# DESCRIPTIVE MODELS OF PERCEIVED RISK

YITONG WANG
L. ROBIN KELLER
The Paul Merage School of Business, University of California Irvine, Irvine, California

JAY SIMON
Defense Resources Management Institute, Naval Postgraduate School, Monterey, California

Risk plays a central role in decision making. Accordingly, risk has been a popular research topic for more than four decades. Finding a generic definition of risk is hard, since this term is used in many areas such as economics, political science, management science, and medical research. However, one thing in common is that risk is always related to both the negative outcomes and uncertainty. In addition, we know that risk is normally subjective and constructed by a human's perception process. But indeed how do people perceive risks? Is there any model capable of describing this procedure and predicting people's perceived risk? In this article, we focus on empirical studies of perceived risk.

In operations research/management science as well as in psychological research, much effort has been spent on defining the subjective perception of risk. The central topic is how we can define or predict people's perceived risk of a risky option based on the characteristics of that option. The basic structure has been simply depicted in Fig. 1 below.

Q1

In Fig. 1, vector $C$ represents an option's characteristics related to its perceived risk. The characteristics can be objectively known or can be based on subjective judgments, and the perceived risk is a real function of these characteristics. Thus, the main research objective is to find what $C$ includes and what the functional form $f(\cdot)$ is.

On the basis of different contexts that risk perception models can be applied to, we roughly divide this topic into two subcategories. One focuses on perceived risk of monetary options, such as risky investments and gambles. The other focuses on societal risks such as natural disasters, terrorist attacks, and new technologies. These subcategories are not mutually exclusive. However, they do have many differences. For instance, monetary options can be explicitly interpreted as gambles with numerical payoffs and probabilities, but societal risks normally are hard or impossible to be transformed in that way. As a result, in the first category, $C$ usually contains objective values from the option rather than subjective values from people's judgments, which are used in the second one.

In the next section, we review the risk perception studies of monetary risks. The section titled "Perception of Societal Risks" mainly describes the research on societal risks in a psychometric framework. The section titled "Further Developments of Risk Models" briefly introduces some developments of perceived risk. The last section concludes the article and gives some possible future research directions.

## PERCEPTION OF MONETARY RISKS

Broadly speaking, financial risks include all options whose consequences and chances of these consequences can be described in a numeric form. For example, a hit and run accident can be regarded as an event with monetary risks (e.g., a gamble) if the driver has a specific subjective probability (i.e., 50%) that there are witnesses who can recognize his/her plate number and will report to the police. And he/she knows that the consequences should be a specific monetary loss (i.e., \$500). As you can see, monetary risks represent a large group of events in which people focus on the monetary consequences. In the remainder of this section, we basically deal with abstract gambles. However, you

*Wiley Encyclopedia of Operations Research and Management Science*, edited by James J. Cochran

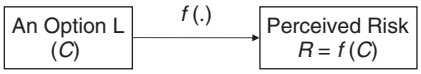


**Figure 1.** Basic structure of perceived risk models.

still need to keep in mind that those gambles are just parsimonious representations of many events in real life.

Obviously, the objective of empirical research on perceived risk models is to discover and verify $C$ and $f(\cdot)$. In most studies, they are first developed on the basis of a series of assumptions or axioms (see Jia *et al*. [1] and article titled ***Axiomatic Models of Perceived Risk*** for details), then they are tested by experiments. There are two possible ways to test the proposed model: (i) to test the validity of its assumptions or (ii) to test the power of this model using people's holistic judgments; either way verifies the model. In the following parts of this section, we do not differentiate between the two ways to test models but focus on the descriptive tests of different models.

### Experiments on Models Using Moments

Just as the name implies, the moments models take $C$ as moments of the distribution of outcomes. These experiments were conducted in the late 1960s–1980s. Coombs and his colleagues [2–5] used the moments of the distribution of payoffs such as mean, variance, and skewness to predict people's risk perceptions. Their work was motivated by Coombs' portfolio theory [6,7], which stated that people face a trade-off between the expected value and perceived risk when choosing among risky options. For example, in one of Coombs and Huang's papers [2], they formulated the gambles into the form of $[a + b, 50\%; b - a]^c$ (e.g., a gamble gives you a 50% chance to win "$a + b$" and a 50% chance to win "$b - a$," and this gamble will be repeated "$c$" times), which has a mean factor "$b$," a dispersion factor "$a$" and a repeat time factor "$c$." Varying the value of "$a$," "$b$," and "$c$," they asked subjects to rank the perceived risk of several sets of gambles. Their data supported the moments model. However, later Barron [8] found contrary results in his experiments. From a more rigorous modeling approach, Pollatsek and Tversky [9] and Rotar and Sholomitsky [10] provided an axiomatic system that supported their risk theory. Their axioms were also tested by experiments [3,4]. Generally speaking, the moments models are not totally successful as descriptive models since the empirical tests gives mixed results. However, using distributional variables to predict people's perception could be suitable in the sense that it is very intuitive. Believing that, Lopes [11] used complex gambles (e.g., gambles with more than three outcomes) as stimuli to test distributional models and stated that "the data support the distributional model of risk . . ., and they show that people's judgments of possible risks are similar functionally to judgments of distributional inequality."

### Luce's Assumptions and Related Experimental Results

Luce [12,13] made assumptions to define several alternative measures of perceived risk. Please refer to Refs 12–16 and the article titled ***Axiomatic Models of Perceived Risk*** in this encyclopedia for the details of the derived measurements and their extensions. Here we only describe the two key assumptions. Specifically, the first assumption said that if all outcomes of a gamble are multiplied by a constant number, the risk either increases additively or multiplicatively. The second assumption said that there might be two ways to transfer the random variable (e.g., a gamble) into a single number (e.g., the perceived risk): (i) to aggregate some transformation of the random variable or (ii) to aggregate some transformation of the density function of the random variable. Notably, this is different from the moments models since it derives measures of risk by assuming some specific characteristics of people's risk judgments. Luce's work [12,13] only provided several possible models. Then, there were several studies testing both the assumptions and people's holistic judgments of his model. For example, Keller *et al*. [14] empirically tested the axioms proposed by Luce. In their study, they asked subjects to rank or directly compare several groups of well-defined gambles. They observed "remarkable consistency in the risk judgments of the US

and German subjects." They also found many other interesting results: first, adding a positive number to all payoffs decreased the risk of the gamble; second, when the probability of loss was high, it had relatively more influence on people's risk perception, whereas when the probability of loss was low, the amount of loss had more influence; third, the skewed gambles were more risky than corresponding symmetric gambles. Almost at the same time, Weber [17] tested the validity of Luce's assumptions and got the result that two-thirds of the data supports the additivity assumption. On the basis of empirical results [17,18], Luce and Weber [15] axiomatized a risk perception model called *conjoint expected risk* (CER), which states that the perceived risk of a gamble is a weighted function of five dimensions: probability of gain, probability of loss, probability of status quo, expected values of gain and loss. Weber [18] ran several experiments testing the holistic validity of the CER model and found that (i) the CER model could predict people's risk perception for risky gambles relatively well and (ii) the CER model was not very powerful to deal with two-outcome gambles. Later, Weber and Bottom [19] empirically tested the adequacy of the axioms of the CER model, and found support for transitivity (if $A$ is more risky than $B$, and $B$ is more risky than $C$, then $A$ is more risky than $C$) and monotonicity (if $A$ is more risky than $B$, then for any $C, p \cdot A + (1-p) \cdot C$ is more risky than $p \cdot B + (1-p) \cdot C$). In addition, they found that the conjoint structure had more power on gambles with negative outcomes than on gambles with positive outcomes.

### Two-Attribute Models for Perceived Risk

By decomposing a lottery ($X$) into its mean ($\overline{X}$) and its standard risk ($X' = X - \overline{X}$), Jia *et al*. [1,20] (see also article titled ***Axiomatic Models of Perceived Risk*** in this encyclopedia) used a two-attribute model to represent people's preference such as value and risk. The model was based on expected utility theory [21]. Since the general form of this model is very flexible, by varying the functional forms of each part, this two-attribute model may be transformed into many existing models such as Pollatsek and Tversky's risk model [9] and Bell's disappointment model [22]. It also included possible different effects between positive payoffs and negative payoffs, which were emphasized in prospect theory [23]. For a detailed description, please refer to the article titled ***Axiomatic Models of Perceived Risk*** in this encyclopedia. The fundamental assumptions (axioms) of this model were also tested, and "the data indicate that the participants' responses were generally consistent with the key assumptions of risk-value models" [24].

In this section, we reviewed several studies on perceived risk of financial gambles. As mentioned earlier, this type of gamble is an abstract representation of a large group of real-life events. Thus, they are important contributions to behavioral decision research as well as public policy making. Though so far no functional form $f(\cdot)$ has been proved to be universally valid even in very simple situations, researchers did find several patterns that are generally consistent among groups. They are (also see ***Axiomatic Models of Perceived Risk***):

1. When the variability (range, variance) of gambles increases, the perceived risk increases [2,25].
2. When the expected loss increases, the perceived risk increases [2,25].
3. When a constant amount is subtracted from the positive outcome, the perceived risk increases [14].
4. When all outcomes of a zero-mean lottery are multiplied by a positive number, the perceived risk increases [26].
5. When a zero-mean gamble is repeated many times, the perceived risk increases [26].
6. A gamble repeated fewer times with a high expected loss is more risky than a gamble repeated more times with lower expected loss [25].

We believe it is unlikely that a mathematically simple form can capture all aspects of perceived risk in realistic situations, but we do believe that every step further in the research on perceived risk will shed some light on how people really make decisions

and what kind of information or framing can lead people to better decisions under risk.

## PERCEPTION OF SOCIETAL RISKS

Is taking a flight more risky than driving a car? Is nuclear power more risky than smoking? Probably most people will say yes in both cases. However, in terms of the monetary risks that we introduced in the last section, their answers are wrong, since there is no evidence that the latter ones have lower probabilities of losses or lower potential losses to the human beings. But why do people think in that way and are they right? As we said at the beginning of this article, people have different interpretations of risks [27]. Experts normally define the risk of a certain event by its consequences (e.g., annual fatalities) and the probability of those consequences. Lay person's judgment of perceived risk is related to additional characteristics of that event. Thus, when we try to predict the general public's perception and response to some risky events, especially those events with rare and delayed consequences, the tools we used in monetary risks do not suffice. We need to employ broader factors that relate to people's risk judgments. In this section, we focus on a special type of risks, which are sometimes hard to convert to pure numeric presentations. They are defined as societal risks.

Consider Fig. 1 again. People's perception of any kind of risk should come from the characteristics of this risk ($C$). It can be objective or subjective. In the domain of financial risks, we use objective values to describe people's risk perception. However, in the domain of societal risks, we use both objective and subjective characteristics. Slovic *et al*. [27–29] developed a psychometric paradigm for societal risks that can be used to understand different risks in a multidimensional manner. They used psychological scaling and multivariate analysis methods to give a quantitative representation to risks. The dimensions vary among different studies. For example, in Ref. 28, the authors employed nine dimensions such as voluntariness, immediacy of effect, known to exposed, known to science, controllability, newness, chronic-catastrophic, dread-common, and severity of consequences. The explanations of these terms [28, p. 133] are as follows: "(i) Voluntariness: Do people get into these situations voluntarily? (ii) Immediacy of effect: To what extent is the risk of death immediate—or is death likely to occur at some later time? (iii) Known to exposed: To what extent are the risks known precisely by the persons who are exposed to those risks? (iv) Known to science: To what extent are the risks known to science? (v) Controllability: If you are exposed to the risk of each activity or technology, to what extent can you, by personal skill or diligence, avoid death while engaging in the activity? (vi) Newness: Are these risks new, novel ones or old, familiar ones? (vii) Chronic-catastrophic: Is this a risk that kills people one at a time, or a risk that kills large numbers of people at once? (viii) Dread-common: Is this a risk that people have learned to live with and can think about reasonably calmly, or is it one that people have great dread for—on the level of a gut reaction? (ix) Severity of consequences: when the risk from the activity is realized in the form of a mishap or illness, how likely is it that the consequence will be fatal?" On these nine scales, people made judgments about their current perceived level of each dimension, which helped researchers to further analyze different risks with respect to their characteristics. In their study, they also found that these factors were not independent. Peters and Slovic [30] found that all the above dimensions could be distilled into two primary factors: dread and risk of unknown, which explained above 90% of the variance.

Numerous studies have been conducted using the psychometric paradigm. For example, Feng *et al*. [31] examined patterns of risk perceptions and decisions when people are facing consumer product-caused quality risks. They focused on the contexts of contaminated pet food and lead-painted toys. They evaluated these two risks and positioned them into a two-factor space diagram (as shown in Fig. 2) of various societal risks. Comparing with other risks, they found that these two risks were similar in the sense that they were very closely positioned

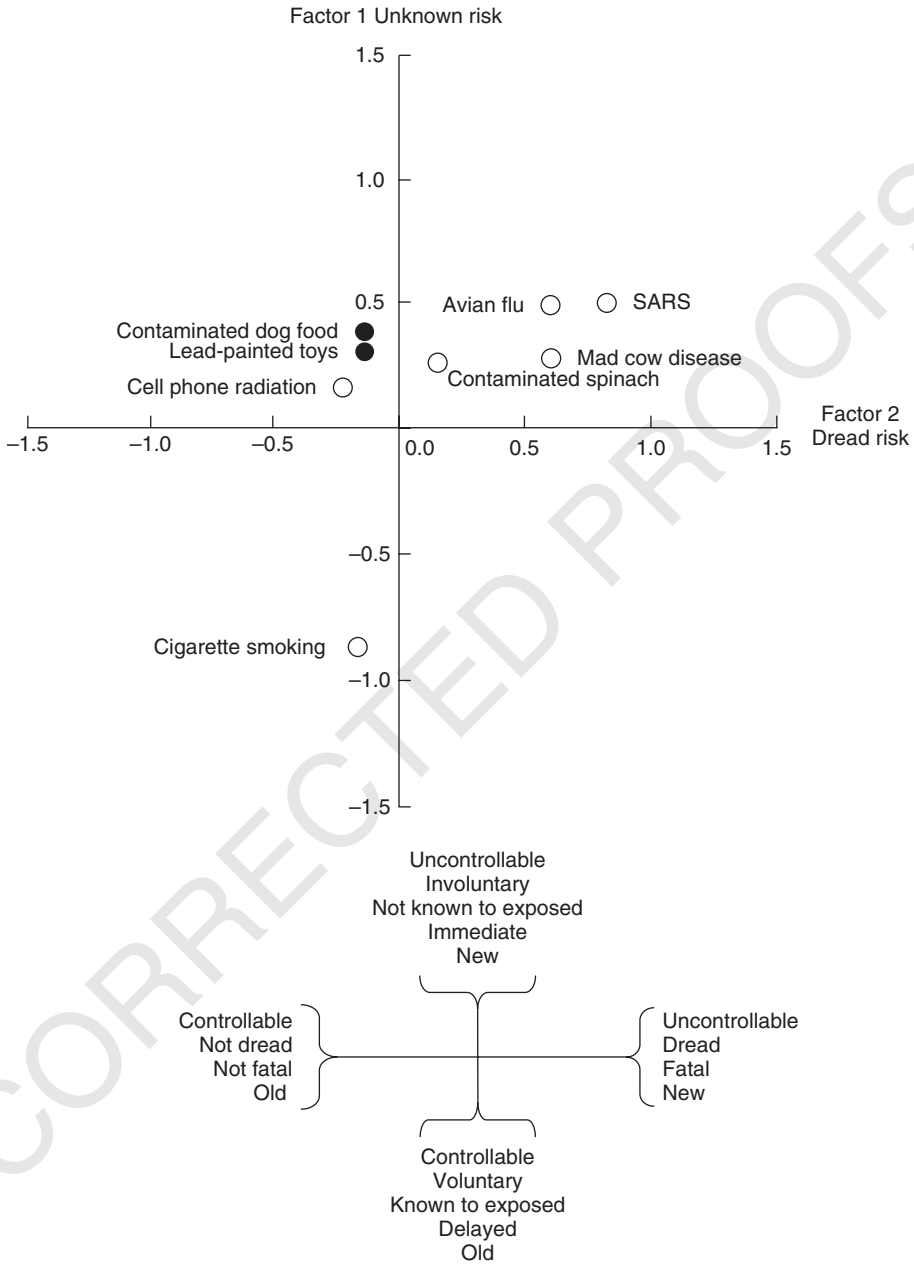


**Figure 2.** Location of two risks within the two-factor space.

in the diagram. As stated in Ref. 27, the locations of risks in the two-factor space can largely predict people's attitudes toward the risks and also can help government and authorities to deliver the right information in the sense that it can help the general public estimate the risks correctly.

## FURTHER DEVELOPMENTS OF RISK MODELS

### Risk-As-Feelings Hypothesis

If we compare the studies in the last two sections, we notice a fundamental difference. The first group of studies tried to use objective factors of risks to evaluate the perceived risk. In other words, these models judged the risk based on an individual's anticipated monetary outcomes. For example, consider a lottery that gives a person a 50% chance to win \$100 and a 50% chance to lose \$85. The perceived risk of this lottery, in the first group of models, basically comes from the projections of loss and gain and their chances to occur. However, in the psychometric models, researchers used different psychological dimensions to predict a person's perceived risk. They include not only anticipated outcomes after their decisions but also feelings before they make decisions. In a highly cited paper, Loewenstein *et al*. [32] proposed a risk-as-feelings hypothesis and defined the former consideration as *anticipated emotions* and the latter consideration as *anticipatory emotions*. The risk-as-feelings hypothesis emphasizes the role of the psychological effect experienced at the moment of the decision making, shows that the emotional reactions and the cognitive judgments are often different and also states that, when emotional reactions and cognitive reactions conflict, the emotional side normally drives an individual's behavior. In their article, they also showed several determinants that could change people's emotional responses, such as mental vividness, time interval, and evolutionary makeup. The risk-as-feeling hypothesis has been used in various fields including decision theory, psychology, and marketing. For example, Weber [33] employed the risk-as-feelings hypothesis to explain why global warming does not scare people. She explained that the effect played an important role in risk perception and people would take action only if they had a vivid personal experience. However, since global warming is not a very salient event, and involves a great temporal distance, people tend to underestimate the risk associated with it.

### A Hybrid Model

Holtgrave and Weber [34] compared two models of risk perception: the CER model and the psychometric model. They used both financial and health risk stimuli, and the CER model provided a better fit if both models were used separately. However, when combining the two models together, they found that the hybrid model could obtain the best fit.

Other than comparing the power between the two models, this research also demonstrates the relationship between them. It proves that Slovic's psychometric model still has an explanatory power even after controlling the effect of probability and outcomes. In addition, this can be regarded as being in favor of the risk-as-feelings hypothesis.

### Cross-Cultural Study of Perceived Risk

The previously described studies focus on constructing a generic model of human risk perception. However, how people perceive risks is not necessarily the same across cultures. If different cultures have different perceptions of the same risk, knowing the difference can help them when there are conflicts between them [35]. For example, a Chinese company and an American company may be both better off if they can reach a settlement that both parties find less risky and in which both get higher payoffs.

Weber and Hsee [35,36] investigated subjects from China, United States, Germany, and Poland by asking them to give both the buying prices and perceived risk of risky financial lotteries. They found that the Chinese participants were more risk-seeking than American participants in a traditional expected utility framework. However, after some further analysis, they found that the difference came from the cross-cultural difference in risk perception. That is, the Chinese subjects and American subjects

are similarly risk-averse but their risk perceptions of the same lottery are different. Furthermore, Weber *et al*. [37] compared the American and Chinese proverbs of risk and risk-taking to give concrete proof of the cultural explanation of the different risk perceptions. Their result is consistent with the conclusion of the cushion hypothesis in Ref. 35: the collectivist Chinese culture gives each individual more of a cushion against financial risks since collectivism usually cushions in-group people to face financial risks and deal with the possible negative outcomes together.

Different cultures also teach people to select different risks for attention. Douglas and Wildavsky [38] divided cultures into five types such as hierarchical, individualist, egalitarian, fatalist, and hermitic. In each culture, people selectively attend to some specific categories of risks and choose to ignore others. In this way, the perceived risk of an event will vary across different types of cultures.

## CONCLUSIONS AND FUTURE RESEARCH

For more than 40 years, researchers of operations research/management science, economics, and psychology have paid much attention to perceived risk. In this article, we have only reviewed part of the literature. Generally speaking, in our article, the research can be categorized into two parts.

The first part focuses on monetary risks or any risks whose information can be distilled into payoffs and their probabilities. The objective is to find a parsimonious functional form to describe and predict people's perceived risk of simple gambles. However, human perception is a complex process and normally is hard to describe in a simple and good way. As a result, there is still a long way to go. Thus, several directions still need to be developed further: (i) a parsimonious way to model people's risk perception; (ii) risk perception and decision making under risk are two well-developed research areas, but little work tries to link them together, so it would be interesting to consider how to incorporate perceived risk models into decision making under risk; and (iii) risk perception with a time dimension.

The second part focuses on psychological research of societal risks such as Slovic's psychometric models. The objective is to find a way to decompose people's processes for perception of risks. By analyzing an individual's feelings of risks in many dimensions, researchers can categorize risks and find appropriate ways to handle risks accordingly. We believe several directions need more investigation: (i) connecting societal risk research with risk communication research to find more effective ways of risk communication; (ii) development of a direct connection between locations of risks in the two-factor space and public policies; (iii) a way to help the general public perceive risks correctly; and (iv) investigating antecedents and consequences of societal risks.

Perceived risk research is a fruitful area. This article has only reviewed part of this work. Specifically, we have only focused on the empirical studies. For those who want to know more about the axiomatic research of perceived risk, please refer to the literature review part of Ref. 1 and the article titled ***Axiomatic Models of Perceived Risk*** in this encyclopedia. Q2

## REFERENCES


1. Jia J, Dyer JS, Butler JC. Measures of perceived risk. Manage Sci 1999;45(4):519–532.
2. Coombs CH, Huang LC. Polynomial psychophysics of risk. J Math Psychol 1970;7(2): 317–338.
3. Coombs CH, Bowen JN. Test of VE-theories of risk and the effect of the central limit theorem. Acta Psychol 1971;35(1):15–28.
4. Coombs CH, Bowen JN. Additivity of risk in portfolios. Percept Psychophys 1971;10: 43–46.
5. Coombs CH, Lehner PE. Evaluation of two alternative models for a theory of risk I: are moments of distributions useful in assessing risk? J Exp Psychol Hum Percept Perform 1981;7(5):1110–1123.
6. Coombs CH. Portfolio theory: a theory of risky decision making. La decision. Paris: Centre National de la Recherche Scientifique; 1969.
7. Coombs CH. Portfolio theory and the measurement of risk. In: Kaplan MF, Schwartz

S, editors. Human judgment and decision processes. New York: Academic Press; 1975. pp. 63–85.

8. Barron FH. Polynomial psychophysics of risk for selected business faculty. Acta Psychol 1976;40(2):127–137.
9. Pollatsek A, Tversky A. A theory of risk. J Math Psychol 1970;7(3):540–553.
10. Rotar VI, Sholomitsky AG. On the pollatsek-tversky theorem on risk. J Math Psychol 1994;38(3):322–334.
11. Lopes L. Risk and distributional inequality. J Exp Psychol Hum Percept Perform 1984;10(4):465–485.
12. Luce RD. Several possible measures of risk. Theory Decis 1980;12(3):217–228.
13. Luce RD. Correction to 'Several possible measures of risk'. Theory Decis 1981;13(4):381.
14. Keller LR, Sarin RK, Weber M. Empirical investigation of some properties of the perceived risk of gambles. Organ Behav Hum Decis Processes 1986;38(1):114–130.
15. Luce RD, Weber EU. An axiomatic theory of conjoint, expected risk. J Math Psychol 1986; 30(2):188–205.
16. Sarin RK. Some extensions of Luce's measures of risk. Theory Decis 1987;22(2):125–141.
17. Weber EU. Combine and conquer: a joint application of conjoint and functional approaches to the problem of risk measurement. J Exp Psychol Hum Percept Perform 1984;10(2):179–194.
18. Weber EU. A descriptive measure of risk. Acta Psychol 1988;69(2):185–203.
19. Weber EU, Bottom WP. An empirical evaluation of the transitivity, monotonicity, accounting, and conjoint axioms for perceived risk. Org Behav Hum Decis Processes 1990;45(2):253–275.
20. Jia J, Dyer JS. A standard measure of risk and risk-value models. Manage Sci 1996;42: 1961–1705.
21. von Neumann J, Morgenstern O. Theory of games and economic behavior. 2nd ed. 1947. Princeton (NJ): Princeton University Press; 1944.
22. Bell D. Disappointment in decision making under uncertainty. Oper Res 1985;33(1): 1–27.
23. Kahneman D, Tversky A. Prospect theory: an analysis of decision under risk. Econometrica 1979;47(2):263–291.
24. Butler JC, Dyer JS, Jia J. An empirical investigation of the assumptions of risk-value models. J Risk Uncertain 2005;30(2): 133–156.
25. Coombs CH, Huang LC. Tests of a portfolio theory of risk preference. J Exp Psychol 1970;83(1):23–29.
26. Coombs CH, Meyer DE. Risk-preference in coin-toss games. J Math Psychol 1969;6: 514–527.
27. Slovic P. Perception of risk. Science 1987; 236:280–285.
28. Fischhoff B, Slovic P, Lichtenstein S, *et al*. How safe is safe enough? A psychometric study of attitudes towards technological risks and benefits. Policy Sci 1978;9:127–152.
29. Slovic P, Fischhoff B, Lichtenstein S. Behavioral decision theory perspectives on risk and safety. Acta Psychol 1984;56:183–203.
30. Peters E, Slovic P. The role of affect and worldviews as orienting dispositions in the perception and acceptance of nuclear power. J Appl Soc Psychol 1996;26:1427–1453.
31. Feng T, Keller LR, Wang L, *et al*. Product quality risk perceptions and decisions: contaminated pet food and lead-painted toys. University of California, Irvine, working paper. 2009.
32. Loewenstein GF, Weber EU, Hsee CK, *et al*. Risk as feelings. Psychol Bull 2001;127(2): 267–286.
33. Weber EU. Experience-based and description-based perceptions of long-term risk: why global warming does not scare us (yet). Clim Change 2006;77:103–120.
34. Holtgrave DR, Weber EU. Dimensions of risk perception for financial and health risks. Risk Anal 1993;13(5):553–558.
35. Weber EU, Hsee CK. Cross-cultural differences in risk perception but similar attitudes toward perceived risk. Manage Sci 1998;44(9):1205–1217.
36. Hsee CK, Weber EU. Cross-national differences in risk preference and lay predictions. J Behav Decis Making 1999;12:165–179.
37. Weber EU, Hsee CK, Sokolowska J. What folklore tells us about risk and risk taking: cross-cultural comparisons of american, german, and chinese proverbs. Org Behav Hum Decis Processes 1998;75(2):170–186.
38. Douglas M, Wildavsky A. Risk and culture: an essay on the selection of environmental and technological dangers. Berkeley (CA): University of California Press; 1982.

**Queries in Article eorms0250**

Q1. Please clarify if the figure caption is ok.

Q2. Please note that we have deleted the cross-references section from this article. Therefore cite these inside text if needed.

**Please note that the abstract and keywords will not be included in the printed book, but are required for the online presentation of this book which will be published on Wiley's own online publishing platform.**

**If the abstract and keywords are not present below, please take this opportunity to add them now.**
**The abstract should be a short paragraph upto 200 words in length and keywords between 5 to 10 words.**

**Abstract**: This article provides a brief introduction to descriptive models of perceived risk. The first part focuses on monetary risks or any risks whose information can be distilled into payoffs and their probabilities. The second part focuses on psychological research on societal risks such as psychometric models. Some further developments are also included such as cross-cultural studies and the risk-as-feelings hypothesis.

**Keywords**: perceived risk; decision making; monetary risks; societal risks; risk-as-feelings