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COMMUNICATION OF AMBIGUOUS RISK INFORMATION*

ABSTRACT. This paper reports on the responses of 646 individuals to environmental risk information involving different forms of risk ambiguity. Recipients of more than one set of risk information do not simply average the risk levels provided. Rather, a variety of aspects of the nature of the risks that are communicated influence their probabilistic beliefs. Individuals' perceptions of the risk levels to which they are exposed are likely to be greater: (i) for more ambiguous risks, (ii) for risks for which the unfavorable risk evidence is presented last even when there is no temporal order, (iii) for risks for which the most unfavorable risk studies have been performed most recently, and (iv) for risks where there is asymmetry in the risk ambiguity that imposes substantial potential downside risks. Although these effects are modest for the median individual, the potential for extreme responses that reflect only the most adverse or the most favorable piece of information provided is quite prevalent. These findings are of interest more generally in that they indicate how individuals form their risk perceptions in the presence of risk ambiguity.

Keywords: ambiguity, uncertainty, Ellsberg Paradox, information.

1. AMBIGUITY AND RISK COMMUNICATION

Risk communication efforts provide risk information to individuals so that they can make more informed decisions about the risks they face.[1] Informational policies can affect behavior when there is a difference in the risk information of the two parties. One party, typically the government or the producer, has more information about a particular risk than does the individual exposed to the risk. The purpose of risk communication policies is to transfer this information to the parties that can use the information to improve their decisions.

In situations in which the provider of the risk information has perfect knowledge, the question is primarily one of conveying this knowledge to the user in the most effective way possible. In many important instances of risk communication, however, even the better informed party does not have perfect information. There will necessarily be considerable uncertainty regarding the exposure level of the

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affected individuals and differences in the risk according to individual sensitivity. Even more fundamentally, there may be underlying scientific uncertainty.

Suppose, for example, that the government believes that there is a potential risk of cancer from a particular environmental exposure, but it is not sure of the extent of the risk. Some studies indicate that the risk is small, but others indicate a larger risk. How should the government attempt to convey this information? Should it indicate the upper end of the risk range? Should the government communicate the lower end of the risk range? Should it simply provide the mean or the median estimate of the risk value and not indicate that there is ambiguity pertaining to the risk?

Choosing among these various alternatives often creates important problems from the standpoint of long-term credibility. If we tell individuals of a specific risk now and then must change our risk assessment in the future, then the credibility of the information provider will be undermined. Moreover, the manner in which this credibility is undermined may depend on whether the subsequent information provided is more or less favorable than was originally given. Truthful disclosure of information would require that we convey the presence of ambiguity pertaining to the risk, but the danger is that individuals may not be able to process ambiguous risk information reliably, and thus their resulting decisions will not be sound.

The problem in communicating ambiguous risks stems from the difficulties individuals have in dealing with probabilities that are not known with precision. The paper by Ellsberg (1961), for example, highlighted the potential role of individual aversion to ambiguous probabilities of winning a prize, as compared with comparable probabilities known with precision.[2] In the case of environmental risks, the reference point is not hypothetical lotteries but instead scientific studies. More importantly, the ambiguity pertains not to the chance of winning a *positively* valued outcome as in the Ellsberg experiment, but the chance of suffering a *negatively* valued loss. It also may be that individuals' attitudes toward ambiguity depend on whether they are facing gains or losses.

From the standpoint of a single decision, individuals seeking to maximize subjective expected utility should be indifferent to a probability of a particular outcome irrespective of whether the probability is known with precision. However, in sequential decision context, individuals should actually display a preference for probabilities that are not known with precision. This result is the basis of the classic two-armed bandit problem whereby individuals will prefer the slot machine with the uncertain probability because it offers the opportunity for learning and adaptive behavior. The individual can stay with the machine if it turns out to be favorable or he can quit and switch to a slot machine with known properties if the outcomes are unfavorable. In this sequential decision context, individuals should have a preference for risk ambiguity.

The literature on the role of ambiguity and how it affects decisions often has led to conflicting implications. Some studies indicate a preference for ambiguity, while others indicate an aversion to ambiguity. Since we review this literature elsewhere,[3] we will focus on the new original research findings in this paper rather than providing a detailed overview of the literature. What should be emphasized is that our concern is with ambiguity regarding probabilities, not ambiguity regarding payoffs. Thus, the major issue is how ambiguity concerning the precision of the probability affects attitudes towards lotteries, not how ambiguity in terms of the spread of outcomes influences behavior. To the extent that individuals are averse to ambiguity, we will refer to this aversion as 'ambiguous belief aversion' to distinguish it from what we would term 'ambiguous payoff aversion', which is the normal type of ambiguity that accounts for the usual risk aversion phenomenon.

The organization of our paper is as follows. Section 2 introduces the study and provides the basic elements of the test of whether ambiguity matters. In Section 3 we indicate how the order of presentation of the ambiguous information influences attitudes toward the risk. Section 4 introduces an additional complication. Not only may the order of presentation of the risk information differ, but there also may be a temporal order with which the studies are undertaken. In such contexts, do individuals weight more recent studies more heavily than studies carried out previously? Later studies presumably should receive more weight if they have a more refined scientific basis or are more pertinent to current risk exposures. In Section 5 we extend our analysis of ambiguous risk beliefs to consider the role of skewness in the risk information that is provided. Section 6 summarizes our principal conclusions pertaining to risk ambiguity. The extent and character of the risk ambiguity greatly affect the risk that respondents believe is equivalent to the ambiguous risk.

2. DOES AMBIGUITY MATTER?

To analyze the effects of risk ambiguity we undertook a survey of individual responses to alternative information presented to them. The sample used for the study consists of 646 subjects who were recruited at a Greensboro, North Carolina shopping mall.[4] After being recruited for the study, these subjects participated in a computer-administered survey in which they indicated their willingness to move to different areas depending on the risks. The particular risks considered in the study were those of non-fatal nerve disease and lymph cancer, where each of these diseases was linked to environmental pollution. The experiment focused on a decision to move to one of the two areas, Area A and Area B, which differed in their risks of contracting one of these two diseases. Subjects were told that the two new locations were otherwise identical to where they now live. They were also informed that in both areas, the risk of nerve disease (or lymph cancer) was less than in their current location. The interviewer also read the subjects a short description of the diseases and asked them several questions to reinforce their understanding of the consequences of contracting them.

Individuals were asked to choose which of these two areas they would prefer if they had to move. Subjects were given risk information pertaining to Area A, for which the risk levels were ambiguous, and they were asked whether they preferred the uncertain risks of Area A to the precise risks of Area B. The known risk for Area B was subsequently altered until the respondent viewed the Area B risk as being equivalent to the ambiguous risks they would face in Area A.

The nature of the survey task can be best illustrated within the context of the information in Table I. Panel 1 of the table presents information concerning the initial test of risk ambiguity. Subjects were told that there had been two studies of the risks of nerve disease posed by exposure in Area A. One study indicated a risk level of 150 cases per 1 million population, whereas a second study indicated a risk of

TABLE I

Risk ambiguity aversion and the size of the nerve disease risk spread.

Panel 1: Risk Ambiguity

Risk Levels in Area A	Sample Size	Median	Mean	Std. Error of Mean	Min (#)	Max (#)
150, 200	65	175.00	178.35	1.24	150.50 (1)	200.00 (1)

Panel 2: Size of Spread Effect

Risk Levels in Area A	Sample Size	Median	Mean	Std. Error of Mean	Min (#)	Max (#)
110, 240	58	180.00	191.08	3.95	115.00 (1)	240.00 (13)

200 cases per 1 million population. They were then asked precisely what risk level in Area B would they view as being equivalent to the risks posed in Area A. This process involved a series of iterative paired comparisons which were modified until indifference was reached. In each case, all aspects of the two areas were held constant other than the one particular risk, which in the case of Panel 1 was nerve disease.

For all of the results considered in the first 4 tables in this paper, the midpoint of the risk range for Area A is always 175.[5] If individuals simply average the risk information provided for Area A, which is what they would do if they placed equal weight on the two studies, then the risk level in Area B that is equivalent to Area A will be 175 for all of the first 4 tables of results. Consequently, the test of risk ambiguity will always be the extent to which the responses for Area B differ from 175.

As is indicated in the results in Panel A of Table I, for the risk combination (150, 200), the median risk response is simply the average of these two risk levels – 175. However, the mean is somewhat greater than 175 – 178.35 – which in this case is significantly different from 175 at the usual confidence levels because of the tight standard error of the mean. As is indicated in the table, one respondent was most influenced by the minimum of the risk range, and a second respondent was at the opposite extreme, but for the most part the respondents were at or somewhat above the average of the two risk levels provided.

If, however, we increase the extent of the risk ambiguity, the effect becomes more pronounced. In the case of Panel 2 in Table I, the size of the spread in the two studies has increased from 50 to 130. This increase in risk ambiguity raises the median risk that is viewed as equivalent to Area A to a value of 180, and the mean risk response increases to 191. Perhaps most strikingly, 13 respondents indicate that the risk in Area B that is equivalent to Area A is 240 cases per million – the high end of the risk range reported for Area A. The fraction of respondents at this extreme is over 20 percent of the sample.

What the results in Panel 2 suggest is that in situations where there is substantial risk ambiguity there will be strong ambiguous belief aversion, as individuals will view a pair of risks with a substantial spread as being more unfavorable than if they have been told the risk was at the midpoint of the range. The way in which people react to risk ambiguity will also be strikingly different, as some individuals may react in an extreme manner. Indeed, in this example the substantial number of extreme responses is consistent with the often alarmist responses that we observe to publicly provided risk information, such as information pertaining to medicine tamperings or food contamination. The risk that people perceive as being equivalent to imprecise risks varies with the extent of imprecision so that alarmist responses to dimly understood but potentially substantial hazards may be quite prevalent.

3. DOES THE ORDER OF PRESENTATION MATTER?

In the risk communication experiment described in Table I, subjects were given information pertaining to two risk assessments for Area A, where the low risk assessment appeared first and the high risk assessment was second. It may be that what we are observing is not purely an ambiguity effect, but rather the influence of the order of presentation. In particular, even though no explicit temporal order was indicated, individuals may place a greater weight on the second study listed.

There are two reasons why we might observe such an effect. The first is a recency effect. When individuals are provided with risk information over time, the more recently provided information should have a greater salience. Although there is not an important time dimension with information provided simultaneously over a computer, if individuals read this information from left to right there is perhaps somewhat greater salience of the second piece of information that is read. More importantly, in all likelihood there is an implied temporal order even though the survey instrument indicated quite explicitly that there were simply two studies and that no temporal order was necessarily to be inferred.

To analyze the effects of temporal order, one must compare the results in Table I with the same outcome and the same nerve disease risk pairs except that the order of the risk information presented is reversed. These results appear in Table II.

For Risk Pair 1 (150, 200), the temporal order appears to make no substantial difference in terms of the median risk that is equivalent to the risk pair, the mean risk response, or the frequency of individuals at the two extremes. The overall result is that there is modest evidence of ambiguity belief aversion in each of the two cases.

Once the spread between the two risk studies is increased from 50 cases per million in Risk Pair 1 to 130 cases per million in Risk Pair 2, the potential role of the order of presentation becomes more apparent. In the case of the risk pair (110, 240), the median risk response of 180

TABLE II

Presentation order effects for nerve disease risks.

Risk Levels in Area A	Sample Size	Median	Mean	Std. Error of Mean	Min (#)	Max (#)
Risk Pair 1:						
150, 200	65	175.00	178.35	1.24	150.50 (1)	200.00 (3)
200, 150	20	175.00	177.88	2.67	150.00 (1)	200.00 (2)
Risk Pair 2:						
110, 240	58	180.00	191.08	3.95	115.00 (1)	240.00 (13)
240, 110	29	175.00	170.35	5.78	110.00 (4)	240.00 (1)

is a bit above the midpoint of the range. With the presentation order reversed to be (240, 110), the median response is exactly at the midpoint of 175. The divergence of the responses is even greater with respect to the means. The mean risk equivalent to (110, 240) is 191, as compared with a mean risk equivalent of 170 for the risk pair (240, 110). Reversing the order of presentation produces a striking difference in the means. This effect can be traced in large part to the outliers in the distribution. For the risk pair (110, 240), 13 of the 58 respondents indicated a risk equivalent of 240, which is the maximum value of the range, as contrasted with only one of the 29 respondents receiving the risk pair (240, 110). Moreover, in the case of the risk pair of (240, 110), 4 of the 29 respondents viewed this risk as being equivalent to the low end of the range – a risk value of 110 cases per million.

Particularly when there is a substantial spread between the risk estimates, the order of presentation appears to be of substantial consequence. The respondents place a greater weight on the second risk values presented. If this weight on the second study is sufficient, as it was in the case where there is a large spread in the risk values for Risk Pair 2, the order of presentation effect can dominate the influence of ambiguous belief aversion.

In all of the cases in Table II, there is a danger of people gravitating to extremes at both ends of the spectrum. Whenever individuals are given a risk range, some individuals may be at one or the other extreme. The great majority of the respondents will be clustered in the middle of the distribution near the midpoint of the range, but the frequency of extreme responses is certainly not negligible. Indeed, 25 of the 172 respondents who are captured in the samples reflected in Table II are either at the high or low value of the risk pairs that were presented to them. Some individuals consequently take both pieces of information into account when processing the risk information, whereas others select one of the two pieces of information as being more credible and focus exclusively on that piece of information. Because clustering at an extreme response is greatest when the second piece of information provided is unfavorable, risk ambiguity aversion is particularly likely to be evident when the worst information is presented last.

4. DOES THE TEMPORAL ORDER MATTER?

If individuals receive risk information over time, presumably they should place greater weight on the second study. In addition to being more recent in their memory, the second study also should provide a more reliable index of the actual extent of the risk to the extent that it is based on superior scientific studies or more pertinent environmental exposure information. By presenting information to respondents regarding the sequence of studies, but presenting the information at the same time, we can isolate the temporal order effect from the recency in memory effect. Thus, the focus of this section is on the extent to which indicating a temporal order for the two studies is of consequence.

Table III summarizes the effects of temporal order for four different nerve disease risk pairs. Consider first the Risk Pair (150, 200), where the first group of respondents listed in Table III did not view these studies as being in any particular temporal order, whereas in the second case an *explicit* temporal order was given. In each case, the study indicating a risk of 200 cases per million was the second in the sequence.

Temporal order has a modest effect on the respondents' mean risk assessment, raising it from 178 in the case of no temporal order to 182 with temporal order. In addition, the extent to which individuals were at the extreme upper end of the range increases substantially in the case of temporal order, in which 12 of the 97 respondents view the risk as being equivalent to 200 cases per million. The overall effect of temporal order is to augment the effect of ambiguous belief aversion, as the respondents place greater weight on the second higher risk study, thus increasing their perceived risk in Area A.

In contrast, if it is the second study that indicates the lower level of the risk, as in the case of Risk Pair 2 (200, 150), we observe essentially the opposite effect. When no temporal order is indicated, the assessed risk level is slightly greater than the midpoint of the range of 175. Once there is a temporal order indicated, individuals place somewhat greater weight on the second of the two pieces of risk information given, thus eliminating the ambiguous belief aversion effect; the mean

TABLE III

Temporal order effects for nerve disease risks.

Risk Levels in Area A:	Temporal Order	Sample Size	Median	Mean	Std. Error of Mean	Min (#)	Max (#)
Risk Pair 1:							
150, 200	No	65	175.00	178.35	1.24	150.50 (1)	200.00 (3)
150, 200	Yes	97	177.50	181.67	1.10	150.00 (1)	200.00 (12)
Risk Pair 2:							
200, 150	No	20	175.00	177.88	2.67	150.00 (1)	200.00 (2)
200, 150	Yes	82	175.00	174.13	1.18	150.00 (6)	200.00 (1)
Risk Pair 3:							
110, 240	No	58	180.00	191.08	3.95	115.00 (1)	240.00 (13)
110, 240	Yes	94	185.00	197.45	2.95	130.00 (1)	240.00 (23)
Risk Pair 4:							
240, 110	No	29	175.00	170.35	5.78	110.00 (4)	240.00 (1)
240, 110	Yes	74	175.00	159.19	3.84	110.00 (18)	235.00 (1)

risk response of 174 is not significantly different from the midpoint value of 175. There is in addition greater clustering of individuals at the low end of the risk range of 150, as 6 of the 82 respondents assess the risk at being at the minimum of the risk range.

Expanding the stated spread of risk values from 50 to 130 in Risk Pair 3 (110, 240) greatly intensifies these effects. Indicating a temporal order for this rising risk sequence boosts the median risk assessment, the mean risk assessment, and most dramatically increases the number of respondents who are at the upper end of the risk range. Overall, 23 of the 94 respondents assess the risk as being 240, as the indication of a temporal order in the studies leads one-fourth of the sample to consider only the second of the two studies as being informative.

Much the same effect, but in the opposite direction, is observed if there is temporal order but the order of the studies is reversed to be (240, 110). In that situation, indication of temporal order leads to a mean risk assessment value of 159, which is below the midpoint value of 175. In addition, 18 of the 74 respondents give a risk equivalent value of the low end of the risk range, 110. Although the tendency to place substantial weight on the second study is somewhat less when the second study indicates a low risk value as opposed to a high risk value, there is still a substantial effect in that direction that more than offsets the influence of ambiguous belief aversion. The substantial size of the spread for this risk pair accounts for the strength of these effects. Overall, the indication of temporal order increases the weight on the second study, increasing the effect of risk ambiguity aversion when the disparity in studies is great.

5. DOES THE SYMMETRY OF THE RISK SPREAD MATTER?

Thus far, all the experimental manipulations have provided risk information centered around a common midpoint of 175. The only variation has been to change the order of presentation of the risk studies and to increase the size of the spread around this risk value.

An interesting economic question is the extent to which individuals also react to the symmetry of the spread. In particular, do they place greater weight on the worst case outcome and what might be termed the down-side potential of the risk?

To analyze these effects experimentally, two different risk scenarios involving terminal lymph cancer were devised. In each situation, the survey informed respondents that the average risk indicated by these studies was 130. However, the high and low end of the range of risk studies differed. In the first case listed in Table IV, the high study observed was 155, and the low study was just below the average of 130, as it was 125. In the second of the two instances, the asymmetry in the risk is in the opposite direction, as the high end of the risk studies observed was 135, which is just above the average of 130. In that instance, the low risk value indicated by the studies was 105, thus producing an asymmetry in the risk range below the average risk

TABLE IV

Asymmetric risk spread effects for lymph cancer.

Risk Studies for Area A: High	Low	Ave.	Sample Size	Median	Mean	Std. Error of Mean	Min (#)	Max (#)
155	125	130	59	130.00	134.90	1.07	128.5 (1)	155.00 (2)
135	105	130	68	130.00	130.38	0.39	112.5 (1)	135.00 (2)

value. In each case the risk spread from the low to high study was the same – 30 cases per million.

Although the median respondent focuses primarily on the average risk value indicated, the mean values differ. In the case of risk study distributions that are skewed in a manner so that the lowest risk estimate is well below the average, there appears to be little role for risk ambiguity aversion. Respondents focus primarily on the average risk amount.

In contrast, if there is skewness that indicates that the potential risk may be much higher than the average amount, the mean response is much greater than the average. The mean risk value associated with the risk range (155, 125) is significantly greater than the mean risk assessment equivalent to the risk range (135, 105) even though the average risk values indicated were the same. Moreover, it is striking that these differences were generated using only a risk spread of 30 cases per 1 million respondents, which is a much tighter distribution than was needed to generate the risk ambiguity effects considered in Tables I–III. These results indicate that the potential source of much of the ambiguous belief aversion is the fear of the worst case outcome rather than simply concern with the risk spread.[6] Asymmetry in the risk spread accentuates the impact of the ambiguous belief aversion when the asymmetry indicates the potential of a much higher risk level.

6. CONCLUSION

Individual processing of risk information consists of more than simply giving equal weight to the various pieces of information that have been received. The potential for extremist responses and alarmist reactions is quite pronounced. Although there is the possibility of individuals focusing at either end of the risk extremes that are presented, several systematic patterns of risk perception responses were identified.

First, there is evidence of ambiguous belief aversion. As the extent of the spread indicated by the alternative risk measures increases, individuals raise their risk assessment. In forming these risk assessments, individuals place a greater weight on the last risk value given to them even if no temporal order in the risk values is indicated. However, if there is an explicit temporal order, there is a much more substantial weight given to the final risk study than to the initial risk study. Consideration of the role of skewness in the risk distribution highlights the factors driving the ambiguous belief aversion. In particular, it is the fear of the worst case scenario that seems to be of greatest concern to respondents. This influence is also reflected in the extreme values of the risk responses, as respondents are much more likely to indicate that the high end of the risk range is the risk equivalent value than they are to indicate that the low end of the risk range is the actual risk level.

What these results suggest is that the communication of ambiguous risk information is a quite sensitive policy process. More fundamentally, individual decisions in contexts in which risks are not defined precisely will be quite sensitive to the character of the information that is available. Being able to predict individual responses will require more than simply knowing which pieces of information individuals have received. We also must know the order in which they have received it and various other aspects of the nature of the risk information that individuals have processed in order to be able to reliably predict behavior. Perhaps the most reassuring aspect of the results is that the median respondent generally weights the information provided equally. The danger is that the responses of the individuals at the extremes may greatly influence the overall societal response to the risk.

NOTES

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[1] For a review of risk communication issues, see Viscusi and Magat (1987) and the National Research Council (1989).

[2] This literature did not end with the original paper by Ellsberg. See, among others, Curley and Yates (1985), Einhorn and Hogarth (1985), Hogarth and Kunreuther (1989), Kahn and Sarin (1988), Kunreuther and Hogarth (1990), Viscusi (1989), and Viscusi and O'Connor (1984).

[3] Our review of the literature on ambiguity appears in Magat, Viscusi, Huber, and Payne (1990). See, for example, the studies cited in note 2, *supra*, for an overview of this research.

[4] This study was undertaken for the U.S. Environmental Protection Agency. A similar sample was used in Viscusi and Magat (1987). In that work we describe in detail the representativeness of that sample, which utilized the same shopping mall intercept to recruit the experimental subjects. It should be noted that because of its representativeness, Greensboro, North Carolina is often the test site for national consumer marketing efforts as well as studies by Federal government agencies, such as the Environmental Protection Agency.

[5] All the results in the tables in this paper are for the sample population which gave consistent responses. Only 56 subjects were eliminated from the sample because they exhibited incomplete or inconsistent responses. Four subjects gave incomplete responses. Seventeen respondents indicated the following type of inconsistency. They indicated a preference for Area A through the sequence of iterations of the questionnaire and then when they were forced to restart the paired comparisons they preferred Area B on the first question or were indifferent. Twenty-nine respondents indicated that they were indifferent to the two areas on every 'first' comparison that appeared in the questionnaire. Five respondents preferred Area A on all of the iterations through to the last question and then on the last question when the risk levels of Area B dominated those of Area A, indicated that they were indifferent or preferred Area A. Finally, five of the responses were incomplete because of missing demographic information.

[6] This risk spread is much smaller than the risk ranges considered in Tables I–III. If one were to expand the risk spread as in those earlier studies, one would expect the effect of the skewedness of the risk distributions to become more pronounced.

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