

## Risk as reproductive variance

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### Abstract

In economics, normative utility theories of decision-making under risk use a single number (expected value) to index subjective utility at the cost of losing information about risk distribution. This paper examines how people make use of risk distributions (that is, variations in expected payoffs) to maximize the probability of reaching a goal and to minimize the likelihood of falling below a minimum requirement (MR). The author proposes and tests a Bounded Risk Distribution model using both hypothetical life–death problems and real reproductive and parental decision problems. Study 1 demonstrated that a given degree of increase in expected number of saved lives had a significant effect on the respondents' risk preference when the increase was likely to cross the average MR of the respondents (in a small group context), but the same increase in expected value had little effect when the change was within a range below the average MR (in a kinship context) or above the MR (in a large group context). Study 2 examined alternative hypotheses for hypothetical risk acceptance with respect to kinship groups and found that whether the decision-maker was responsible or not had little effect on the setting of the MR and risk preference. The MR setting was mainly determined by the kinship context itself and was further fine-tuned by the framing of the choice outcomes. Study 3 was conducted in four rural villages in northwest China, and assessed real reproductive decisions. Interbirth intervals but not breast-feeding duration varied with a family's wealth, the sex of a child, and the perceived resemblance of a child to a parent. These results are interpreted in terms of the same Bounded Risk Distribution model that was applied in the hypothetical scenario studies. © 2002 Elsevier Science Inc. All rights reserved.

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## 1. Introduction

The defining features of risk are variations in probabilistic outcomes and their subjective values (utilities). In the field of economics or finance, risk is commonly conceived as reflecting variation in the distribution of possible outcomes, probabilities and their subjective values (e.g., March, 1988; March & Shapira, 1992; Markowitz, 1952, 1959).

From a Darwinian viewpoint, probabilistic outcomes and their subjective values should be measured by their effects on reproductive fitness. Cooper (1987) argues that the notion of rationality as used, for instance, in the phrase “rational man” should be first and foremost a “biological man.” Using the criterion of expected offspring, Cooper showed that rationality axioms of expected utility (EU) theory are ultimately derivable from evolutionary principles. Similarly, Simon (1990) proposed that the ultimate measure of economic utility should be reproductive fitness or expected number of progeny. According to Dawkins (1995), the true utility function of life, that which is being maximized in the natural world, is genetic posterity. Maximizing such evolutionary utility may often be inconsistent with the notion of economic efficiency or utilitarian striving for “the greatest happiness of the greatest numbers” since genes neither care nor know.

Although it may seem appealing to measure risks and risky outcomes in terms of variations in reproductive fitness, the topics of risk and risky choice have not been prominent in the discussions of evolutionary psychology. Yet, risk in various forms underlies much of what evolutionary psychologists, biologists, and anthropologists are interested in, from foraging to paternity confidence to mate choice. If we view risks in terms of variations in reproductive fitness, the analysis of risk and risky choice should incorporate contemporary understanding of evolution by natural and sexual selection. The sources of risk thus may originate from not only the variations in monetary payoffs but also variations in ecological environments, in the reproductive status of the decision-maker, and in the genetic relatedness between a decision-maker and different decision recipients.

The concept of variance in reproductive payoffs has been pivotal in some recent evolutionary analyses of human behavior (see, for example, Daly & Wilson, 1997). The evolutionary logic for risk/variance sensitive strategies is that selection would favor a greater risk-proneness when risk avoidance promises not fitness but reproductive failure. In their analysis of homicide data, Daly and Wilson (1988, 1997) use reproductive variance to predict and interpret sex differences in risk taking. They predicted and demonstrated sex and age differences in risk taking based on the fact that men have a higher variance in reproductive fitness than women.

Variance in ecological environments has been a driving force that shapes behavior and ultimately reproductive success. Foraging bees demonstrate an astonishing ability to detect and adapt to the variation in available resources (see Real, 1991, for a review). Bees constantly make trade-offs between the expected mean reward and the variability in floral reward, and prefer foraging where higher variance in foraging resources brings about higher caloric payoffs.

A functional account of utility in risk-sensitive foraging can be generated from examining the outcomes of biomechanical parameters and not just on the basis of observed behavior. For

example, the rate of net energy uptake per flower for an individual foraging bee is a function of specific physiological parameters such as the energy content, nectar density, nectar concentration, and nectar volume, the bee's mass, duration of each visit to a flower, flight time between flowers, energetic cost of probing and flying, and the time required for entering and leaving a flower. This physiologically based model of utility has proven to be an accurate predictor of the bumblebees' choice behavior.

In marked contrast to the smartness of risk-sensitive foraging bees, humans have been described as “error prone,” “irrational,” and “cognitively illusionary” in making judgments and decisions in psychologists' laboratories and classrooms. A widely cited example of human irrationality is the framing effect first demonstrated by Tversky and Kahneman (1981), using the “Asian disease problem.”

In the cover story of the problem, the participants of the experiment were asked to imagine that “the US is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed.” The outcomes of the programs were then framed (phrased) differently. In the “**positive framing**” the subjects were told, “if Plan A is adopted, 200 people will be saved. If Plan B is adopted, there is a one-third probability that all 600 people will be saved, and two-thirds probability that none of them will be saved.” Given a binary choice between the two alternative plans, the majority of participants (72%) were risk averse, preferring the *sure outcome* (Plan A) over its risky *gamble* equivalent (Plan B). However, when the same outcomes were “**negatively framed**” in terms of lives lost (“If Plan A is adopted, 400 people will die. If Plan B is adopted, there is a one-third probability that none of them will die, and two-thirds probability that all 600 people will die.”), the majority of the participants (78%) were risk taking. They favored the gamble over the sure outcome.

This framing effect is considered to be a cognitive illusion because it appears to violate the invariance principle of EU theory, which requires a rational decision-maker to have a consistent preference order among identical choice prospects independent of the way the prospects are presented or framed.

So what is wrong with human rationality? Even juvenile monkeys are adept at inferring causality, transitivity, and reciprocity in social relations (e.g., Cheney & Seyfarth, 1985) and foraging birds and bees behave rationally when making risky choices between a low-variance food source and a high-variance one, based on their energy budgets (e.g., Real & Caraco, 1986; Stephens & Krebs, 1986). This picture of “rational bees and irrational humans” suggests that either people have evolved to be irrational and illogical, or the laws of probability and the rational axioms of logical consistency fail to capture the evolved designs of human decision-making. Studying human rationality without considering the constraints of the task environments is equivalent to measuring color vision in a nocturnal environment, where a conclusion that the subject tested is color blind may be empirically reliable but essentially incorrect.

In the following discussion, I first use the example of framing effects to show how the apparently irrational reversal in risk preference can be eliminated by providing evolutionarily meaningful cues about group living (e.g., kinship, group size). Second, I interpret the findings within the framework of a Bounded Risk Distribution model that takes into account the

variance in the expected outcomes and the task specific minimum requirement (**MR**). Third, I test new hypotheses about the rationality of kith-and-kin decision-making.<sup>1</sup> Finally, some key assumptions of the Bounded Risk Distribution model are evaluated in the contexts of making both hypothetical life–death decisions and real reproductive and parental decisions.

## **2. A kith-and-kin decision rationality: findings from previous studies**

The aforementioned framing phenomenon raises questions about the design features of human decision-making. What causes this irrational reversal in risk preference? Would the task environment be a precondition for the presence of a framing effect? In the original Asian disease problem, Tversky and Kahneman (1981) did not identify the 600 people whose lives were at stake. For a domain-general, normative model of decision-making, “decorative” information about the context and content of a problem should not be of great theoretical interest. However, what would happen if contextual and content variables inform us about the evolutionarily recurrent structure of a decision-maker’s ecological and social environments? What would happen if the number of the lives at risk were 6 rather than 600? What would happen if the six lives at stake were your friends or relatives?

In a series of studies, my colleagues and I have shown how framing effects wax and wane in response to changing task contexts. Using a life–death problem similar to the Asian disease task, we systematically manipulated three evolutionarily important variables that are expected to be relevant for adaptively designed decision mechanisms: group size, relational structure of the group (i.e., kinship), and the composition of the group at risk.

For over 95% of hominid evolution, humans lived in small social groups organized mainly by kinship and reciprocity relationships. The size of these primitive human groups rarely exceeded 100 people (see Knauft, 1991; Lee & DeVore, 1968; Reynolds, 1973). Such evolutionarily prolonged circumstances may have shaped human decision mechanisms to be sensitive to the risk distributions in groups and the relational structure and size of a group.

The life–death decision problem has proven to be a useful empirical paradigm for manipulating the social group context of a decision problem in an implicit manner. Each group of subjects was given only one version of the life–death problem (Wang, 1996a, 1996b). The framing effect (i.e., the irrational reversal in risk preference) was evident, but it occurred only when the problem was presented in a large group context involving either 6000 or 600 people. In smaller group sizes of 6 and 60, the framing effect was absent, and the majority of the participants favored the gamble option under both the saving- and losing-lives framing conditions. These results suggest that the size of a social group (within a two-digit number) evokes small group living and a higher interdependence between group members as would have been typical of our evolutionary past.

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<sup>1</sup> The term “kith” refers to socially but not genetically related individuals, such as friends, neighbors, and acquaintances.

The observed preference shift towards risk acceptance in the small group contexts was intensified by explicitly indicating a kinship context. That is, when the six hypothetical patients were described as close relatives, participants unambiguously preferred the gamble option to the sure option, presumably in order to give everybody an equal chance to survive. Interestingly, the participants, although clearly willing to take the risk, became even more risk accepting if the choice outcomes were framed negatively in terms of lives lost. In the first study (Wang, 1996a), the percentage increased from 72% for the risky choice under the positive framing to 94% under the negative framing and similarly, from 67% to 90% in a second study (Wang, 1996b).

In a recent study, Wang, Simons, and Brédart (2001) examined how group composition influences the presence and absence of a framing effect. As in previous studies, no framing effects were observed when the endangered group was homogeneous, consisting of either six kin or six strangers. However, when the group became heterogeneous, consisting of either one kin and five strangers or two kin and four strangers, the effects of framing the outcomes as lives saved or lives lost became statistically significant. If the framing effects with reversed risk-preference patterns under different framing conditions are signs of irrationality in decision-making, such irrationality appears to occur only when (1) the task environment is novel and lacks ecologically valid cues (e.g., large and anonymous groups) or (2) decision cues and goals are in conflict (e.g., heterogeneous groups).

### 3. A Bounded Risk Distribution model

At the heart of EU theory, and many contemporary models of decision-making, has been the idea that decision-makers aim to maximize their EU. The classic work by von Neumann and Morgenstern (1947) showed that the idea of EU maximization is derivable from a small set of axioms of behavioral consistencies in risky choice behavior. These axioms appeared so reasonable and parsimonious that they have widely been used to define rational decision-making.

One limitation of these normative models of decision-making is their lack of consideration of the variance in expected outcomes. The use of a single value (the expected value) for each choice option is done at the cost of ecologically critical and socially valuable information about risk distributions. As a result of this focus on EU, each choice option is represented by a single value:

$$EU = \sum_{i=1}^n p_i u(v_i)$$

where  $p_i$  is the probability of outcome  $i$ ,  $v_i$  is its objective value,  $u$  is a utility weighting function, and  $n$  is the number of possible outcomes.

The importance of payoff variance and distribution for decision-making lies in the fact that under risk, one must consider not only those options that have the highest mean expected value (MEV), but also the positive and negative variation from the MEV against task-specific goals

and bottom lines. To search for a satisfying solution under the constraints of the task requires a decision about the trade-offs of maximizing the likelihood of reaching a goal and minimizing the likelihood of falling below an MR. In contrast to the normative concept of maximizing EU values, a choice alternative yielding the highest expected value may not have a risk distribution that satisfies the task constraints as measured by the goal level and/or the MR.

Theories of risk-sensitive foraging have provided some useful concepts and ideas for understanding human risky choices. Foraging theories often address the interaction between the mean and variance of some important environmental variables, such as the food consumed or the time spent acquiring energy (e.g., Kacelnik & Bateson, 1996, 1997; Real & Caraco, 1986; Stephens & Krebs, 1986). A central idea embodied in these models is that risk preferences of foraging animals are contingent on their concurrent survival requirement and the expected mean and variance of potential outcomes.

Suppose a forager needs a minimum of 200 calories to survive, and two available resource patches have the same expected payoffs of 250 calories but differ with respect to the variability of this expected payoff. Risk-sensitive foraging theory (e.g., Real & Caraco, 1986) predicts that a forager ought to forage on the lower-variance patch, because the lower-variance patch is more likely to satisfy the MR of 200 calories. In other words, the lower-variance patch less often provides outcomes of less than 250 calories than the high-variance patch would do. However, if the MR is higher than the expected payoff of the patches, say 300 calories, then the best hope for surviving is to forage on the higher-variance patch because the more variable outcome distribution provides an increased probability of obtaining the necessary amount of food. Obtaining the average is no better than getting nothing at all.

Consistent with the relevant concepts from foraging theories, the proposed Bounded Risk Distribution model places a special emphasis on a four-way relationship between (1) the MEV of choice outcomes, (2) risk distributions (proximately measured by variances in the expected outcomes),<sup>2</sup> (3) the MR, and (4) the goal setting bounded by the task structure of the social and ecological environments.

Let us focus on the relationship between the MR and MEV. The MR is expected to vary in different social contexts. Depending upon the MEV–MR relationship, the *mean–variance principle* suggests different choice strategies. As illustrated in Fig. 1, the short-hand rule is: be

<sup>2</sup> Several conceptual issues regarding the use of variance as an index of risk should be clarified.

(1) It should be noted that the concept of risk is correlated with but not identical to the concept of variance. For example, when the expected mean value of a choice outcome is just above its MR, a small variance in the outcome would be perceived as quite risky. However, if the mean is much higher than the MR, an equal or even larger amount of variance in the outcome would not be considered as risky.

(2) The same amount of variance in payoff may occur with different distributions and thus different degrees of riskiness.

(3) The variance factor used in the model is a useful but not always accurate proxy of the degree of deviations from the mean of outcomes. Psychologists have shown that the use of variance as a measure of risk is adequate only if gambles have normal distributions (see Sarin & Weber, 1993, for a review).

Thus, variance should be used only as an approximate measure of risk. When nonnormal distributions of the gambles are present, other statistics such as skewness, and the range of outcome distributions should be used within the same framework.

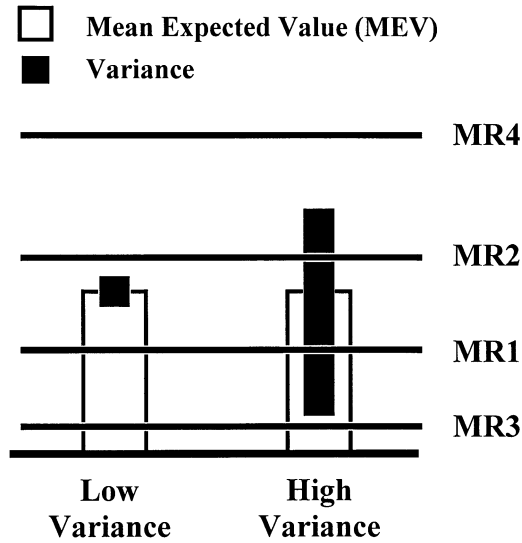


Fig. 1. A schematic model of the MEV–variance analysis. Horizontal bars represent the locations of different MRs: MR1 is the MR that is below the MEV, MR2 is the MR that is above the MEV, MR3 is the MR that is below the lower bound of the high variance, and MR4 is the MR that is above the upper bound of the high variance.

risk/variance averse when the MEV is above the task-relevant MR ( $MEV > MR1$ ), but be risk/variance seeking when the MEV of choice outcomes is below a task-relevant MR ( $MEV < MR2$ ).

The mean–variance principle assumes a nonlinear utility function where the same difference in expected value depends on the MEV–MR relationship (the value location of the MR). The utility of an increase from Value A to Value B should be greater when the MR is between the two values than when the MR is either higher than B or lower than A. Such a nonlinear relationship between outcomes and their utility, plus the unpredictability of outcomes, are considered the two conditions sufficient to indicate the need for risk-sensitive decision-making (Winterhalder, Lu, & Tucker, 1999).

An evolutionary analysis of the mean–variance trade-off also sheds light on other puzzling choice phenomena. For instance, Rode, Cosmides, Hell, and Tooby (1999) recently tested how people avoid or seek unknown probabilities in decisions under uncertainty. By manipulating the MR of the participants, they were able to make the “ambiguity effect,”<sup>3</sup> commonly viewed as a cognitive illusion in making probability judgments, appear and disappear as predicted from an analysis of mean–variance trade-offs.

Following the logic of the Bounded Risk Distribution model, two special conditions might change or reverse the risk preference from what the mean–variance principle prescribes. The

<sup>3</sup> The ambiguity effect occurs when people choose an option for which the probability information is explicitly stated (e.g., a box containing 50 real 1-dollar bills and 50 fake 1-dollar bills) over another option for which the probability information is either imprecise or lacking (e.g., a box containing 100 bills in an unknown combination of real 1-dollar bills and fake 1-dollar bills), even though both have the same expected value.

question is what would be a rational choice when the distance between MEV and MR is beyond the range of the mean plus variance?

1. The first special condition involves an MR that is below the lower bound of the variance in the outcome distribution (see MR3 in Fig. 1). This relationship between the MR and the outcome distribution can be found in two different cases. First, the MR setting is very low and beyond the lower end the variance, assuming that the “variance” bars in Fig. 1 represent the full range of the outcome distribution. Second, both the MEV and the full range of the variance in the outcome distribution are above the MR. In both cases, the Bounded Risk Distribution model predicts risk seeking. When the MR is very low, a decision-maker would be free of the fear of possible null consequences and become risk taking for the highest return possible. In the second case, the cost of risk taking is minimal. The higher the mean plus variance ( $M+r^2$ ) relative to the MR, the lower the danger of falling below the MR (for a similar analysis, see March, 1988; March & Shapira, 1992).
2. When the variance in the expected outcomes fails to reach MR or a goal (see MR4 in Fig. 1), the model predicts a risk-averse preference to maintain the status quo. When a decision-maker’s MR is beyond the range of ( $M+r^2$ ) in a certain option, the person should abandon all the current options and seek better alternatives. Temporal uncertainty and temporal variance may bring new options with a higher reaching outcome distribution.

This rationale can also be used to explain some joint ventures, such as playing lotteries to greatly extend the range of the up-reaching variance and buying medical insurance to cover otherwise unaffordable expenses. However, when there is no other means available, instead of wasting energy, maintaining the status quo or even learned “helplessness” may be functional. This argument seems to be consistent with some experimental findings of nonhuman animal studies that are seemingly contradictory to the energy budget rule or the mean–variance principle in general. For example, some animals (such as rats whose survival is not directly related to daily energy intake as is that of bees and most birds) show a lower sensitivity to energy budget manipulations. In the case of diseases due to malnutrition, sometimes rats tend to avoid risks and wait for environmental changes to bring better foraging outcomes (see Kacelnik & Bateson, 1996; McNamara, 1996, for a review).

Related to the notion of MR or goal setting is its psychological translation of aspiration level. Lopes (1987) was among the first advocating the view that instead of maximizing EU, decision-makers often strive to maximize the probability of meeting a goal or aspiration level. Lopes’ two-factor model focuses on the interactions between dispositional (individual) and situational factors. In her model, the first factor (“security” versus “potential”) reflects individual differences in the amount of attention paid to the worst outcomes versus the best outcomes in a distribution. The second factor (aspiration level) is a situational factor reflecting the opportunities at hand and the constraints imposed by the task environment. Thus, the model assumes a single reference point (aspiration level). The current Bounded

Risk Distribution Model, however, places more emphasis on the relationship between the goal level or aspiration level, MR and MEV, and cross individual effects of social and ecological constraints on the setting of these reference points. Although not directly tested in this study, the current model assumes separate effects of goal level and MR on both risk perception and risky choice.

#### **4. Study 1: Effects of increasing survival probability on risk preference—a new test of the Bounded Risk Distribution model**

##### *4.1. Hypothesis*

Can the Bounded Risk Distribution model make explicit predictions about how decision utility is affected by quantitative changes in relevant variables? In the following studies, I explore some marginal conditions where the MEV–MR relationship yields specific predictions. Under these specific conditions, the risk preference of a decision-maker should be determined not only by the qualitative relationship between MEV and MR but also their quantitative relationship.

A key assumption of the Bounded Risk Distribution model is that depending on the location of the MR the same amount of change in expected value would yield different utilities and thus different risk preferences.

Recognition that the effects of probability on choice behavior depend on the setting of goals and the MR is crucial for understanding human decision-making. For instance, increasing the probability of survival from one-third to two-thirds may or may not have a significant behavioral effect on risk taking, depending on whether the MEV–MR relationship changes as a result. If the MR were to save half of the group members at risk, a two-thirds survival would suffice. Thus, an increase in the survival rate from one-third to two-thirds should significantly increase the choice of the sure outcome over the gamble option of equivalent expected value. However, if the MR is to save more than two-thirds of the group, the same increase in survival probability should not have any marked effects on risk taking.

With regard to the life–death problem, the MR can be inferred by asking the question: What is the minimum percentage of survival for a group at risk that will elicit the sure choice? The operational measure of the MR used here is the sure survival offered by the sure outcome that is favored by at least 50% of the respondents, called MR50+. We predict that the goal for a decision-maker should be to save everybody at stake. However, the MR should be highest for kin, second highest for kith (lives in a small group) and lowest for strangers in a large anonymous group.

There are two main reasons for making the assumption that the MR is highest for kin, second highest for the members of a kith group, and lowest for a group of strangers. First, measured by Hamilton's (1964) inclusive fitness, the average cost of losing a given percentage of a group to a survivor should increase from a stranger group to a kith group and to a kin group. Thus, the same loss in terms of the percentage of a group may result in quantitatively different impact on one's fitness depending on whose lives are at stake.

Second, the interdependence among the members of a group should be another determinant of the MR setting for saving group members. We assume that, on average, the interdependence is highest among kin members, lower among the members in a small group, and lowest among the members of a large group. The higher the interdependence, the higher the MR should be in order to maintain the functions of a group.

Our previous empirical findings suggest that the size of a group is a cue of relational structure of a group. Small groups are psychologically perceived as “kith” or “we” groups, and larger groups are often treated as “stranger” or “they” groups (Wang, 1996a). Considering the data obtained in large group contexts under positive framing, the MR50+ is no greater than one-third of the group because about 60% of the respondents favored the sure option that would save one-third of the group. However, the MR50+ for saving hypothetical family members is significantly higher. Fifty-five percent of the subjects preferred the probabilistic outcome to the sure survival of two-thirds of the group members, although the gamble option had a lower (one-third) survival rate (Wang, 1996a). This particular finding suggests that the MR50+ in a kin group context is to save no less than two-thirds of the hypothetical family members at risk. The MR50+ for saving lives in a small group context then is expected to be higher than the sure survival of one-third of the group members, but lower than the sure survival of two-thirds of the group members.

According to the above analysis, we hypothesized that increasing the survival probability and thus the expected value in a life–death decision problem would have differential effects on risk preference depending on the group environments. (1) In a large group, saving one-third of the group for sure would have already reached the averaged MR for the participants, so increasing the probability from one-third to two-thirds would not have a strong effect on participants’ risk preference. (2) In a kinship group, saving even two-thirds of the group should not satisfy the MR of the participants, so the increase in the survival probability from one-third to two-thirds would not reduce the strong risk-seeking preference. (3) However, in a small group, the averaged MR of the participants should be higher than the MR for the large group but lower than the MR for the kin group. Thus, increasing the survival probability from one-third to two-thirds would be most likely to affect the risk preference of the participants. Once the two-thirds survival of the sure outcome exceeds the average MR of the participants, a choice preference reversal from risk seeking to risk aversion is expected.

#### *4.2. Method*

In this study, each group of participants was given one version of the life–death problem. The participants were asked to “Imagine that  $X$  people are infected by a fatal disease.” The number  $X$ , however, was different for each group of participants. Four numbers were used: 6000, 600, 60, and 6. There were two 6-lives conditions, six anonymous lives and six kin (denoted as 6r), at stake.

A second manipulated variable was the probability of survival. Out of 10 participant groups, 5 received a life–death problem with a one-third probability of survival and 5 received a life–death problem with a two-thirds probability of survival. The participants were 368 undergraduate students (249 females and 119 males) enrolled in introductory psychology

courses at the University of South Dakota who agreed to participate for extra course credit. The average age of the participants was 20.5 years.

Participants were randomly assigned to one of the 10 experimental groups (five hypothetical group contexts  $\times$  two survival probabilities). Participants were instructed that there were no right or wrong answers and were asked to choose between two effectively identical choice options: a sure outcome and a gamble of equal expected value.

#### 4.3. Results and discussion

The choice percentage data from each experimental group are shown in Table 1.

As predicted, increasing survival probability from one-third to two-thirds had significant effects on risk preference only in the two small group contexts with either 6 or 60 hypothetical lives at stake. In the two large group contexts with 6000 and 600 lives at risk, the participants were risk averse under both probability conditions. However, in the kinship context, the participants were risk seeking under both probability conditions.

The findings of Study 1 support the predictions from the Bounded Risk Distribution model with several theoretical implications. First, the findings challenge most contemporary risk-value models, which assume that risk is location-free (see Sarin & Weber, 1993, for a review). The location-free models presume that if a constant amount of wealth is added to all outcomes of a gamble, then the relative utilities are unchanged. Study 1 shows that a constant increase in expected value has a much greater impact on risk preference if it passes across the MR setting.

Secondly, unlike EU theory (von Neumann & Morgenstern, 1947) and prospect theory (Kahneman & Tversky, 1979), the Bounded Risk Distribution model predicts a step function across the MR point instead of a linearly concave or convex function.

Thirdly, unlike some other mean–variance models of risky choice (e.g., Markowitz, 1959) where the utility function is increasing and always risk averse (a person prefers higher mean

Table 1  
Effects of probability change on risk preference in a hypothetical life–death problem in different group contexts

Experimental group	Total ( <i>n</i> )	Survival probability	Group context	Choice of the sure option (%)	Chi-square statistics
One-third (6000)	31	one-third	large	61.29	$\chi^2 = 0.01, P = .917$
Two-thirds (6000)	40	two-thirds	large	62.50	
One-third (600)	31	one-third	large	58.06	$\chi^2 = 1.11, P = .292$
Two-thirds (600)	34	two-thirds	large	70.59	
One-third (60)	33	one-third	small	42.42	$\chi^2 = 5.63, P = .018$
Two-thirds (60)	40	two-thirds	small	70.00	
One-third (6)	30	one-third	small	33.33	$\chi^2 = 4.22, P = .040$
Two-thirds (6)	32	two-thirds	small	59.37	
One-third (6r)	44	one-third	kinship	27.27	$\chi^2 = 0.22, P = .641$
Two-thirds (6r)	31	two-thirds	kinship	32.26	

The word “one-third” or “two-thirds” in experimental group names represents the overall survival probability of the life–death problem; 6000, 600, 60, and 6 are the number of lives at risk; r denotes that the hypothetical patients in the life–death decision problem were described as the subjects relatives.

and lower variance), the Bounded Risk Distribution model predicts variance seeking when the expected value is below the MR.

Fourthly, although some researchers realize the trade-off between mean and variance is a critical part of risky choice, the trade-off is often modeled as a coefficient reflecting individual differences (e.g., Pollatsek & Tversky, 1970). In the present model, however, the mean–variance trade-off is a result of the MR or goal setting determined by the task environments.

## 5. Study 2: MR hypothesis versus responsibility avoidance hypothesis of kinship effects

### 5.1. Hypothesis

Why do people become more risk taking in these hypothetical dilemmas when they involve kinship groups than when they involve heterogeneous or stranger groups? We interpreted the finding in terms of the relationship between the expected value of the choice outcomes and the MR of the decision agent (e.g., Wang, 1996a; Wang et al., 2001). As noted before, the MR for functional survival of a kin group should be higher than that for a heterogeneous group. As a result, when the expected value of the sure outcome fails to reach the MR, the all-or-none gamble became the preferred choice. In addition, the framing of the expected outcomes is viewed as a secondary cue in the decision problem, which fine-tunes the setting of the MR. The distance between the MR and MEV looms larger under the negative framing. Thus, a framing effect (a preference shift but not a preference reversal) is observed. Let us call this interpretation the *MR hypothesis*.

The finding of a risk-preference shift due to the framing of choice outcomes in a kinship context is open to an alternative interpretation. The alternative reason for the strong risk-seeking inclination in kinship contexts is that people are more reluctant to choose a particular relative to save. To avoid the accountability or responsibility of saving only part of the group, people choose the risky option. The risky gamble allows the possibility of saving everyone and removes the responsibility of choice from the decision-maker. Moreover, this motive to avoid responsibility becomes stronger under the losing-life framing condition. Thus, the *responsibility avoidance hypothesis* can also explain why the choice percentage for the gamble option in a kin context was higher under losing-lives framing than saving-lives framing.

From the perspective of the MR hypothesis, the risk-seeking shift in a kinship context due to the framing of choice outcomes should be reflected in the setting of the MR for the life-saving task. This effect on the MR setting should exist in a low-responsibility situation as well as in a high-responsibility situation. However, the MR hypothesis does not exclude the possibility of a framing–responsibility interaction effect.

In contrast, the responsibility avoidance hypothesis would predict that the risk-seeking preference should be greater in a high-responsibility condition than in a low-responsibility condition. In addition, the risk-seeking preference would be augmented under negative framing.

In Study 2, we examined the effects of a responsibility manipulation on participants' risk preference and the MR settings under both framing conditions.

## 5.2. Method

Using a between-subjects design, each participant received one of the six life–death scenarios: two frames  $\times$  three responsibility conditions. The survival probability of all the scenarios was 50% and the sure option and the gamble option had the same expected value. The participants were given a life–death scenario to read and were asked to make a binary choice between a sure option and a gamble option.

The following is the *high-responsibility, positively framed* scenario:

Imagine that six people in your family, including both of your parents, your brother(s), and your sister(s), are infected by a fatal disease. Without any treatment, they will die. Two alternative medical plans to treat the disease are available. *You are the person who has to make a final choice between the two medical plans.*

Assume that the exact estimates of the consequences of the plans are as follows:

If Plan A is adopted, three of your family members will be saved.

If Plan B is adopted, there is a 50% chance that all six of your family members will be saved and a 50% chance that none of your family members will be saved.

In the *negative-framing* versions, the participants were told that Plan A would result in the death of half of the group and Plan B would have a 50% chance that no one would die.

Note that the responsibility manipulation is in italics.

In the *low probability "voter"* scenario, the following statement replaced the above responsibility manipulation: "*All six of them will vote to make a final choice between the two medical plans . . . which of the two plans would you choose if you were one of them?*"

In the *low-responsibility "observer"* scenario, instead of being one of the voters, the participant was an observer who was asked to indicate *which of the two plans ought to be chosen by the six relatives at risk.*

In order to test the MR hypothesis, it was necessary to directly measure the MR across different social group conditions. The MR was measured after the participant made the choice between the two medical plans. Each of the participants was asked to indicate what was his/her minimum number of lives that must be saved by the sure option. The participants who chose the sure option were asked to indicate what would make them switch to the gamble option if the sure option was only capable of saving fewer lives. The participants who chose the gamble option were asked to indicate what would make them switch to the sure option if it could save more lives.

The participants were 233 student volunteers (141 females and 92 males) recruited from the School of Business and Management at the Hong University of Science and Technology. They averaged 19.4 years of age. The instructions and questionnaires were all in English, which was also the language used in teaching at the university. The student participants were all fluent in English.

### 5.3. Results and discussion

The risk preference and MR data obtained from each of the six experimental groups are shown in Table 2.

The results of Study 2 do not support the responsibility avoidance hypothesis. The participants in the high-responsibility groups were not significantly more risk seeking than those in the low-responsibility groups. However, the framing of the choice outcomes had a statistically significant effect on the risk preference of the participants. The overall choice of the sure option under the saving-lives framing was 19.0% whereas the overall choice of the sure option under losing-lives framing was 5.1%. A logistic analysis showed a significant framing effect,  $\chi^2(1)=8.88$ ,  $P=.0029$ , but the effects of responsibility and the Framing  $\times$  Responsibility interaction were not significant.

A logistic analysis also showed that the participants' MR setting had a significant effect on their risky choice,  $\chi^2(1)=42.87$ ,  $P<.00001$ .

Consistent with the predictions of the MR hypothesis, the risk-preference changes due to the framing of the choice outcomes were closely correlated with the participants' MR for the sure option. The average MR under the positive framing was 4.68 (lives) whereas the average MR under the negative framing was 5.36 (lives),  $F(1, 231)=14.44$ ,  $P=.0002$ . The result suggests that negative framing elevates the setting of the MR and promotes risk seeking, while positive framing lowers the setting of the MR and lessens the degree of risk seeking.

In addition to the observed framing effects, there were significant differences in the MR measure between the high-responsibility–positive-framing (HR–P) group and the high-responsibility–negative-framing (HR–N) group,  $F(1, 80)=3.92$ ,  $P=.051$ , and between the low-responsibility–positive-framing (LR–P) group and the low-responsibility–negative-framing (LR–N) group,  $F(1, 80)=13.94$ ,  $P=.0004$ . However, no significant difference in the MR measure was found between the LR<sub>2</sub>–P group and the LR<sub>2</sub>–N group, nor did these groups exhibit a significant framing effect by differing in their choices.

The observer–low-responsibility manipulation resulted in an absence of framing effects, suggesting that responsibility and self-involvement may be antecedent conditions for framing effects.

Table 2  
Effects of framing and responsibility on the setting of MR and risk preference

Experimental group	Total ( <i>n</i> )	Framing	Responsibility	Decision role	MR	Choice of the sure option (%)
HR–P	38	positive	high	decider	4.47	21.05
HR–N	44	negative	high	decider	5.14	9.09
LR <sub>1</sub> –P	41	positive	low	voter	4.37	21.95
LR <sub>1</sub> –N	41	negative	low	voter	5.46	0
LR <sub>2</sub> –P	35	positive	low	observer	5.31	11.43
LR–N	34	negative	low	observer	5.44	8.82

HR represents high-responsibility, LR<sub>1</sub> and LR<sub>2</sub> represent low-responsibility “voter” and low-responsibility “observer,” respectively, P and N denote positive framing and negative framing, respectively. MR is the self-reported minimum number of lives that must be saved by the sure option.

In the six experimental groups, the risk-seeking choice dominated (see Table 2). In the kinship context, the respondents were risk seeking under both positive- and negative-framing conditions. The effects of framing did not cause a reversal in risk preference but a choice preference shift to greater risk seeking under negative (losing lives) framing. This result was consistent with our previous findings (Wang, 1996a, 1996b), suggesting that kinship context was the primary factor determining overall risk preference. The framing of the choice outcomes served as a secondary cue for adjusting risk preferences around the risk-seeking baseline.

Another factor that may influence the MR setting is heterogeneity of a kin group (e.g., two parents and two cousins versus two children and two uncles, etc.). When making life–death decisions concerning a heterogeneous kin group, the probability of the death of close versus distant kin may affect the MR independent of the overall mortality or survival rate of the group. In addition, the size of a kin group may serve as a cue for assessing relatedness between any pair of group members. In most cases, the larger a kin group, the lower the average degree of relatedness between two group members. Thus, the larger a kin group, the less costly any unspecified death. These issues are worthy of investigation in future studies.

## **6. Study 3: Reproductive decisions and variance in fitness and kinship: the Da-An study**

### *6.1. Hypothesis*

This study examined the implications of the Bounded Risk Distribution model in making reproductive and parental decisions. Reproductive and parental decisions should vary when the expected variance in offspring's reproduction changes. In fact, in the Da-An area where our field study was conducted, polygyny was a common practice until about 1950 when monogamy was enforced by the government. According to the logic of the Trivers–Willard hypothesis (1973), a rich parent who would be more likely to have a successful offspring should favor sons where there is an opportunity for sons to be polygynous. Conversely, a poor parent should prefer a daughter because she is not as likely to be reproductively unsuccessful as a son is. In essence, the Trivers–Willard hypothesis is a mean–variance analysis.

Gaulin and Robbins (1991) tested the Trivers–Willard hypothesis in a study of North American women. Consistent with the predictions, they found that more than half of the daughters born to low-income women were breast-fed, while fewer than half of the sons were. In contrast, around 60% of the daughters born to affluent women were breast-fed, versus 90% of sons. Another measure of parental investment, interbirth interval, showed a similar pattern. Low-income women, on average, had another child within 3.5 years of the birth of a son and within 4.3 years of the birth of a daughter. For affluent women, the opposite was true: daughters had a sibling within 3.2 years of birth, sons within 3.9 years.

However, in a recent study with larger data sets, Keller, Nesse, and Hofferth (2001) report that their results did not replicate the findings of the Gaulin and Robbins (1991) study. Based on the analysis of the results from their own and other previous studies, they conclude that Trivers–Willard effects are at best tiny in the contemporary United States where resources are rich compared to the typical conditions of hominid evolution. Their own study,

however, did not include interbirth interval because the information was unavailable in their data sets.

Would the Trivers–Willard effect manifest itself in an ecologically and culturally different environment, namely Chinese villages located in an area where favoritism of sons was both traditionally and presently popular (see Jing, 1994)? Would Chinese peasants be sensitive to cues of the differential reproductive variance in their sons and daughters, and would reproductive decisions and parental investment, measured by interbirth interval and breast-feeding duration, therefore vary with the variance in reproductive fitness of sons and daughters? Would other cues of risk in kinship such as physical resemblance of a child to a parent, indicating paternity (un)certainty, influence parental decisions?

It was hypothesized that:

1. Overall, sons would be favored over daughters. Because of patrilineal and partrilocal practices, sons are more valuable to their parents. For parents, it is better to invest more resources in those who will live with them for a lifetime under the same roof.

The parents' favoritism of one child over another child is expected to be reflected in a longer interbirth interval and a longer duration of breast-feeding.

2. However, when parental wealth is taken into account, a culturally adjusted Trivers–Willard effect is expected. That is, son favoritism should be most evident among the wealthier parents. For poor parents, son favoritism should be reduced if not reversed.
3. Physical resemblance of a child to a parent may be used as a risk indicator of nonpaternity. If so, irrespective of the sex of a child, the offspring resembling the putative father should be breast-fed longer and lead to a longer interbirth interval.

## 6.2. Method

### 6.2.1. Background of the villages

The Da-An study was conducted in the villages of Da-An town of DingXi county in GanXu province in the northwest region of mainland China.

Da-An was one of the poorest and least developed areas of mainland China. The underdevelopment was mainly a result of its geographical location and prolonged drought. Da-An town has a total of 10 villages located on hilly mountains, with 2845 households scattered over an isolated area of 131 km<sup>2</sup>. In each village, clusters of about four to five households were within a 10- to 40-minute walk of each other.

Our interview study was conducted in four adjacent villages, Chakou, Zhongzhuang, Dujiapu, and Dalaodi. The four villages had a total of 1134 households and about 6400 people. At the time when this study was conducted in 1999, there were no TVs, telephones, or automobiles in these villages.

### 6.2.2. Interview procedure and participants

We randomly selected about a dozen clusters of households and interviewed one person in each available household within a cluster. The total number of households interviewed was 49.

The families interviewed were both patrilineal (i.e., assets are inherited through the male line) and patrilocal (i.e., residence is with husband or husband's family).

Four trained local middle-school teachers who did not know the purposes of the study conducted the interviews. Within the 49 households, 23 men and 26 women were interviewed. The average age of these participants was 40.86 years. In most of these interviews, the spouse and other family members of the interviewed parent were also present.

The total number of genetic offspring of the interviewed parents was 97 (43 daughters and 54 sons). All the children had been breast-fed and none had major health problems during the breast-feeding or before the arrival of a younger sibling.

Questions related to the dependent and independent variables of this study and some other questions not reported in this paper were asked during the interview. Each interview lasted about 40 minutes. At the end of the interview, each participant was paid 10 yuan for her/his assistance.

### 6.2.3. *Dependent and independent variables*

The two dependent measures of reproductive decisions were the duration of breast-feeding and the interbirth interval. Both the interbirth interval and duration of breast-feeding are viewed as good measures of parental investment (Gaulin & Robbins, 1991). The “one-child-per-family” policy first proposed in the early 1980s was not in strict practice in the area. This permitted interbirth interval measures to be collected from most of the interviewed families. The birthweight and health conditions of each child were also asked.

One independent variable was the sex of the offspring of the interviewed parents. A second independent variable was the wealth condition of the interviewed household. In order to measure the overall wealth condition during the prior 10 years rather than the wealth condition at the time of the interview, we measured the relative wealth condition in the decade against all the other households in the same village. The interviewed parents rated the relative wealth condition of their households on a 1 to 9 scale, with 1 representing a *very poor condition*, 5 representing the *average condition*, and 9 the *very wealthy condition*. In order to know the real range and variation in wealth condition, household annual income was also measured. The mean reported household income was 5498 yuan, ranging from 550 to 20000 yuan in 1998, including cash income and other sources of income converted to cash values. The main sources of wealth were food crops, vegetables, herbs, and livestock.

Unlike Gaulin and Robbins's study (1991), our Da-An sample did not include single mothers and did not exclude the middle-wealth households.

Another independent variable was the overall physical resemblance of a child to either the father or the mother (i.e., facial features, body features, facial expressions, and gait) as perceived by the interviewed parent. The parents were asked to make a binary choice between “more similar to the father” and “more similar to the mother.”

### 6.3. *Results and discussion*

Table 3 shows the interbirth interval, breast-feeding data, and sample size for each of the target conditions. The two wealth conditions were determined by splitting the self-ranked

Table 3

Breast-feeding duration and interbirth interval (mean  $\pm$  S.D., in months) as a function of sex of the offspring, family wealth conditions, and physical resemblance to father or mother

Independent variables	Breast-feeding	Interbirth interval	Interbirth statistics
<i>Children's sex</i>			
Daughters	18.90 $\pm$ 1.68 ( <i>n</i> = 43)	32.64 $\pm$ 5.04 ( <i>n</i> = 25)	<i>F</i> = 4.90, <i>P</i> = .031
Sons	20.56 $\pm$ 1.50 ( <i>n</i> = 54)	47.80 $\pm$ 4.62 ( <i>n</i> = 30)	
<i>Children's sex by perceived family wealth</i>			
Daughters/high	18.10 $\pm$ 2.36 ( <i>n</i> = 22)	33.00 $\pm$ 7.00 ( <i>n</i> = 12)	<i>F</i> = 0.24, <i>P</i> = .678
Sons/high	21.63 $\pm$ 2.13 ( <i>n</i> = 27)	37.13 $\pm$ 6.06 ( <i>n</i> = 16)	
Daughters/low	19.76 $\pm$ 2.42 ( <i>n</i> = 21)	32.31 $\pm$ 6.72 ( <i>n</i> = 13)	<i>F</i> = 7.43, <i>P</i> = .012
Sons/low	19.48 $\pm$ 2.13 ( <i>n</i> = 27)	60.00 $\pm$ 6.48 ( <i>n</i> = 14)	
<i>Physical resemblance</i>			
To father	20.12 $\pm$ 1.45 ( <i>n</i> = 51)	47.25 $\pm$ 4.50 ( <i>n</i> = 32)	<i>F</i> = 3.70, <i>P</i> = .061
To mother	19.16 $\pm$ 1.92 ( <i>n</i> = 29)	32.25 $\pm$ 6.45 ( <i>n</i> = 16)	

All the statistics reported are based on the interbirth interval data. There was no significant difference in the duration of breast-feeding in any of the paired comparisons.

wealth scores at the middle point of the 1–9 scale. Twenty-seven households receiving a ranking score lower than 5 were classified into the low-wealth condition category whereas the 22 households receiving a score equal to or higher than 5 were classified into the high-wealth condition category.

Table 3 summarizes the main findings of the Da-An study.

1. As predicted, the costs of sons were reflected in the interbirth interval measure. The average interval after having a daughter was 32.6 months, which was significantly shorter than the average interval of 47.8 months after having a son.
2. However, the other dependent measure of parental investment, the duration of breast-feeding was not significantly different between the daughters and sons. The duration of breast-feeding for sons and daughters remained very similar in all of our subsequent comparisons across the two wealth conditions.
3. As shown in Table 3, when wealth condition was taken into account, the interbirth interval difference after having a daughter versus a son disappeared in the high-wealth families but remained significant in the low-wealth families. The mean number of children at the time of the study was not significantly different between the above median-wealth families (2.21) and the below median-wealth families (2.04).
4. However, the difference in interbirth intervals was in the opposite direction than predicted from the Trivers–Willard hypothesis. In the families of higher wealth, the average interbirth interval after having a daughter (33.0 months) was close to that (37.1 months) after having a son. In contrast, for the lower-wealth families in the villages, the average interbirth interval after having a daughter (32.3 months) was markedly shorter than that after having a son, which was 60.0 months. This finding is unlikely to be a result of higher needs for sons in poor families since the pay scale, food

ration, and land allocation were equally applied to all the families in Da-An. If anything, there was a biased treatment against wealthy families of previous landlords during the period from the Agrarian Reform in the early 1950s to the end of the Cultural Revolution in 1977.

This unpredicted result can be interpreted within the framework of the Bounded Risk Distribution model. Conceivably, the status quo of the low-wealth families was more distant from the average reproductive goal of the village families than the higher-wealth families. This greater distance from the status quo to a reproductive goal or MR is more likely to be overcome by sons with a greater reproductive variance than daughters. A greater reproductive variance in sons should be viewed in terms of not only the variance in completed fertility but also a greater potential of reaching higher social status.

A problem of this study was that for some elderly parents, the relative wealth condition over the previous 10 years might not reflect the wealth condition of the family at the time when the reproductive decision of having a child was made.

To see if the observed pattern of interbirth intervals would change when the age of the offspring was better controlled, I conducted another test excluding all the children who were over 15 years of age at the time of the study. The number of the data points decreased from 97 to 55 after the screening. However, the difference between the length of interbirth interval after having a daughter versus a son remained significant,  $F(3, 51) = 4.58, P = .012$ .

One possible reason for the lack of a Trivers–Willard effect is that all the families in the Da-An study were not rich. Since the overall level of wealth in the villages was quite low, the expected son favoritism in “wealthy” families would not occur. In other words, the reproductive MR or goal settings would be elevated only when the wealth and economic status of the parents are much higher, which none of the village families had yet achieved.

Given the mixed findings in human studies of the Trivers–Willard effects, Keller et al. (2001) try to specify situations in which the Trivers–Willard effects should be expected. They argue that only certain types of parental investment, such as a bias in the sex ratio should show the effect, whereas optimal allocation of resources after the child is born is achieved not by the simple bias predicted by the Trivers–Willard hypothesis but by allocating resources among offspring in ways that yield the largest marginal inclusive fitness gains.

From this perspective, the finding in Study 3 that interbirth interval but not breast-feeding duration varied with parental wealth suggests that while both measures reflected the amount of investment in an existing child, the interbirth interval was also determined by parental decisions about whether and when another child is “needed.” As suggested by the breast-feeding duration measure, a parent is equally attached to a daughter as to a son, once the child is born.

5. Another independent variable analyzed in the Da-An study was the overall physical resemblance of a child to either the mother or the father, perceived by the parents. In the interviews where both parents were present, mothers and fathers were in agreement. In the analysis, 17 indecisive responses, such as “not sure which parent the child resembles more” or “resemble both parents” were not included. The reported physical

resemblance had no effect on the duration of breast-feeding. However, a trend was found in the interbirth interval data. The average interbirth interval (47.3 months) after having a child resembling the father was longer than the average interbirth interval (32.3 months) after having a child resembling the mother (see Table 3). The sex of the child did not make a difference. The finding suggests that the reproductive decision of a parent on whether to have another child may depend partly on cues of the degree of paternity (un)certainty. Again, such an effect would constitute a case in which parents are sensitive to cues that signal their reproductive risks.

## **7. General discussion**

The “smartness” of kith-and-kin rationality relies on its fit with the social and ecological structure of group environments. Risk distributions, as reflected in the variation in expected values of choice outcomes as well as in reproductive fitness, vary as a function of the task structure of environments. Adaptation to the unique distributions of risk in different task environments makes use of the variance to maximize the probability of reaching a task-specific objective. Variance is sought when the mean expected return is below an MR or goal level of the decision agent, whereas variance is avoided when the mean expected return is satisfying. Such a decision mechanism thus takes into account the distance between the MEV and the MR for survival or between the status quo and reproductive goal setting.

In a nutshell, the Bounded Risk Distribution model assumes that instead of trying to maximize expected values of choice outcomes, a decision-maker tries to maximize the chance of reaching a task-specific goal with a minimal acceptable outcome, called MR. Holding the MR constant, goal settings or aspiration levels should influence risky choices in a manner similar to the MR.

Study 1 demonstrated that the same degree of increase in expected number of “saved-lives” had a significant effect on the respondents’ risk preference only when the increase was likely to cross the average MR of the respondents in a small group context but not when the change in the expected value was in a range below the average MR in a kin group context or in a range that was above the MR in a large group context.

Study 2 examined an alternative accountability/responsibility avoidance hypothesis to account for strong risk taking on behalf of a kin group and found that this manipulation had little effect on risk-taking preference in kinship contexts. The setting of MR was largely determined by the kinship cue in the problems and was further fine-tuned by the framing of the choice outcomes. The negative framing in terms of lives lost elevated the average MR, and the positive framing in terms of lives saved lowered the setting of average MR of the participants. As a result, the choice preference of the respondents shifted from moderate risk acceptance to more extreme risk acceptance under negative framing.

Study 3 was conducted in four rural villages in northwest China. Reproductive decisions, measured by the length of interbirth interval, varied with the wealth condition of the family, the sex of the children, and perhaps with the perceived resemblance of a child to father versus mother, although these variables did not seem to affect breast-feeding duration. Controlling

the wealth factor, the length of interbirth interval was significantly longer after having a son than a daughter, indicating an overall preference for sons. Taking wealth into consideration, the above difference in the interbirth interval disappeared in wealthier families but remained significant in poor families. We assume that the distance from the status quo to a reproductive goal was greater for the parents in low-wealth families than the parents in wealthier families. Given this assumption, the difference in the length of interbirth interval between poor families and wealthier families suggests that the poor parents invested more in sons than daughters for a greater reproductive potential in sons to reach a more distant reproductive goal.

From a Darwinian perspective, risk as variance might be viewed as variance in kinship and in fitness. In this light, the coefficient of relatedness,  $r$ , in Hamilton's rule (1964) can be considered as a risk index. The reproductive risk of altruism increases as the  $r$  value of a recipient decreases. This means that the higher the relatedness between a decision-maker and a decision recipient at stake, the greater risk the decision-maker would be willing to take in a joint venture since the risk is discounted by the  $r$  value.

In addition, variance in the reliability of the  $r$  value of a child to his/her parents represents another adaptive problem, namely parental uncertainty. Whereas women are 100% certain of their maternity, men face a varying degree of paternity uncertainty. Parents, particularly fathers, should search for cues indicating this reproductive risk. One of these cues is the physical resemblance of a child to a parent. The results of Study 3 suggest that the length of interbirth interval to the next child may be longer when a child is judged to resemble the father more than the mother, suggesting that parental investment was higher when this cue of paternity was deemed concordant with the putative father. When there is uncertainty of kinship, one is expected to search for and process relevant information to reduce the uncertainty. Paternity uncertainty can be reduced by various means. The physical resemblance of a child is one of the cues for making a paternity judgment.

In sum, human decision-makers appear to be sensitive to variations in both expected payoff and reproductive fitness. Social and ecological rationalities in decision-making are bounded by and adapted to the risk distributions in evolutionarily recurrent task environments.

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