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Risk--Mathematical models

RISK PERCEPTION, LEARNING, AND INDIVIDUAL BEHAVIOR

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Economically rational behavior does not require that individuals make perfect decisions. With repeated decisions, people often learn from their mistakes. Over twenty years ago Arrow in his Jahnssonin lectures recognized the essential role learning plays in a model of individual behavior under uncertainty. He observed that:

> "...subjectivity of beliefs does not exclude their being influenced by experience... 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. The influence of experience on beliefs is of utmost importance for a rational theory of behavior under uncertainty..." (Arrow [1971], pp. 45-46)

Unfortunately, most economic models for individual choice under uncertainty assume that individuals know the correct probabilities of the events at risk. For example, we assume that an individual knows the risk of an accidental death when taking a job. Significant deviations from the predictions of the conventional expected utility (EU) framework are interpreted as evidence of irrationality.

In reality, decisionmakers are confronted with a diverse array of information about risks. Many of these risks may involve complex processes--e.g., health choices, financial decisions, or even vacation plans. How people deal with this complexity is an essential element in

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individuals' marginal valuations of risk changes. In these cases the MRS is an ex ante measure (i.e., along a constant expected utility locus).

Table 1 summarizes the ex ante MRS for the conventional EU framework and four popular competing models. The table uses a simple tradeoff--between some monetary loss (L) from current income (y) that arises with probability p. The models include expected utility with state-dependent preferences (i.e., the utility function is assumed to depend on which state of the world--loss (L) or no loss (N)--occurs), prospect theory, weighted expected utility, and generalized expected utility. In each case, the MRS is defined to hold the value of the corresponding objective function constant. For example, in the weighted expected utility model, the ratio of a probability weighted sum of U(.) (evaluated in each state) to the corresponding weighted sum of D(.) (in each state) guides individual choice. The relevant tradeoff between L and p for comparison is the one that holds this ratio constant. Also, note that in the weighted expected utility the level of the objective function, k, enters the expression for the MRS.

Two aspects of this table are noteworthy. First, the conventional model and two of the four alternative models yield expressions that imply the MRS will be proportional to 1/p. The modifications in the conventional model determine how the proportionality factor changes with the events at risk. Thus, they affect the size of the tradeoff between L and p but **not** the sign of how it changes with changes in p. Even the generalized expected utility model leads to an MRS that varies less than proportionately to 1/p, so that the testable hypotheses become weak rather than strict inequalities. Only the objective function arising with prospect theory departs from the proportionality assumption. The relationship in this case will depend on the size of p and the shape of the weighting function, $\pi(.)$.

Second, none of these models explains the source of p. Even prospect theory assumes that people know (or act as if they know) the probability. Consequently, these models do not incorporate learning as a component of the behavioral decision process.

One way to incorporate learning is to view the formation of an individual's risk perceptions as a Bayesian estimation problem. In the Bayesian case, an individual would estimate p to minimize the expected loss arising from imprecise estimates (see La Valle [1970] for examples). If the loss function is quadratic in the estimate of p, then the optimal estimate is the conditional expectation, given the most recently available information. This learning strategy could be used to derive reduced form models for the updating of risk perceptions by assuming that an individual's loss function is defined in terms of the optimal (given a value for p) ex ante indirect utility functions associated with the specific model and constraints to behavior.

To test this more general framework requires that we observe how individuals' risk perceptions and behavioral decisions change with information on risk. While the overall objective of our panel study is to implement such an integrated model, the experiment providing our data is still under way. Therefore we do not have complete information on the sample respondents' decisions. Nonetheless, the data acquired thus far permit analysis of how households undertook two separate updates of the risk perceptions in response to information about radon in their homes.

EXPERIMENTAL DESIGN AND SAMPLE

The New York State Energy Research and Development Authority (NYSERDA) established the sample design to measure short-term (winter) and annual radon readings in detached single-family homes. All homes were owner-occupied. Two radon monitors were placed in the living area and one in the basement. Participants returned one of the living area monitors after about two months, and the other two after one year.

To date, four interviews have been completed with adult decision-makers--an initial screening interview to determine eligibility; a baseline interview, about six months before any radon results were available, to obtain the decisionmakers' radon risk perceptions, knowledge of radon, attitudes, and demographic and economic characteristics; and two followup interviews, one after the two-month radon readings, and a second after the annual readings were sent.

With the cooperation of state and federal officials, we varied the information format for explaining the risk from radon exposure. The design includes six different information treatments. We designed four to vary two features:

- the extent of quantitative risk information (labeled quantitative versus qualitative), and
- the degree of directive guidance versus encouragement to make personal judgments (labeled command versus cajole).

Pairing each possibility, the four booklets conveyed approximately the same factual information. They are labeled command/quantitative (COQUANT), command/qualitative (COQUAL), cajole/quantitative (CAQUANT), and cajole/qualitative (CAQUAL). The official EPA brochure, A Citizen's Guide to Radon, and a one-page fact sheet similar to those used by some states and testing companies comprised the two remaining information treatments (see Smith et al. [1987] for more details).

To implement the design, we randomly assigned one of the six alternatives among participating homeowners with one important qualification. Because the fact sheet contained somewhat less information than the other alternatives, only homeowners with low radon readings (below one picocurie per liter) were allowed the possibility of receiving it.

Based on an initial evaluation of the information materials after the first followup survey, we found that homeowners who received the fact sheet had more difficulty understanding their risks and were unnecessarily concerned about radon. Consequently, we randomly assigned one of the remaining five booklets and sent this new information along with their annual radon readings. Other households received a slightly updated version of the original type of information booklet they received with their two-month readings, or the EPA Citizen's Guide.

RESULTS AND IMPLICATIONS

The panel participation has been very good with response rates above 90 percent for the baseline and first followup and 75 percent for the second followup. Our results focus on approximately 800 homeowners who had complete radon readings and provided sufficient information during the baseline and two followup interviews to implement a simple Bayesian learning model.

The quadratic loss function (described earlier) implies that an individual's current risk perception (R_t) is a weighted sum of his prior risk perception (R_{t-1}) and the risk message communicated in the new information. Equation (1) defines an estimating model that links the implicit risk message to the radon reading(s) and the features of the information treatments (designated here by Z_i and the I_j variables):

$$R_{it} = \alpha_0 + \alpha_1 R_{it-1} + \alpha_2 Z_i + \sum_j \beta_j I_{ji} + e_i \qquad (1)$$

where e_i designates a stochastic error.

Table 2 reports the maximum likelihood estimates (using a two-limit tobit estimator) for the two separate risk updates. Risk perceptions are based on homeowners' responses about perceived seriousness of the risk from radon exposure using a 1-to-10 scale. (The same decisionmakers were interviewed at each stage of the process.) The specified determinants of the current risk perceptions at each stage are the prior risk perception along with variables describing the information received. We have added to these demographic characteristics a qualitative variable describing attitudes toward health, the time spent reading the booklets at each stage, and an inverse Mills ratio to evaluate whether NYSERDA's original selection criteria might have biased our estimates of households' risk updating (see Smith et al. [1988] for the specifics on this variable and other tests for selection effects associated with sample attrition).

The information variables include the three radon readings--the two-month reading for the first risk update and the two annual readings (a basement and living area) for the second. The other information variables refer to which booklet was received with the two-month reading. The information booklets are represented in the model as qualitative variables (0,1) with the fact sheet the omitted category. Based on our preliminary analysis, changing the materials sent to the fact sheet households did not appear to have influenced their responses.

The model for the first update indicates that the two-month radon reading and prior risk perception were significant positive determinants. On average, people with higher readings increased the perceived seriousness of the risk. Moreover, the quantitative booklets served to reduce stated risk perception relative to the fact sheet. Few demographic variables, other than education, influenced the risk perceptions (see Smith et al. [1988] for more discussion of these findings).

In the model for the second update, the posterior risk perception of the first followup becomes the prior risk perception. These prior risk perceptions incorporate most of the effects of the information booklets. There is one important exception for the command/qualitative booklet. In this case it has a positive and significant effect on posterior risk perceptions, reversing the effects of longer booklets with the first update. Because it contains less information on how to adjust risk for personal circumstances, this booklet seems likely to induce individuals to think of the EPA guideline as a threshold. Readings below the 4 picocurie guideline are "safe"; those above are not. Thus, the positive effect for this booklet is consistent with the nature of the information given to the households for interpreting the risks from radon. This conclusion is readily understood once the pattern of two-month and annual readings are given. The average two-month living area readings were 1.69 picocuries per liter of air. The annual living area readings provided little new information because they were approximately the same--about 1.34. However, the basement readings were more than double the annual living area readings, averaging 3.37. The second updating model reflects the basement reading as new information, and in some cases as a surprise moving them above the Action Guideline as a threshold.

These findings are important because they involve homeowners' perceptions of real risks. They clearly indicate that risk perceptions are updated to respond to the content and the format of risk-related information. As such, they also offer support for the prospect of testing an integrated risk perception/behavioral response model with data collected under either the controlled conditions of laboratory experiments or in the semi-controlled setting of a panel study.

FOOTNOTES

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[1]Reviews of how the psychological literature treats this problem can be found in Kahneman and Tversky [1984] and Slovic, Fischhoff, and Lichtenstein [1985]. The economics literature that considers how individuals learn about risk is more limited, see Pingali and Carlson [1985] for a study of the role of information and learning in how accurately farmers' subjective perceptions of the risks of crop loss conform to actual (ex post) estimates of these loss probabilities. Viscusi and Magat [1987] have also considered how the amount and format of information affects the stated behavior of workers and households in risk-related decisions.

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Table 1. The Objective Function and Marginal Rate of Substitution for Recent Alternatives to a Conventional EU Framework[a]

Model	Description of Behavior	MRS (dL/dp)
Conventional	$p\,U(y-L) + (1-p)\,U(y)$	$\frac{-(U(y) - U(y-L))}{p\,U'(y-L)}$
State-Dependent (Cook and Graham [1977])	$p\,U_L(y-L) + (1-p)\,U_N(y)$	$\frac{-(U_N(y) - U_L(y-L))}{p\,U_L'(y-L)}$
Prospect Theory (Kahneman and Tversky [1979])	$\pi(p)\,V(y-L) + \pi(1-p)\,V(y)$	$\frac{-(\pi'(1-p)\,V(y) - \pi'(p)\,V(y-L))}{\pi(p)\,V'(y-L)}$
Weighted Expected Utility (Chew and MacCrimmon [1979])	$\frac{p\,U(y-L) + (1-p)\,U(y)}{p\,D(y-L) + (1-p)\,D(y)}$	$\frac{-[(D(y) - D(y-L))\,k - (U(y) - U(y-L))]}{p(U'(y-L) - D'(y-L)k)}$
Generalized Expected Utility (Machina [1982])[b]	$pU(y-L;\,\phi) + (1-p)\,U(y;\,\phi)$ $\phi = p\,G_{y-L} + (1-p)\,G_y$	$\frac{-[U(y;\,\phi) - U(y-L;\,\phi)]}{p\,U_1(y-L;\,\phi)}$

[a]For functions of one variable the first derivative is denoted by a prime as $dU/dY = U'$. For functions of two variables the partial derivative is denoted by a subscript identifying the relevant argument.

[b]ϕ represents the distribution for this example.

Table 2. Evaluation of Radon Risk Perceptions with Time and Information[a]

Independent Variables	Risk Updating Two-Month Reading		Risk Updating Annual Readings	
Prior Risk Perception	.065	(3.396)	.448	(10.668)
2 Month Radon	.022	(4.288)	--	
Annual Radon (Living Area)	--		.002	(0.287)
Annual Radon (Basement)	--		.005	(2.341)
COQUANT	-.080	(-1.943)	.021	(0.630)
COQUAL	-.030	(-0.707)	.084	(2.372)
CAQUANT	-.123	(-2.975)	-.003	(-0.075)
CAQUAL	-.059	(-1.486)	-.024	(-0.705)
EPA	-.017	(-0.406)	-.007	(-0.192)
Sample Size	783		783	

[a]These results are a partial summary of a more detailed model including measures of the respondent's age, education, cigarette consumption, time spent reading the information materials, and an adjustment for selection effects. The numbers in parentheses are the ratios of the estimated coefficients to their estimated asymptotic standard errors. The estimates are based on the Rossett-Nelson [1975] two limit tobit estimator.

Source: Smith et al. [1988].