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Abstract

Biases in risk perception potentially have a large effect on insurance and risk-related behavior. The government can alter these perceptions either through informational programs or controlling the risk. Policies that convey a higher risk level generally have the expected effects on insurance and protective actions, whereas efforts that increase the precision of either the government risk information or private beliefs typically have ambiguous effects. In some cases, the structure of how government policies enter the risk-belief function is consequential. Ascertaining the magnitude of the effects, not simply the direction, also is an important issue. For example, misperceptions have a dramatic effect on the tradeoffs between compensating differentials and the size of the loss but a negligible effect on the tradeoff between compensating differentials and the magnitude of the probability.

Key words: risk perception, insurance, moral hazard, information

1. Introduction

The rather substantial literature on insurance began with economists assessing the conditions for optimal insurance, with these conditions dependent on the structure of utility functions, the nature of the accidents, and the terms on which insurance was being offered. This literature has also considered ramifications such as individual decisions to exercise care in preventing accidents as well as the pertinence of moral hazard (see, for example, Zeckhauser [1970], Arrow [1971], Spence and Zeckhauser [1971], Ehrlich and Becker [1972], and Pauly [1968]).

Although these concerns remain dominant building blocks of many insurance models, there has been substantial interest in recent years with variations on this basic model. One class of issues pertains to irrational aspects of choice under uncertainty. A considerable literature in economics and psychology has documented systematic shortcomings in individual decisions (see, for example, Machina [1982] and Kahneman and Tversky [1979]). These inadequacies include a wide range of errors in risk taking, which will affect not only the risky actions people choose to undertake but also the insurance decisions they make with respect to this behavior. Some recent contributions to the literature on insurance have begun to explore the implications and anomalies in individual decision making and in risk perceptions for insurance-related behavior (see, for example, Karni [1992], Konrad and Skaperdas [1993], and Marshall [1992]). In this paper I focus on a specific class of errors in decision making, in particular those associated with perceptual biases. However, in addition to

presenting results that are pertinent more generally to problems of misperception, my formulation also incorporates an explicit structure of the misperceptions. Thus, it will be possible to explore the specific components of the risk perception and how these influence insurance-related behavior. It will also be possible to assess which manipulations in the character of risk perceptions will alter insurance decisions and in what direction.

Restricting the focus of the analysis to perceptual biases in no way implies that all failures in the expected-utility model are attributable to perceptions. Irrational aspects in the way in which people process outcomes and incorporate these values in their decisions may also be consequential. In some instances, the irrationality may arise irrespective of whether there is a probabilistic component, such as a simple lack of transitivity. Other potential failures may involve the interaction of the probabilities with the consequences as in the case of overestimation of risks associated with particularly severe loss outcomes. What this paper indicates is how one class of biases, those arising solely from biases in risk belief, may influence insurance and risk decisions.

Insurance choices also differ from the private-insurance-decision models in that the government is also an important player in these risky decisions. In some cases the government provides insurance directly. In others the government regulates the risk that people face. It is also possible for the government to influence risk perceptions through the provision of risk information. Risk regulations may alter both the level of the risk and risk beliefs. This paper is concerned with each of these forms of intervention, where the risk-information and the risk-control aspects of the decision are quite similar in that each may influence risk perceptions. Although there have been a number of analyses that have considered the role of the government and its influence on private insurance behavior (see, for example, Briys, Kahane, and Kroll [1988]), there has been less emphasis on the effect of risk information on these beliefs and the subsequent effect on insurance-related behavior.

Section 2 of the paper explores the character of the risk beliefs that will be incorporated in the model. Risk perceptions play a central role in determining risk-taking and insurance decisions, and the nature of these perceptions will influence the efficiency properties of individuals' insurance purchasing decisions. Much of Section 2 is devoted to exploring the nature of the biases in these beliefs as well as the factors that influence these biases. Section 3 examines the influence of risk perceptions and risk information on risk tradeoffs. In particular, how is the level of compensation demanded per unit risk and for each dollar of loss related to risk perceptions and the factors that influence these perceptions? This section also examines which tradeoffs appear to be particularly sensitive to perceptual biases. Section 4 examines individual self-protection decisions in situations in which there is mandatory insurance, and Section 5 permits insurance to be a choice variable as well. Section 6 concludes the paper.

The results of the paper are in four main areas. First, what factors influence the risk compensation demanded for individuals to be willing to accept a risk of a more severe accident loss? This compensation value increases with any risk information probability that is communicated but is not unambiguously affected by the precision of the information. Second, what are the determinants of the statistical value of an injury that, in the case of fatalities, is known as the implicit value of life? This value also increases with the risk probability communicated (provided that state-dependent-effect assumptions hold). Third, self-protection from accident losses increases with the level of the risk communicated (provided

that state-dependent-effect assumptions hold) and is ambiguously affected by the precision of the information. Finally, insurance coverage responds similarly, increasing with the communicated risk level and is ambiguously affected by the precision of the information.

The consistently ambiguous nature of the precision effect should not be regarded as a disappointing result with respect to the potential role of risk communication. How decisions react to increased information depends on the nature of the information conveyed—whether, for example, the communicated risk is higher or lower than the individual's own belief. Viewed in this way, risk information plays a potentially productive role in overcoming the effect of perceptual errors.

2. The structure of risk beliefs

Risk beliefs seldom coincide with objective measures of risk. Documenting these errors in risk perception and formulating theories that recognize these biases has generated a substantial literature on choice under uncertainty. Although the nature of these biases is often complex, depending on the nature of the risk and the information individuals have received, an important class of biases focuses on the variation of the biases with the level of the risk. The formulation adopted here is such a risk-level-based approach, which I have termed *prospective reference theory* (see Viscusi [1989]). In effect, I adopt a quasi-Bayesian approach in which individuals lack perfect knowledge of risks but update their beliefs in a Bayesian manner. This behavior accords with the usual rational Bayesian learning process. The application of this approach often leads to a quite different perspective on empirical results in this literature. For example, if individuals are presented with information in an experimental context, they may not treat it at face value but instead may view it as being partially informative.

The principal advantage of incorporating this approach to capturing biases in risk perceptions in a model of insurance decisions is that it imposes a specific functional form on the character of risk beliefs. It will consequently be possible to derive explicit predictions regarding the effect of risk perception biases on insurance-related behavior. Moreover, it will also be feasible to ascertain how important determinants of risk perceptions affect risk beliefs and insurance-related behavior.

This formulation is sufficiently broad to capture a diverse array of perceptual biases identified in the literature and to account for many observed irrationalities and inconsistencies in choices under uncertainty. For example, the general pattern of people overestimating low-probability events and underestimating larger risks is accounted for explicitly. This formulation has been fitted empirically in Viscusi [1985, 1992] to the original Lichtenstein et al. [1978] data documenting the overassessment of small mortality risks and the underassessment of larger mortality risks. The results were consistent with the specific formulation of the risk-belief function to be adopted here. This risk-perception model has also been estimated in other contexts, such as those involving job safety and consumer product safety. One of its advantages is that the explicit structure permits empirical estimation of the model.¹ The specific character of the risk-perception function also enables one to derive specific empirical predictions regarding observed anomalies in choice behavior. In particular, the model *predicts* a wide variety of aberrant phenomena, such as the Allais paradox

and the representativeness heuristic, and it yields Kahneman and Tversky's [1979] general principle underlying violations of the substitution axiom as a theorem rather than an empirical regularity, as in their prospect theory. As documented by Carbone and Hey [1994], the overall empirical performance of the prospective reference theory model in explaining behavioral anomalies is relatively high.

The Bayesian learning formulation that is used employs the beta distribution, which is quite flexible and can assume a wide variety of skewed and symmetric shapes.² As has been indicated by Pratt, Raiffa, and Schlaifer [1965], the character of this distribution makes it ideally suited to analyzing Bernoulli-type trials of the kind frequently encountered in lottery situations.

Suppose that individuals have a prior risk assessment of the adverse outcome p with an associated precision γ , where the individual acts as if the prior reflects γ draws from a Bernoulli urn. In addition, the individual has an assessed context-specific risk q , with an associated precision ξ . In the case of laboratory choice experiments, it is often reasonable to assume that the prior has a value $1/n$, where n is the number of lottery outcomes, and q is the stated lottery branch probability.³ For actual risk contexts, the probability component q may reflect a situation-specific component of the probability that can be influenced through appropriate care. In particular, I will frequently let the context-specific risk $q(c)$ be a function of the level of self-protection c , where $\partial q/\partial c \leq 0$. The individual's assessed risk π of the adverse outcome is consequently given by

$$\pi = \frac{\gamma p + \xi q}{\gamma + \xi}. \quad (1)$$

In cases in which individuals have received information indicating that the risk q is 0 or 1, π will be set equal to 0 or 1 in these extreme certainty situations. As indicated in Viscusi [1989, 1992], it is also possible to develop the model without this assumption. However, treating the certainty cases in this manner generates predictions more closely in accordance with empirical evidence. In addition, specifying the behavior of the perceived probability as the risk level q approaches 0 or 1 eliminates the indeterminacy present in some models with respect to the character of risk perception as q approaches 0 or 1.

Figure 1 sketches the assumed linear relationship AC between risk perceptions and the context-specific probability of (0, 1), where the certainty case endpoints have values along the 45 degree line. The intercept is given by $\gamma p/(\gamma + \xi)$, so that higher values of the prior p or a higher fraction of the informational context accorded to the prior $\gamma/(\gamma + \xi)$ increase the value of the intercept. The slope of AC is the fraction of the informational context $\xi/(\gamma + \xi)$ associated with the context-specific risk. The intersection point is the value B at which $q = \pi$, which occurs when q equals p .

Since a primary concern will be with the role of government information provision, the approach here uses a variant of this basic model. To assess the effect of incremental changes in informational policy, I adopt two different formulations to parameterize the government's action. Two different structures—an additive model and a multiplicative model—are used to permit some flexibility in the manner in which government risk information may affect risk perceptions. The first approach, which is multiplicative in character, allows for an

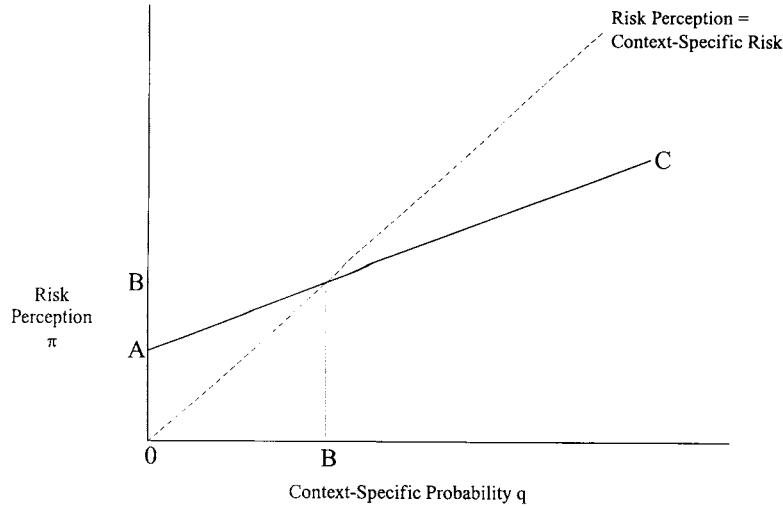


Figure 1. The relation of risk perceptions to the context-specific risk.

entity such as the government or a firm to provide risk information that may alter the precision α or the level β of the risk q , so that

$$\pi = \frac{\gamma p + \xi \alpha \beta q}{\gamma + \xi \alpha}. \quad (2)$$

Higher values of α reflect greater weight on the q component of π but do not alter this risk perception. In contrast, altering β affects the risk associated with the specific context. Thus, the way in which q influences π is tied to the influence of government actions, which can potentially mute or increase the impact of q on risk perceptions. In the case of public information campaigns, both α and β may be affected. Government risk regulations that directly influence the level of the risk likewise have an influence that can be captured in the parameter β as effective regulations will lower β and the risk level associated with the particular accident situation.

For simplicity, the role of the risk-level parameter β is restricted to focusing on how it affects the context-specific probability. Prior beliefs p about a general activity are assumed to be independent of β . This assumption is not, however, consequential for what follows. In particular, the signs of all the key components of the analysis remain unchanged so that the description of the general direction of the effects remains unaltered.⁴

The second formulation of risk perceptions utilizes an additive formulation in which the context-specific risk and the government-related component enter separately, or

$$\pi = \frac{\gamma p + \alpha \beta s + \xi q}{\gamma + \alpha + \xi}, \quad (3)$$

where α reflects the informational content of the government effort, β is the parameter that shifts the risk level, and s is the level of the risk communicated by the government.

In this formulation, the value of the individual's risk beliefs and their informational weight will continue to influence π , unaffected by government action. However, the proportional weight accorded to private risk judgments will decrease as α increases. If all context-specific information stems from that provided by the government, set $\xi = 0$.

The structure of this approach permits the context-specific probability parameter q to be a function of the individual's precautions c . However, unlike equation (2), government components of the formulation cannot directly influence these context-specific values. Situations in which all context-specific information is dependent on c are captured in the multiplicative variant of the model.

Letting the precaution term c influence the prior probability p as well as the context-specific probability q does not greatly alter the character of the results.⁵ For concreteness, the development here will restrict influences such as precautions and information to their effects on the context-specific probability.

During the course of the model's development, a variety of aspects of the character of the π function will play a central role. For ease of reference, these relationships are summarized in Table 1. In each case, both the vertical intercept of the π function and the slope π_q are positive and have as their denominator the total informational content received by the individual in the particular context for the perceptual structure indicated.

The role of the risk-perception parameters p , γ , and ξ is of interest in that these parameters reflect how the difference in the character of risk beliefs that make π differ from q affect risk perceptions. One parameter that has a clearcut effect is the prior risk assessment p since π_p is always positive; higher assessed prior probabilities always boost the value of π .

Changing the precision γ of the prior beliefs does not have the same kind of unambiguous consequences in affecting the value of π since the effect depends on the level of the prior probability. More precise prior beliefs raise the value of π if the prior probability is sufficiently large. More specifically, the sign of π_γ is the same as that of $p - \beta q$ in the multiplicative case and a weighted average of $p - \beta s$ and $p - q$ in the additive case, where these weights depend on the informational content of the competing risk values. Increasing the weight ξ on the context-specific probability q is subject to analogous ambiguities except that the relative magnitude of q relative to p and βs is the matter of concern (see Table 1). In both models, however, a higher value of ξ rotates the line AC in Figure 1 closer to the 45 degree line. The effect of higher values of ξ on the level of the perceived probability depends on where along AC the point lies.

Increases (decreases) in the risk-shift parameter β reflects either a higher (lower) communicated risk level or a higher (lower) actual risk level due to government action. Such increases in β have a clearcut influence, as $\pi_\beta > 0$ for both the additive and multiplicative models. Government policy changes that raise the communicated risk level always raise π .

Increases in the value of the government-provided informational content α have an ambiguous effect on π as did the individual's information content parameters since its influence depends on the level of the probabilities involved. This ambiguity is not a disturbing result but rather follows directly from the potential role of risk information and its character. In particular, whether communicated risk information is likely to raise lower probabilities depends on the level of the communicated risks relative to the initial prior beliefs and the context-specific probability. In the case of the additive model, higher values of α perform in much the same manner as higher values of ξ . In particular, they rotate AC toward the

Table 1. Summary of risk perception function relationships.^a

| Perception Probability Relationship | Multiplicative Model (Equation (2)) | Additive Model (Equation (3)) |
|-------------------------------------|---|--|
| Intercept | $\frac{\gamma p}{\gamma + \xi \alpha} > 0$ | $\frac{\gamma p + \alpha \beta s}{\gamma + \alpha + \xi} > 0$ |
| Slope: | | |
| π_q | $\frac{\xi \alpha \beta}{\gamma + \xi \alpha} > 0$ | $\frac{\xi}{\gamma + \alpha + \xi} > 0$ |
| π_p | $\frac{\gamma}{\gamma + \xi \alpha} > 0$ | $\frac{\gamma}{\gamma + \alpha + \xi} > 0$ |
| π_γ | $\frac{\xi \alpha (p - \beta q)}{(\gamma + \xi \alpha)^2} \cong 0$ | $\frac{\alpha (p - \beta s) + \xi (p - q)}{(\gamma + \alpha + \xi)^2} \cong 0$ |
| π_ξ | $\frac{\gamma \alpha (\beta q - p)}{(\gamma + \xi \alpha)^2} \cong 0$ | $\frac{\gamma (q - p) + \alpha (q - \beta s)}{(\gamma + \alpha + \xi)^2} \cong 0$ |
| π_β | $\frac{\xi \alpha q}{\gamma + \xi \alpha} > 0$ | $\frac{\alpha s}{\gamma + \alpha + \xi} > 0$ |
| π_α | $\frac{\gamma \xi (\beta q - p)}{(\gamma + \xi \alpha)^2} \cong 0$ | $\frac{\gamma (\beta s - p) + \xi (\beta s - q)}{(\gamma + \alpha + \xi)^2} \cong 0$ |
| π_c | $\frac{\xi \alpha \beta q'}{\gamma + \xi \alpha} \leq 0$ | $\frac{\xi q'}{\gamma + \alpha + \xi} \leq 0$ |
| $\pi_{c\alpha}$ | $\frac{\gamma \xi \beta q'}{(\gamma + \xi \alpha)^2} \leq 0$ | $\frac{-\xi q'}{(\gamma + \alpha + \xi)^2} \geq 0$ |
| $\pi_{c\beta}$ | $\frac{\xi \alpha q'}{\gamma + \xi \alpha} \leq 0$ | 0 |

^aThe indicated signs are based on an assumed nonzero value of p and q .

45 degree line. For the interactive case, the sign of one term ($\beta q - p$) determines the net effect of α on π , whereas in the additive case, two terms— $(\beta s - p)$ and $(\beta s - q)$ —weighted by their respective informational contents associated with p and q determine the net effect. What these relationships suggest is that if people tend to neglect risk relative to the information being communicated, more information will boost their risk beliefs. In particular, in the case of the multiplicative models, let us for the moment neglect ξ , which does not play an essential role. Then the value of π_α can be written as

$$\pi_\alpha = \frac{\beta q - p}{\gamma + \alpha}, \quad (4)$$

so that the sign of the term hinges on whether the probability influenced by government policy exceeds the subjective probability π . If $\pi < \beta q$, or people tend to neglect risk, then $\pi_\alpha > 0$, or increasing the amount of risk information raises the subjective probability of an accident. If $\pi > \beta q$, or people overestimate the probability, more vigorous information campaigns decrease the probability.

Increases in the level of precautions c reduce the risk q and decrease the value of π in each case, unless $\partial q/\partial c = 0$, in which case $\pi_c = 0$. The interactive effect of the information parameters and the level of precautions c will also be of subsequent interest in determining the ramifications of information provision for the desirability of exercising care. Increasing the informational weight α makes the value of π_c more negative for the interactive case, but higher values of α have a positive effect π_c for the additive case. In the final variant, $\pi_{c\beta}$ has a negative sign in the multiplicative model case, as increasing the probability scale level makes precautions more influential in affecting π . This term has a zero value in the additive case. If $\partial q/\partial c = 0$, then π_c , $\pi_{c\alpha}$, and $\pi_{c\beta}$ will equal 0 for both models.

3. Information, perceptions, and risk tradeoffs

The structure of risk perceptions and biases may affect an individual's attitudes toward risk-taking generally. Here I examine these influences, assuming individual precautions and insurance levels are fixed. This formulation makes it possible to explore the usual compensating differential results with respect to risk bearing. In particular, how does the provision of government risk information affect observed risk tradeoffs? Let individual utility in the no-accident state be denoted by U and utility in the accident state be denoted by V , where $U', V' > 0$ and $U'', V'' \leq 0$. In the no-accident state, utility is dependent on one's income level I and risk compensation Y . This compensation may take the form of higher wages for a risky job or lower prices for a hazardous product. If there is an accident, the individual suffers a monetary loss L , possibly zero.⁶ If accidents consist only of monetary losses, U and V are identical functions, where the difference in notation will be used to express the difference in their arguments. If accidents change the structure of utility functions, as in the case of adverse health effects and death, $U'(X) > V'(X)$ for any given level of income X . Let U_0 be the individual's current expected utility level, where

$$U_0 = (1 - \pi)U(I + Y) + \pi V(I + Y - L). \quad (5)$$

The first matter of interest is the effect of the size of the loss L on risk compensation Y , or $\partial Y/\partial L$. Totally differentiating equation (4) and solving for $\partial Y/\partial L$, one has

$$\frac{\partial Y}{\partial L} = \frac{\pi V'}{(1 - \pi)U' + \pi V'} = \frac{V'}{\frac{1 - \pi}{\pi} U' + V'} > 0. \quad (6)$$

If q represents the probability that would pertain in the presence of less than full information and perceptual biases, then $\partial Y/\partial L$ will be greater than with a standard model if

$(1 - \pi)/\pi$ is less than $(1 - q)/q$. If the perceptions are altered to increase the relative odds of the no-accident state relative to the accident state (i.e., all points along OB in Figure 1), then $(1 - \pi)/\pi$ will be increased and $\partial Y/\partial L$ will be reduced. Which factors affect the value of π can be explored using the results in Table 1, and these are examined explicitly below.

A frequent focal point of economic analyses is on the risk-money tradeoff, where it is the probability of the adverse actions that is being traded off against the monetary component. If we treat π as a parameter, ignoring the dependence of π on terms such as α , and solve for $\partial Y/\partial \pi$, one obtains the standard risk-money tradeoff compensating differential result that higher risks require additional compensation, or

$$\frac{\partial Y}{\partial \pi} = \frac{U - V}{(1 - \pi)U' + \pi V'} > 0. \quad (7)$$

This functional form is a familiar result in the compensating differential literature.⁷

Assessing the effect of this tradeoff of having risk beliefs π rather than q depends not only on the relative magnitudes of π and q but also on the size of U' and V' . If losses consist only of monetary equivalents, the effect of having a loss L in the accident state will be to make $V' > U'$ since U and V are identical utility functions but with different arguments. For this utility function structure, a value of π in excess of q will make the fractional weight on V' greater and U' commensurately less, thus making $\partial Y/\partial \pi$ smaller. If accidents alter the structure of utility functions, the relative magnitudes of U' and V' will be unclear. The loss L will raise the marginal of money in the accident state, but the influence of the change in utility functions arising from the state-dependent structure may lower it. The key concern is whether on balance the expected marginal utility of income is diminished.

The practical consequence of biases in risk perceptions π on these tradeoff levels may be affected. Even in situations in which the directions of influence are the same, the relative magnitudes of the influence may differ. To explore the nature of these differences, it is useful to consider parameters based on explicit estimates of utility functions for the job-risk case. In Viscusi and Evans [1990], we estimate different functional forms for utility functions, including unrestricted Taylor's series approximations to general utility functions. These flexible functional forms yielded results that were not distinguishable from the results obtained using logarithmic utility functions, so that I focus on the logarithmic case for concreteness. In the case of the healthy state, individual utility is given by

$$U(Y) = 1.077 \ln Y, \quad (8)$$

which has an associated marginal utility of income given by

$$U'(Y) = 1.077 \left(\frac{1}{Y} \right). \quad (9)$$

To specify analogous results in the postaccident case, it is also necessary to indicate how income levels are affected by an accident. In the case of job injuries, the fraction of income

retained by the worker after the injury is given by k . This approach captures the general character of social insurance and workers' compensation programs. One consequently has a utility function in the state of ill health given by

$$V(Y) = \ln kY, \quad (10)$$

with an associated marginal utility of income of

$$V'(Y) = \frac{k}{kY} = \frac{1}{Y}. \quad (11)$$

The rate of income replacement in the United States is approximately two-thirds of worker income, but this amount is subject to various ceilings that make the replacement rate a bit less for workers in higher income groups. The overall average value of k for the Viscusi and Evans [1990] sample is 0.64, and this value is used for illustrative purposes in the empirical example below.

Substituting these values into equation (5) to establish the tradeoff between the level of the financial losses associated with the accident and the risk compensation Y , one has

$$\frac{\partial Y}{\partial L} = \frac{\frac{1}{Y}}{\left(\frac{1-\pi}{\pi}\right) 1.077 \left(\frac{1}{Y}\right) + \frac{1}{Y}} = \frac{1}{\frac{1-\pi}{\pi} 1.077 + 1}. \quad (12)$$

The value of this expression depends on the assumed level of probabilities, as the role of income cancels out of this expression. The average U.S. worker injury rate in the Viscusi and Evans [1990] sample was 0.08, where this is the annual probability of a nonfatal job injury. To explore the influence of biases in perception, let us consider two cases—that in which workers' perceptions π equal 0.08 and the situation in which workers' perceptions are double the actual value of the risk, or 0.16. In the case in which the value of π is 0.08, the value of $\partial Y/\partial L$ is 0.075. If, however, workers overestimate the risk by double so that π equals 0.16, then the value of $\partial Y/\partial L$ equals 0.150.

What these results suggest is that the required value of compensation that the individual must receive per dollar loss is very sensitive to the probability involved. If there is overestimation of the risk by, for example, double, then there is a doubling of the required compensation amount. For the kind of small changes considered here, the overall character of the results is very similar to what would prevail in the risk-neutral situation. Doubling the perceived probability of the loss will double the expected value of the loss and consequently have a comparable effect on the amount of compensation an individual would require to face such a higher risk.

If we now consider the effect of perceptual biases on the tradeoff between Y and π , then we obtain

$$\frac{\partial Y}{\partial \pi} = \frac{1.077 \ln Y - \ln kY}{(1-\pi)(1.077) \left(\frac{1}{Y}\right) + \pi \left(\frac{1}{Y}\right)}. \quad (13)$$

Unlike the value of $\partial\pi/\partial L$, this expression continues to depend on the income level as well as on the perceptual parameters. For concreteness, I will use as the income level the average U.S. per capita income in 1992.⁸ At the average U.S. per capita income level and a value of k equal to 0.64, and at a perceptual π value of 0.08, one has a risk-money tradeoff amount $\partial\pi/\partial Y$ of \$22,358. The value of $\partial\pi/\partial Y$ evaluated at a perceived probability of 0.16 is \$22,486. This risk-money tradeoff is the statistical value of a job injury. It is the nonfatal risk analog of the implicit value of life. Unlike the tradeoff between income and the loss amount, the tradeoff between income and the perceived probability π , or $\partial Y/\partial\pi$, is not particularly sensitive to variations in the perceived probability level.

The reason for the contrast in the sensitivity to misperceptions of $\partial Y/\partial L$ and $\partial Y/\partial\pi$ stems from the difference in the character of the two influences. In the case of $\partial Y/\partial L$, altering the perceived probability affects the expected loss proportionally, with similar kinds of influences even in the risk-averse case. However, in the case of the value $\partial Y/\partial\pi$, altering the perceived probability π is equivalent to shifting the base risk level from which one considers possible tradeoff amounts. This shift is less influenced by potential risk overestimation than is the risk-compensation loss tradeoff amount.

Policy manipulations that alter π in an unambiguous manner also have a similar effect on the Y values required to maintain the constant expected-utility level. To assess the effect on the required compensation Y of higher values in β , one has

$$\frac{\partial Y}{\partial\beta} = \frac{\pi_{\beta}(U - V)}{(1 - \pi)U' + \pi V'}, \quad (14)$$

where

$$\text{sign} \left(\frac{\partial Y}{\partial\beta} \right) = \text{sign} \left(\frac{\partial\pi}{\partial\beta} \right), \quad (15)$$

which is always positive. Higher risk parameter β values raise the assessed accident risk π (see Table 1) and consequently increase the required compensation level Y .

For much the same reason, increasing the context-specific risk q raises the accident probability π (see Table 1) and the required compensation, or

$$\frac{\partial Y}{\partial q} = \frac{\pi_q[U - V]}{(1 - \pi)U' + \pi V'} > 0 \quad (16)$$

since $\pi_q > 0$ (see Table 1).

The effect on Y of altering the nature of information provision depends on the character of the influence of the information on π . In particular,

$$\frac{\partial Y}{\partial\alpha} = \frac{\pi_{\alpha}(U - V)}{(1 - \pi)U' + \pi V'}, \quad (17)$$

or

$$\text{sign} \left(\frac{\partial Y}{\partial\alpha} \right) = \text{sign} \left(\frac{\partial\pi}{\partial\alpha} \right). \quad (18)$$

As is indicated in the Table 1 summaries, the sign of $\partial\pi/\partial\alpha$ is ambiguous since the effect of more informational content on the publicly provided information depends on the relative magnitude of the probabilities being conveyed. This ambiguity is not unexpected and is not a reflection of inefficacy of information provision efforts. Rather, what matters is the level of the risk being communicated. When this risk level is sufficiently great, making the information content greater has clearcut effects. Similar ambiguities pertain in the case of variations in the levels of γ and ξ .

Overall, the pattern of compensating differentials follows the expected patterns. The pivotal matter of concern in most instances is whether the parameter change raises or lowers the accident probability π . The effect on $\partial Y/\partial L$ is a variant of this result since the issue is not dependent on a derivative of π but whether the role of risk perceptions makes the perceived risk π greater than q . The level of π rather than its slope is consequential in this instance.

4. Self-protection with mandatory insurance

A fundamental concern is how the character of risk perceptions alters the degree of precautions c . Suppose that the individual can exercise care c , which imposes a monetary cost equivalent in each state but which reduces the value of q . For this model, c will be the only choice variable, as the government will mandate insurance coverage x and charge a premium rx in each state. The U.S. workers' compensation system satisfies this general structure. Many social insurance programs throughout the world have a similar structure. Compensation for accidents through tort liability likewise has this overall character, where x is the expected liability award and rx is the higher price the consumer pays to cover the firm's higher liability costs.

The individual's task is to select the optimal level of precautions that will

$$\text{Max}_c Z = (1 - \pi)U(I - rx - c) + \pi V(I - L - rx + x - c), \quad (19)$$

which after some rearrangement of terms leads to the first-order condition

$$\frac{\partial\pi}{\partial c} = \frac{-[(1 - \pi)U' + \pi V']}{U - V}. \quad (20)$$

Precautions are increased until $\partial\pi/\partial c$ equals the negative of the effect of c on the expected marginal utility of income, normalized by the utility difference between the two states.

Substituting the value for $\partial\pi/\partial c$ for the multiplicative case in Table 1 and solving for $\partial q/\partial c$, one has

$$\frac{\partial q}{\partial c} = \frac{-[\gamma + \xi\alpha]}{\xi\alpha\beta} \frac{[(1 - \pi)U' + \pi V']}{U - V}, \quad (21)$$

and for the additive case one has

$$\frac{\partial q}{\partial c} = \frac{\gamma + \alpha + \xi}{\xi} \frac{[(1 - \pi)U' + \pi V']}{U - V}. \quad (22)$$

In the discussion below reference will be made to the second-order condition as well, which in both the multiplicative case and the additive case is given by

$$D = \pi_{cc}(U - V) - 2\pi_c U' + 2\pi_c V' - (1 - \pi)U'' - \pi V'' > 0. \quad (23)$$

The main matters of interest pertain to how government actions through either compensation or risk information affect the importance of exercising care. In both the multiplicative structure case and the additive case,

$$\frac{\partial c}{\partial x} = \frac{\pi_c r(V' - U') - \pi V' - (1 - \pi)U''r - \pi V''r + \pi V''}{-D}, \quad (24)$$

where D is positive. The value of $\partial c/\partial x$ is clearly negative in the risk-neutral case in which $U'' = V'' = 0$ so that higher mandated insurance amounts will always reduce precautions. In the usual state-dependent utility-function approach in which $U' > V'$ and individuals are risk averse, all terms in the numerator will be positive except the final $\pi V''$ term. Extremely rapid diminishing marginal utility in the accident state could potentially lead higher insurance amounts to boost precautions, but otherwise one will observe the more generally expected results of a negative effect.

The information parameters have different effects depending on whether it is the precision or the level of the risk belief that is being altered. Shifting the precision has a less clearcut effect since its influence depends on the relative magnitude of the individual's prior probability and the information being conveyed. For both the multiplicative and additive cases,

$$\frac{\partial c}{\partial \alpha} = \frac{\pi_{c\alpha}(U - V) - \pi_{\alpha}(U' - V')}{-D}. \quad (25)$$

Since the denominator is negative, more information will increase precautions if the numerator is negative. Consider the multiplicative case. Since $(U - V) > 0$ and $\pi_{c\alpha} \leq 0$ (see Table 1), the first term in the numerator is either negative or zero. The sign of $\partial c/\partial \alpha$ will only be unambiguously positive if $\pi_{\alpha}(U' - V')$ is positive. Since π_{α} has an ambiguous sign (see Table 1) and $U' > V'$ in the pure state-dependent case but $U' < V'$ in the monetary loss equivalent case, the net effect depends on which combinations of these situations prevail. Somewhat different ambiguities pertain in the additive probability case as well, which one can verify using the results in Table 1. The value of $\pi_{c\alpha} \geq 0$ in the additive case, but $\pi_{c\alpha} \leq 0$ in the multiplicative case. In the additive situation, higher values of α will dilute the incentive to exercise care, whereas in the multiplicative case these incentives will be enhanced.

The effect on precautions of increasing the risk parameter p is given by

$$\frac{\partial c}{\partial \beta} = \pi_{c\beta}(U - V) - \pi_{\beta}(U' - V'). \quad (26)$$

In the multiplicative case, from Table 1, $\pi_{c\beta}$ is negative (or zero if $\partial q/\partial c = 0$) and π_{β} is positive. For the state-dependent utility function case (that is, $U > V$, $U' > V'$), then $\partial c/\partial \beta$

is positive. Higher communicated risk parameters increase the level of precautions. This result also holds for the additive case but with a somewhat simpler form since $\pi_{c\beta} = 0$.

Of the various actions the government can take, boosting β has the most clearcut effects in raising precautions. Policies that alert people to risks will raise β values, whereas government safety programs that lead to safety technology improvements will lower β . In many situations raising the mandated compensation level will also have an ambiguous effect in decreasing precaution taking since the incentives for taking care will have been diminished. Making these messages more precise is most clearcut in its effect because the influence depends on the level of the risk being conveyed.

5. Private insurance decisions

If the government does not mandate insurance levels but instead leaves them as a matter for individual discretion, then the individual will select both c and x , or

$$\text{Max}_{c,x} Z = (1 - \pi)U(I - rx - c) + \pi V(I - L - rx + x - c). \quad (27)$$

The first-order condition for the choice of c , given a value of x , is the same as that given above in equation (19), and the pertinent condition for the choice of x satisfies

$$Z_x = (1 - \pi)U'(-r) + \pi V'(1 - r) = 0, \quad (28)$$

or the familiar result that

$$\frac{U'}{V'} = \frac{(1 - r)\pi}{r(1 - \pi)}. \quad (29)$$

Suppose that the price of insurance is on an actuarially fair basis when viewed from the standpoint of the individual's risk perceptions π . Then full insurance is desirable, leading to $U' = V'$. If $\pi > r$, then individuals will purchase more insurance than would be desirable from an actuarial standpoint, leading to $U' > V'$, since from their perspective insurance has been underpriced. The opposite result occurs if $\pi < r$.

For fixed values of c , the effect of adding the risk-perception aspects of the problem to the more basic context-specific probability q depends on the relationship between π and q . More specifically, if

$$\frac{\pi}{1 - \pi} > \frac{q}{1 - q}, \quad (30)$$

which is simply $\pi > q$, then it will be optimal to have a higher U'/V' or to buy more insurance and to transfer more income to the post-accident state.

The conditions under which π will exceed q were explored in Section 2. For low probabilities, which tend to accord with the rare event view of most accidents, π will exceed q . Similarly, accidents for which there has been substantial effort to raise β through a risk

communication effort will have a high π and a higher insurance amount. The opposite will occur if β is reduced through either risk communication of a direct risk-reduction program.

The character of the individual's own probability parameters γ and β also will influence the attractiveness of insurance. From Table 1, increasing the prior probability weight γ will increase π and the desirability of insurance for large values of p but not for smaller values. More precise prior beliefs raise π only when the p value that is being weighted exceeds the other risk components, where the specific functional relationships vary depending on whether it is an additive or multiplicative case.

Higher p values always raise π and increase the desirability of insurance. As in the case of the government-risk-level parameter-shift term β , the influences are always unambiguous and will raise π . As a result, the desired U'/V' ratio rises so that there is more of a transfer of income to the postaccident state than with lower values of p . High values of the prior probability p and increases in its informational content parameter γ will increase the value of the intercept and thus the spread between π and q .

6. Conclusion

Most aspects of risk taking and insurance-related decisions hinge on the relationship between the perceived probability by the individual and the actual risk. Biases in decisions consequently will be governed by this discrepancy. For example, this type of relationship is pertinent in influencing the compensation demanded for the value of economic losses resulting from an accident as well as influencing the risk-compensation tradeoff. Similarly, the choice of individual precautions as well as the choice of the level of insurance also hinges on the perceived probability of an adverse outcome.

In the case of precaution taking, however, it is not only the level of the risk that is pertinent but also the responsiveness of the perceived risk to changes in precautions. Because of this dependence, the derivative of perceived probabilities with respect to the level of precautions is the key matter of concern. Factors that dampen this relationship, such as increases in the weight on the prior probability, will tend to make perceived probabilities less responsive to changes in precautions, thus decreasing the incentive to take these precautions.

Government information provision has differing effects on risk perceptions and subsequent behavior depending on the character of the information that is generated. In the case of information that enters multiplicatively, more risk information reinforces the influence of the precaution-taking term on perceived risks. If, however, the information enters in additive form, in effect it will mute the influence of the precaution-taking term on the perceived probability, leading to a lower incentive to take care. Government information provision consequently may have quite different effects on incentives for precaution taking depending on the way in which this information affects the structure of perceived probabilities.

More generally, changes in the risk level tend to have more unambiguous effects on perceived risks and consequently on decisions than do changes in informational content. Increasing the context-specific risk, the prior probability, or the risk level conveyed by the government all tend to increase the perceived risk. Increases in precaution taking decrease the perceived risk. In the interactive model case, increases in the amount of government information or the risk conveyed by government information both make the effect of precaution taking on the perceived risk greater. However, in the independent-model case in which

the role of the government information enters additively, higher amounts of government information dampen the effect of precaution taking on risk perceptions, and increasing the risk level conveyed by government information has no effect on the effect of precaution taking on π . This disparity in effect highlights the importance of resolving the way in which risk information alters the character of individual beliefs.

Many of the effects considered here move beyond the standard reference-point assumption that small risks are overestimated and large risks are underestimated. Although this characterization of risk perceptions was incorporated in the model, the primary focus was in elaborating how different parameters that influence risk perceptions alter the relationship between perceived and actual probabilities and the influence of these probabilities on subsequent insurance and precautionary decisions.

The parameters that are associated with the amount of informational content of different components of the assessed probability tended to have ambiguous effects. The informational weight on prior risk beliefs, the informational weight on the context-specific probability, and the informational weight on the government-provided risk information all had an ambiguous influence on perceived probabilities. In every case the direction of the influence depended on whether the probability that was being weighted was higher than the other components of risk beliefs. Thus, the influence of increasing the precision of the component tended to hinge on differences in probabilities, where these differences were generally weighted by the informational content associated with the respective components.

When examining the various biases that result in decisions as a result of imperfect risk information, the typical emphasis is on the direction of the effects. Failure to adequately perceive risks, for example, may lead to inadequate levels of insurance or inadequate precautions. What such results fail to convey is which effects are consequential and which are not. In an effort to address the quantitative significance of some of these effects, I employed explicit estimates of utility function structures that have been obtained in the job safety case. Utilization of these utility functions indicated that, for example, the risk tradeoff with respect to compensation required to face a risk and the amount of economic loss was much more sensitive to perceptual biases than was the tradeoff between compensation and the risk level. In the case of the risk-loss tradeoff, the effect of the biases was almost proportional to the level of probabilities, whereas the risk-money tradeoff was only marginally responsive to the level of the perceived probabilities.

These results suggest that examination of theoretical characteristics of biases in decisions resulting from irrational choices of various kinds should not be restricted to the theoretical explorations alone. We need to obtain a better sense of the magnitudes of the biases that result from flaws in decision making and to identify which biases appear to have the greatest effect in distorting individual decisions. Assessing the incidence of the market failures resulting from irrational choices under uncertainty will also identify the locus of the market failure and assist in targeting government interventions intended to alleviate these inadequacies.

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Henri Loubergé provided excellent comments that affected both the structure and interpretation of the models.

Notes

1. See Viscusi [1992] for a review of some of these studies.
2. One is led to an equivalent mathematical formulation using the normal distribution.
3. This formulation is adopted in Viscusi [1989, 1992].
4. Consider the summary of the key risk-perception relationships in Table 1. The relationships where making the role of p dependent on β will be consequential are π_β and $\pi_{c\beta}$. Suppose π is given by $\pi = (\gamma p\beta + \xi\alpha\beta q)/(\gamma + \xi\alpha)$ in the multiplicative model and by $\pi = (\gamma p\beta + \alpha\beta s + \xi q)/(\gamma + \alpha + \xi)$ in the additive model. The value of π_β is given by $(\gamma p + \xi\alpha q)/(\gamma + \xi\alpha)$ in the multiplicative model and by $(\gamma p + \alpha s)/(\gamma + \alpha + \xi)$ in the additive model, where each of these are positive as in Table 1. Since p is not dependent on c , the value of $\pi_{c\beta}$ is identical to the values in Table 1 even if β influences p as specified above.
5. Consider the results in Table 1. The first key relationship is π_c , which becomes $(\alpha p' + \xi\alpha\beta q')/(\gamma + \xi\alpha) \leq 0$ in the multiplicative case and $(\gamma p' + \xi q')/(\gamma + \alpha + \xi) \leq 0$ in the additive case. The value of $\pi_{c\beta}$ is unchanged. The sign of $\pi_{c\alpha}$ becomes ambiguous, as it is given by

$$\xi(\gamma\beta q' - \alpha p')/(\gamma + \xi\alpha)^2 \stackrel{?}{=} 0$$

in the multiplicative case. In the additive case, one obtains a value of $\pi_{c\alpha} = -(\gamma p' + \xi q')/(\gamma + \alpha + \xi)^2 \geq 0$, as before.

6. Because of the use of state-dependent utility functions, there may nevertheless be a welfare loss even if L is zero.
7. For example, other than for a change in notation, it is the same as the wage-risk tradeoff for the occupational health and safety context. See Viscusi [1979a].
8. More specifically, this amount is the per capita personal income value in 1992 of \$19,802 reported by the U.S. Bureau of the Census. See U.S. Department of Commerce [1993, p. 445]. This amount is a bit less than the average worker income level reported in Viscusi and Evans [1990], where for their sample the average weekly earnings was \$392, or an annual earnings amount of \$20,384.

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