their radon readings and wanted additional information. Because their responses to learning and risk perception questions and questions intended to measure their demands for more information provided strong support for the need for intervention, we modified the design in subsequent contacts with this group. They were randomly assigned to one of the five remaining information treatments. All other households received the same information treatment that they were assigned prior to the first followup.

^bIn implementing the mailed survey we generally followed Dillman's [1978] suggestions. However, after two mailings and reminder postcards, we used a telephone contact (rather than a certified letter) to attempt to increase response rates.

^cThis estimate is calculated based on households with completed and correct radon readings--1,825 of the originally 2,300 recruited for the sample.

TABLE 3. Determinants of Radon Testing: Maryland Panel Sample^a

Independent Variables	Before Information Programs	After Information Programs
Family Income (in Dollars)	.26x10 ⁻³ (0.648)	.29x10 ⁻³ (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	-1.59 (-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)

^aThese models are probit estimates. The numbers in parentheses below the estimated coefficients are ratios of the coefficient to the estimated asymptotic t-ratio.

^bAn 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.

TABLE 5. Updating of Radon Risk Perceptions:
NYSERDA Sample^a

Selected Independent Variables	First Followup ^b	Second Followup ^b	Final Followup N2SLS ^c	Final Followup Tobit
Prior Risk Perception	.063 (3.228)	.458 (10.897)	.074 (4.411)	.097 (4.424)
Two-Month Radon Reading (living area) ^d	.024 (2.927)	-.031 (-0.760)		
Annual Radon Reading (living area) ^d		.013 (1.004)	.008 (1.356)	.007 (1.023)
Annual Radon Reading (basement) ^d		.006 (2.355)	.003 (1.371)	.003 (1.006)
Command/Quantitative	-.084 (-2.048)	.021 (0.583)	-.025 (-0.848)	-.021 (-0.518)
Command/Qualitative	-.030 (-0.721)	.088 (2.448)	-.013 (-0.457)	-.013 (-0.340)
Cajole/Quantitative	-.122 (-2.974)	-.002 (-0.007)	.003 (0.092)	.021 (0.538)
Cajole/Qualitative	-.059 (-1.486)	-.020 (-0.585)	-.003 (-0.080)	.016 (0.403)
EPA Citizen's Guide	-.018 (-0.427)	-.001 (-0.671)		
Mitigation			-.103 (0.562)	.128 (3.622)
Radon Basement and Use Basement			.006 (1.669)	.010 (2.765)
Originally Received Fact Sheet			.019 (0.805)	.034 (1.162)
Sample Size	785	785	853	853

^aThese results are based on a model assuming currently stated risk perceptions (R_t) is a linear function of immediately prior statements of risk perceptions (R_{t-1}) plus variables describing information respondents received. The numbers in parentheses below the estimated parameters are ratios of the coefficients to their estimated asymptotic standard errors. The models reported are not the complete specifications.

^bThese estimates were derived using the two-limit Tobit framework of Rosett and Nelson [1975]. See Smith et al. [1990] for a complete description of the model and results.

TABLE 5. (continued)

^cThese estimates are derived using a nonlinear 2SLS estimator proposed by Barrow, Ca and Goldberger [1981] to allow for the potential for simultaneity of the dummy variable f reported mitigation and the final risk perception.

In this model, the information brochure qualitative variables refer to the "final" brochure received. In the case of households receiving the fact sheet, this changed after our analysis of the results from the first follow-up survey. For all others it did not change. The variables are measured relative to the EPA Citizen's Guide. In the earlier models, the omitted category was the fact sheet.

The variable "originally received fact sheet" is a dummy variable to evaluate whether initial receipt of the fact sheet influenced households' updating even though they received new information prior to this interview. Our investigation of this issue with the annual updating indicated the treatment of this effect did not alter our conclusions from the annual updating model (see Smith et al. [1990]).

"Mitigation" is a qualitative variable for people reporting they had undertaken some form of mitigation since the annual readings were sent and that follow-up survey was conducted to reduce radon levels.

"Radon Basement and Use Basement" refers to an interaction variable between the annual radon reading for the basement and a variable initially collected asking households if they used their basements for daily activities (-1) or not (-0). These results are based on joint research currently in process with Bill Desvousges and John Payne.

^dThese statistics correspond to the average and range of readings for households in our sample based on each monitor.

TABLE 6. Relative Size of Incremental Option Price
Under PRT versus the Conventional Framework

$\frac{\gamma}{\gamma+\alpha}$	(.1, .5)	(P, P ⁰)				
		(.1, .7)	(.3, .5)	(.3, .7)	(.5, .7)	(.5, .9)
<u>Z/Y = 10%</u> a = .5 b = .2						
.05	.010	.008	.031	.025	.034	.025
.25	.063	.051	.167	.138	.183	.211
.50	.167	.138	.375	.325	.401	.445
.90	.643	.590	.844	.813	.858	.878
<u>Z/Y = 80%</u> a = .5 b = .2						
.05	.010	.008	.031	.023	.038	.031
.25	.063	.048	.167	.132	.202	.169
.50	.167	.132	.375	.312	.431	.379
.90	.643	.577	.844	.804	.872	.846

FIGURE 1. Viscusi's PRT Locus
of the Valuation-Risk Perception Tradeoff

Notes

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1. Visualizing it is easy with nondurable goods. When we move to durables or services, explaining the implicit exchange becomes more difficult. "Time" usually becomes the quantitative metric that allows us to conceptualize tradeoffs. Such a modeling strategy treats the amount of time the durable is used or the service takes as the good exchanged for some other commodity.

2. This conclusion is consistent with evidence from laboratory experiments and contingent valuation experiments. Early work by Grether [1980] involving experiments with and without monetary incentives found behavioral departures from Bayesian learning. Experience and the financial incentives improved the adherence to a Bayesian framework. Camerer [1987] also found that experience with compound lotteries improves the performance of a Bayesian learning model. By contrast, McClelland, Schulze, and Coursey [1986] report substantial departures from a systematic learning process, especially with low probability events. A substantial fraction of participants do not appear to learn, even with financial incentives and repeated trials.

3. Erikson [1990] highlights two features of what he describes as "toxic emergencies" that apply equally well to most environmental risks. First, they are unbounded in the sense of having no time frame or ending. He describes this as using an analogy to rules of drama, characterizing them as a different sort of tragedy. Secondly, people cannot apprehend them through the unaided senses. Because of this feature, they are more frightening.

3. Risk will be used here synonymously with the probability of specific undesirable events.

4. See Slovic, Fischhoff and Lichtenstein [1985] and Slovic [1987] for good overviews of this literature.

5. These critics generally overlook the ethical constraints that must be imposed on any "experiments" where people face real risks at varying levels with the analyst observing their response to these risks and controlling the information they receive.

6. These cases may not be completely hypothetical. For example, contingent behavior studies have asked respondents their perceptions of risk from specific sources and then presented hypothetical policies to address the source of risk. The perception relates to an actual risk, and the behavior is contingent on the situation described in the questions. This approach contrasts with Weinstein et al.'s study [1989] that used hypothetical information about the levels of radon or asbestos and asked responses. In this case, all answers relate to hypothetical situations.

7. Radon is a colorless, odorless gas that occurs naturally and is considered to be the second leading cause (after smoking) of lung cancer in the United States. See National Research Council [1988] for an evaluation of the EPA risk assessment model for radon.

8. We defined a variable indicating whether a respondent talked to a friend, neighbor, or co-worker about radon after the program and found that both the Hagerstown and Frederick programs raised awareness, as measured in these terms. To the extent this increased awareness independently contributes to the likelihood of monitoring, as the results in Table 3 would imply, the programs may have further impact on monitoring decisions. See Appendix A, Desvousges, Smith and Rink [1989].

9. The authors note that they set targets of 50 respondents as a threshold, after which the sampling would stop. To the extent the analysis envisions modeling categorical response variables and multivariate models that acknowledge a role for demographic and economic variables in addition to those describing the information programs, this plan is inadequate. The specific samples recruited by town were:

SAMPLE			
Town	Baseline	Dependent Followup	Independent Followup
Clinton	208	45	49
Fitchburg	202	38	55
Worcester (control)	81	51	---

10. One reason I feel the sample is specialized follows from the NYSDA criteria for entry to the sample: people who would place the monitors in their homes and had no plans to move for at least one year. The analysis did consider whether this criteria significantly affected risk perceptions using a variation on a Heckman [1979] selection model, and the results indicated it did not appear to influence any of the conclusions. See Smith et al. [1990] for the details.

11. The research design and planning for the project was jointly undertaken with Ann Fisher of the U. S. Environmental Protection Agency and F. Reed Johnson of the U. S. Naval Academy.

12. The level of one picocurie was selected because it is well below levels that remediation technologies at the time of the study could achieve and corresponds to the level experts estimated was the average level in the United States.

13. This estimator is a variation on one proposed by Barrow, Cain and Goldberger [1981] for the case of endogenous qualitative variables. See Smith, Desvousges and Payne [1990] for the details.

14. Studies involving laboratory experiments were not discussed because they must confront people with lotteries. As a result, they are not especially useful in any effort to evaluate how risk perceptions are formed when information about the process does not come to people in a form comparable to a lottery.

15. Viscusi's original paper [1989] describing PRT assumed state independent preference. His discussion of applications to health risks (Viscusi [1990]) allows for state dependency. The central question in a state-dependent specification is the extent of differences in the marginal utility of income across states. See Arrow [1974] for the first identification and discussion of the significance of this assumption.

16. Option price measures use the expected value of the marginal utility of income in defining ex ante monetary measures of the value of some change. Other measures will depend more on the opportunities for ex ante adjustment in the form of insurance markets. See Graham [1981] and Smith [1990] for discussion of ex ante benefit measures.

17. Plummer and Hartman [1986] describe the way uncertain prices or income could be used to explain uncertain state dependent preferences. Of course, these are not the only possibilities, as the Cook-Graham [1977] discussion clearly suggests.

18. Machina [1990] would certainly accept other non-EL objective functions, and these could incorporate probabilities in a nonlinear form, violating the independence axiom. What appears to be at issue in his recommendations is "correct" use of what he views as objective information about probabilities.

This may well be the best strategy for simple lotteries where the process is known (e.g., rolling a die, drawing a colored ball from an urn, etc.), but it is not an appropriate characterization of the form of risk information in environmental lotteries.

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