Information Presentation in Decision and Risk Analysis: Answered, Partly Answered, and Unanswered Questions

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Running head: Information Presentation in Decision and Risk Analysis

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ABSTRACT

For the last thirty years, researchers in risk analysis, decision analysis, and economics have consistently proven that decision makers employ different processes for evaluating and combining anticipated and actual losses, gains, delays and surprises. While rational models generally prescribe a consistent response, people's heuristic processes will sometimes lead them to be inconsistent in the way they respond to information presented in theoretically equivalent ways. We point out several promising future research directions by listing and detailing a series of answered, partly answered, and unanswered questions.

KEY WORDS: Decisions; Information presentation; Utility theory; Risk perception; Risk analysis; Message Design

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1. INTRODUCTION

Would you describe a partly filled glass as half empty or half full? The way a person describes or presents the water glass can and will influence follow-up actions. If the glass is compared to a full glass, a drinker may complain that the glass is half empty. If the glass is compared to an empty glass, ready to be cleared away, a drinker may say it is still half full. Similarly, the way a risky situation is presented can influence actions stakeholders may take.

Greenberg et al.[(1)] listed ten key accomplishments for the field of risk analysis over the last thirty years, with the second being the recognition "that personal decisions reflect different processes for valuing and combining anticipated and actual losses, gains, delays, and surprises." Taking their work as a starting point, this essay expands upon the discussion about personal decision-making phenomena, by presenting future research directions for risk analysts taking into account these phenomena.

With inputs from psychology and economics, ever since the early rational decision theories of von Neumann and Morgenstern[(2)] and Savage[(3)] were challenged by behavioral decision research

pioneers such as Daniel Kahneman, Sarah Lichtenstein, Herbert Simon, Paul Slovic, and Amos Tversky, decision-making researchers have claimed and firmly established that human beings are not rational much of the time. Their preferences and decisions can be easily changed by variations in decision contexts[4], embedded emotions[5] or quickly experienced affective reactions, and many other factors. Essentially the same decision problem, with just a few variations in the way it is presented, can lead to dramatically different reactions. Such behavioral inconsistency could influence risk analysts, policy makers, and members of the public impacted by risk analyses. A number of phenomena have been documented from laboratory experiments and field studies. However, like all other fields, there are still many unanswered questions.

We first review questions that have been answered and point to selected examples of relevant literature and then present several important questions that we think need more investigation in the future. Then we discuss implications for assessing risk perceptions and communicating risk messages.

2. ANSWERED QUESTIONS

This section contains three general questions about information presentation that we are able to answer based on a significant amount of evidence. The evidence to answer each question is briefly discussed in its own subsection.

2.1. Do Information Presentation Modes Change Choices and Judgments?

The answer is "Yes". Different information presentation modes that should lead to the same response, according to rational theories, can systematically lead to different responses. Risk

analysts should be aware that how they present information to experts or novice decision makers or how they elicit information from them could lead to biases in responses.

Much of the research in the last 30 years on violations of rational decision principles was motivated by demonstrations of irrationality in choice behavior when deciding between risky options (the Preference Reversal Phenomenon of Lichtenstein and Slovic and the Allais Paradox) and in handling probabilities (the Ellsberg Paradox and Tversky and Kahneman's[6] heuristics and biases in probability judgment). Subsection 2.1 presents these classical examples and subsection 2.2 discusses why information presentation mode differences matter and briefly reviews some theoretical explanations and models for these phenomena that have introduced a number of concepts useful for risk analysts to consider.

2.1.1. Preference Reversal Phenomenon

When investigating a person's preferences, the presentation mode of the preference elicitation questions can affect the answers. Lichtenstein and Slovic[7] showed that when people choose between a pair of specially constructed risky monetary gambles (see Table I), they can come up with a different preference order than when they assign a monetary certainty equivalent to each gamble. Switching the preference order due to different assessment methods violates most rational decision theories, since they do not specify the specific process task for ordering decision options.

Such a preference reversal due to the way in which the preference is assessed (via choice or a matching of a monetary amount to the gamble) has led to a great deal of research on this type of reversal, and others (such as in choices between multiple attribute options, with no probabilistic uncertainty, the so-called choice vs. matching prominence effect.[8,9]). Grether and Plott[10]

attempted to get rid of the preference reversal, but, in general, they did not succeed. One explanation for this effect is that different judgment processes are used in the two tasks. Since risk analysts need to design means to assess preferences from members of the public or decision makers, care needs to be taken in designing the choice or judgment processes.

Table I. Preferences Reverse under Choice versus Matching Tasks

Preference Reversal Tasks: "Choose between 2 options" or "Name a minimum selling price"			Higher Mean Certainty Equivalent	Preferred under Choice Task
More Risky Option (MR) or "$ bet"	33% chance of $16	67% chance of -$2	✓	
Less Risky Option (LR) or "P bet"	99% chance of $4	1% chance of -$1		✓

LR will tend to be chosen over MR. But, when a monetary amount is attached to the MR gamble, its value tends to be higher than LR's value. The heuristic process followed when making a matching judgment might first anchor on the largest amount and adjust downward. But, a person may not adjust sufficiently, so when anchoring on a high amount (such as $16), then adjusting downward, the resulting certainty equivalent may still be a relatively high amount. When making a choice, the person may look at the probabilities and payoffs and tend to prefer the gamble which appears to have less risk, when the gamble is in the gains domain with non-negative monetary outcomes. (Data from Lichtenstein and Slovic[7].)

2.1.2. Switching from Risk Aversion to Risk Proneness by Varying Problem Structure

Allais[11] demonstrated, in what is now called the Allais Paradox, that people make pairs of specially structured choices that violate axioms of expected utility theory.[2] Allais provided a number of examples using old French francs in his original article; the structure of the most common example, translated using dollars, is shown in Table II. While Allais was providing such examples to refute and confront expected utility theory with a paradox that theoretically allowed preference-invariant transformations will lead to changed preferences, his examples and related ones have been interpreted as evidence of instability of risk attitudes. Note that von Neumann and Morgenstern[2] gave no prescription that a person should have a stable risk attitude, just showing that, if a set of axioms are satisfied, there would be a stable utility function for a decision maker

that can be used to rank order risky options. See Simon et al.[12] for a detailed discussion of this and other paradoxes.

Table II. Switching from Risk Aversion to Risk Proneness (Allais Paradox)

Options	.10 probability	.89 probability	.01 probability	Preferred under Choice Task
A	$1 million	*$1 million*	$1 million	✓
B	$2 million	*$1 million*	$0	
A'	$1 million	*$0*	$1 million	
B'	$2 million	*$0*	$0	✓

Most prefer the risk averse option A, gaining $1 million for sure over the risky option B yielding a higher expected value. In the transformed choice, the common outcome of *$1 million* with the .89 probability is changed to the common outcome of *$0*. Then, comparing a .11 chance of $1 million versus a .10 chance of $2 million, most prefer the riskier choice of B' over A'. Any assignment of utility values of u, v, and w to gaining $2 million, $1 million and $0 will result in the pair of choices that maximizes expected utility being either A and A' or B and B', which does not match the majority choice pattern of A and B'.

Having seen that people could switch from risk aversion to risk proneness in the transformed problem in the Allais Paradox, further examples were developed to demonstrate such a shift. For example, making the outcomes to be losses (such as in the Table II example) will lead to a flipped reflection of the choice seen in the original cases involving monetary gains.[13]

In their classic Asian Disease problem, Tversky and Kahneman[14] cleverly constructed the disease scenario so that describing the outcomes in one frame as lives saved, and in a transformed frame as lives lost (by number of people dying), would result in preference reversals, even though the original and transformed scenarios are objectively identical. The trick to construct such isomorphic consequences was to say that 600 people were expected to be killed by the disease. Then, an outcome of 200 dying is isomorphic to an outcome of 400 being saved. Here is the loss-framed version:

Imagine the U.S. 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. Assume that the exact scientific estimate of the consequences of the programs are as follows:

If Program C is adopted 400 people will die.

If Program D is adopted there is 1/3 probability that nobody will die, and

2/3 probability that 600 people will die.

Which of the two programs would you prefer? (p. 453)

The majority of people choose the risky Program D when framed in the loss format (avoiding 400 sure deaths) and choose the risk averse Program C when framed in a gain format (of 200 people being saved for sure). Overall these findings imply that when designing risky messages, the framing of the messages and their evoked emotions could potentially lead to different affective reactions to the risky event. See Finucane et al.[15] for discussion of the affect heuristic.

Moving closer to some actual consumer decision settings, Steinhardt and Shapiro[16] examined choices for monetary problems when presented in the standard non-narrative way of the original gain/loss frame experiments or in a story-like narrative. They found that the different majority choices resulting from changing the non-narrative descriptions from gains to losses did not show up when the narrative context was used. The story itself might provide a new frame of reference and thus dampen differences between gain or loss wordings. They also looked at a medical case of surgery vs. radiation, originally studied in the non-narrative format by McNeil et al.[17] but did not get such clear cut results. So a story-like message design *might* mitigate differences due to gain vs. loss framings, or might modify such effects. Practitioners and analysts should carefully consider the consequential variations in respondents' behavior to accurately deliver the desired

messages.

2.1.3. Precise Probabilities Preferred over Ambiguous Probabilities

Ellsberg used a similar choice structure to that used by Allais, but focused on events (drawing a colored ball from an urn) as Savage did, rather than specifying probabilities. Ellsberg[18] demonstrated, in what is now called the "Ellsberg Paradox", see Table III, that people prefer a precisely specified probability of winning over an ambiguous one, violating the laws of probability when a set of specially constructed choices are made. Since risk analyses can involve both ambiguous and precise probabilities, choices of how probabilistic uncertainty is presented should be carefully considered. See Simon et al.[12] for a summary of why this paradox violates rationality.

Table III. Ellsberg Paradox Demonstrated Preference for Precise Probabilities of Winning

Options	30 Balls	60 Balls		Preferred under Choice Task
	Red balls	Black balls	Yellow balls	
A	$100	$0	*$0*	✓
B	$0	$100	*$0*	
A'	$100	$0	*$100*	
B'	$0	$100	*$100*	✓

The unambiguous 30/90 chance of winning $100 in option A when a red ball is drawn is usually chosen over the ambiguous probability of winning $100 in option B when a black ball is drawn, knowing there are 60 black or yellow balls in some unknown mix. Transforming the choice between A and B, by changing a yellow ball's common outcome of *$0* to *$100*, reverses the majority choice, so B' (with an unambiguous 60/90 chance of winning) is chosen over A'. Any specific subjective probability *b* of a black ball and *y* of a yellow ball being drawn would lead to either the pair of choices of A and A' or B and B', which would conform with probability theory.

In the area of managerial accounting, Ho et al.[19] studied managers' investigation decisions on a department's performance given performance benchmarks expressed in precise or ambiguous numerical intervals. Ho et al.[20] studied the impact of ambiguous information and non-financial factors on managers' capital budgeting decisions, and found that managers behaved differently in gain and loss conditions. With non-financial factors in mind, a significant number of managers chose the self-serving option in the gain domain, but chose the firm-value maximization option in the loss domain.

2.1.4. Probability Judgment with Contextual Information

Tversky and Kahneman's[6] classic article summarized findings on heuristics and biases in probability judgment. In general, by adding a richer context, people may make more errors. For example, in the classic Linda problem by Tversky and Kahneman [21], when laboratory subjects were given a description of Linda, a woman matching their stereotype of a feminist bank teller, 85% violated the laws of probability by judging the joint probability that Linda was both a bank teller and a feminist as higher than the marginal probability that she was a bank teller. A person might be able to state the abstract rule for calculating the joint probability of a conjunction of two events F and B, and might be able to state that it should be no higher than either of the marginal probabilities of P(F) and P(B), but still fall prey to the so-called *conjunction fallacy* when a richer context obscures the abstract structure. See Table IV for an illustration of the conjunction fallacy for the Linda problem.

Table IV. Illustration of Probability Conjunction Fallacy by Categorization of 100 Women Matching Linda's Description into Groups

	Number N_i in Each Group		
Target category	**Bank Tellers (B)**	**Not Bank Teller (NB)**	**Total**
Feminist (F)	$N_{B\text{-}F}$ (Prob .= $N_{B\text{-}F}/100$)	$N_{NB\text{-}F}$ (Prob. = $N_{NB\text{-}F}/100$)	N_F (Prob. = $N_F/100$)
Not Feminist (NF)	$N_{B\text{-}NF}$ (Prob. = $N_{B\text{-}NF}/100$)	$N_{NB\text{-}NF}$ (Prob. = $N_{NB\text{-}NF}/100$)	N_{NF} (Prob. = $N_{NF}/100$)
Total	N_B (Prob. = $N_B/100$)	N_{NB} (Prob. = $N_{NB}/100$)	100 (Prob. = 100/100=100%)

We know that in the table above:

$N_{B\text{-}F} + N_{NB\text{-}F} = N_F$, $N_{B\text{-}NF} + N_{NB\text{-}NF} = N_{NF}$;

$N_{B\text{-}F} + N_{B\text{-}NF} = N_B$, $N_{NB\text{-}F} + N_{NB\text{-}NF} = N_{NB}$;

$N_F + N_{NF} = 100$; $N_B + N_{NB} = 100$.

Therefore, $N_{B\text{-}F} \leq N_F$ and $N_{B\text{-}F} \leq N_B$

The probability of the conjunction of B and F = P(F and B) = $N_{B\text{-}F}/100 \leq P(F) = N_F/100$ and also $\leq P(B) = N_B/100$.

The conjunction fallacy occurs when this rule is violated.

Ho and Keller[22] examined the probability conjunction fallacy in an auditing context. When professional auditors serving as experiment subjects made probability judgments of individual audit events (e.g., ending inventory was overstated) or conjunctions of events (e.g., both ending inventory was overstated and interest expense decreased significantly), they made a number of conjunction errors by making the probability of both events occurring be higher than at least one of the component events, violating the probability conjunction rule.

2.2. Why Do Information Presentation Modes Matter?

2.2.1. Differences in Message Content vs. Delivery

Different presentation modes matter, since they lead to different choices or judgments. The variations in a decision or judgment task with its choice options have two components: the

messages we deliver[23] and the way we deliver the messages[24-27]. First, the contents of the message matter. For example, in one of Loewenstein's[23] experiments, subjects were asked to make tradeoffs between the size of the reward and its delay or speed-up for the same three-week period (i.e., from week 1 to week 4, or from week 4 to week 1). The mean delay premium was significantly higher than the mean speed-up cost, which proved that thinking of a time span as a delay or as a speed-up will impact greatly on individual decision making over time and the implicit discount rate being used. Second, the way we deliver the messages also matters. For example, a set of studies has shown that the impact of message contents might be influenced by the reader's metacognitive experiences (e.g., if the message is easy or hard to process). More specifically, processing fluency has been shown to impact decision makers' judgments of truth[28], aesthetic pleasure[29], and affective response[30].

2.2.2. Dynamic Inconsistency in Choices

Why is it problematic that variation in a message's presentation mode leads to inconsistent choices? For example, if a person makes a choice first, and then faces a transformed but equivalent choice task later, she may display a preference reversal, where option *A* is preferred over option *B* at one time, and the transformed choice is *B*' over *A*'. Such intransitive choices display "dynamic inconsistency" which may lead to a "money pump": If she would pay a dollar to get *A* over *B* at the first stage, and then a dollar to get *B*' over *A*' at the next stage, then another $1 to get *A*'' over *B*'' at the next stage, it is possible to "pump money" out of her. So, decision makers can be taken advantage of, and policy makers and practitioners can't win either if they do what people say they want ahead of time, then the same people aren't happy at the time it comes around.

Keller[31,32] discusses such dynamic inconsistency and clarifies the distinction between descriptive, normative, and prescriptive theories. If one thinks about what choice to make today, a choice between a sure thing and a gamble that may lead to a gain will often result in a choice of the sure thing. But, if one thinks back to a younger time and thinks about the whole series of choices and outcomes that have been made, today's choice would look like the end of a whole set of risky choices. Back then, one might have planned to take the risky option, but when today arrived, the safe option would be chosen, demonstrating dynamic inconsistency (which would be normatively prohibited, but descriptively an accurate depiction).

2.2.3. Models and Theoretical Concepts

Based on the classic examples in Section 2.1, a number of researchers have developed models and theoretical concepts as potential explanations of the observed patterns of choices and judgments. In section 2.1.2 we presented the Allais Paradox as an example of switching from risk aversion to risk proneness by varying the problem structure. This is one of the many ways that similar patterns of choices have been explained; other ways include regret aversion,[33,34] responsibility aversion,[35] lottery dependent expected utility with the existing probabilities,[36] etc. There are at least two general types of responses: i) generalized utility models which capture the preference patterns, and ii) psychological explanations of processes. Among them the most prominent approach is Kahneman and Tversky's[13] prospect theory, which has components of both approaches, and which introduced and popularized a number of terms and concepts.

Kahneman and Tversky used the term *framing* to indicate that a person may go through a preliminary phase of examining and *framing* a decision relative to a *reference level* or "*zero*" *point*,

prior to making the decision. Such a preliminary phase may lead a person to *isolate* attention to the components of decision options that are unique. Their prospect theory model, aiming to be a more realistic descriptive model of choice as an alternative to the rational decision theory model of von Neumann and Morgenstern, has two main components, 1) an S-shaped value function over outcomes that is concave above the zero reference point, convex below the zero point, and steeper in the loss domain just below the zero point than it is in the gains domain just above the zero point (which is called *loss aversion*) and 2) a probability weighting function that changes abruptly near the end-points where probability is equal to 1 or 0. The value of an option is calculated similar to the way it is calculated in expected utility theory, where the utility of each outcome is weighted by its probability. The concavity above the zero point can model risk averse choices in the gains domain and the convex value function below the zero point can model risk prone choices in the loss domain, so the *reflection* of choices in the gains domain versus the loss domain described in section 2.1.2 can be modeled. A more detailed discussion to improve the understanding of prospect theory is provided by Bromiley[37].

In addition to Tversky and Kahneman's general concept of framing, many researchers from a variety of fields have borrowed the concept of loss aversion,[38, p. 1039] and extended it to be the psychological result of "losses looming larger than gains."[39, p. 298]

Some additional terms related to the way a judgment or a decision is presented have been introduced and promoted by others. The term *mental accounting* refers to the idea that when making a decision, a person may assign actions and the resulting mental debits or credits to so-called mental accounts.[40] For example, suppose a person loses a $50 football game ticket en

route to the stadium, and that loss is mentally subtracted from the mental "recreation" account. That person may be unlikely to buy another ticket and might just go home. If the same person loses a $50 bill, it is subtracted from the mental "cash" account, and the person is more likely to buy the ticket and go into the game, despite the disappointment of losing the money.

Thaler and Benartzi[41] and Thaler and Sunstein[42] use the term *choice architecture* to refer to the actions a decider has to take and what happens in the default if no action is taken. They label a choice architecture that is designed in a way that the policy maker believes is in the best interest of the decider as a *nudge*. Such a design will nudge the decider to make a good decision.

2.3. Are Information Presentation Effects Generalizable to Practical Risk Analysis Domains?

While the classic examples focused on choices without richly specified choice contexts, a number of practical risk analysis contexts have been shown to fall prey to information presentation effects. This section provides some examples in health, environmental, and financial and consumer decision domains. See section 3.4 on ways to debias, such as changing the choice mechanism (e.g., opt-in or opt-out).

2.3.1. Health Contexts

Wansink and Cheney[43] found that when people had larger dinner plates, they tended to eat more. The plate size served as a manipulation tool where a larger plate led to a smaller perception of portion size. Wansink and van Ittersum[44] found that when bartenders pour a supposedly standard serving into a glass, they pour more into a short fat glass than a tall skinny glass.

Moreover, in a study on organ donation, Johnson and Goldstein[45,46] reported that in Austria, Belgium, France, Hungary, Poland, Portugal and Sweden, people were presumed to be willing to donate their organs when they die, and they must actively make the choice to opt out of that plan, while in Denmark, the Netherlands, the United Kingdom, and Germany, people must explicitly opt in to donating their organs. In the European countries with an opt-out policy, the range of effective consent rates (of people who end up as willing to donate) is from 85.9% to 99.98%. In contrast, in the countries with an opt-in policy the range is from 4.25% to 27.5%. The big gap partially shows the powerful role of the default option. Meanwhile, they also reported a regression analysis on European donations from 1991 to 2001, finding that, controlling for various other factors, there was a statistically significant difference in actual donations from 14.1 (under a no donation default in "opt-in" European countries) to 16.4 per million (under a donation default in "opt-out" European countries). In a similar analysis on the data in 1999 for a bigger set of European countries, Gimbel et al.[47] found an even larger increase (from 10.8 to 16.9 per million). Finally, in a study on reported life expectations, Payne et al.[48] studied the framing of life expectations questions as either live-to or die-by and found that individuals in a live-to frame report significantly higher numbers than people in a corresponding die-by frame.

2.3.2. Environmental Contexts

Significant impacts have also been observed in the presentation of environmental risks. For example, in the context of global climate change, the Intergovernmental Panel on Climate Change has been communicating risks to the public across the globe using verbal descriptions of uncertainty (virtually certain, very likely, likely, about as likely as not, etc.) in the report text with a translation table in the appendix linking words with numerical probability ranges. Budescu et

al.[49] found that experiment participants around the globe interpreted the uncertainty more accurately when they were presented with a dual-scale combining probability phrases and numerical ranges, such as “It is **very likely (greater than 90%)** that hot extremes, heat waves, and heavy precipitation events will continue to become more frequent” than when they were presented with just the verbal information (translated into the local language).

Vaughan[50, p.176-177] discusses risk presentation in African-American communities about hazardous waste disposal sites, pointing out that: "Because some communities will be more likely than others to frame risk management situations in terms of distributive and procedural justice, communicators will need to incorporate into messages and procedures language or terms that are compatible with the predominant framing. It might be useful, for example, when presenting a possible risk management option (e.g., in the case of public hearings for a Superfund clean-up site) to point out instances where similar actions were considered in other communities: This point addresses questions of distributive justice."

Information presentation also has an impact on the decision making of professionals facing environmental risks. Wilson et al.[51] studied 206 USDA Forest Service line officers and incident command personnel, and found that despite having professional training and risk experience, they still fell prey to loss aversion, discounting anomalies, and status quo bias. Hämäläinen[52] calls for more consideration of such biases and other behavioral issues in environmental modeling.

2.3.3. Consumer and Financial Decision Contexts

Benartzi and Thaler[53] studied decision makers' behavior with repeated gambles and its implications in retirement investments. They showed that university staff invested more of their retirement savings in stocks if they were shown long-term return rates. Later, Thaler and Benartzi[41] proposed the Save More Tomorrow project that employed a manipulation to increase savings for retirement. The project greatly reduced the self-control problem associated with the reduction of current spending by moving the commitment into the future rather than in the present time. It also employed the power of a choice default by listing saving as the default option. Eventually, these manipulations were adopted by some organizations and more savings behavior was observed. In a more recent work, Goldstein et al.[54] designed a software interface to aid retirement investment decisions by helping decision makers choose investments to build their desired probability distributions of wealth.

Nowlis and Simonson[55] showed that consumers can reverse preferences under different task frames. When a person makes a choice between brands, so-called comparison attributes (more precise and easy-to-compute attributes such as a consumer product price) tend to be more heavily weighted in comparing two brands. When a person judges a brand separately, so-called enriched attributes, such as the brand name, tend to be more heavily weighted. Such enriched attributes are more meaningful on their own and are difficult to compare.

2.4. Summary

As discussed above, a great deal of evidence supports that the information presentation mode can affect perception and choice. When a person (in the role of a consumer, policy maker, political leader, business executive, medical patient, etc.) makes a choice among alternatives or a judgment about a probability or a value, the way the task is articulated can influence the choice or judgment.

We don't know yet, or at least we don't agree yet, what way of presenting the information is best in different contexts. We don't even know if it is possible to decide on a best one. The next section lays out some questions for future research.

3. PARTLY ANSWERED AND UNANSWERED QUESTIONS FOR FUTURE RESEARCH

In this section we present some partly answered or unanswered research questions that should be addressed further in the upcoming decades.

3.1. What is a Reference Point and How is it Formed?

A key part of the way a decision is represented is the reference point, using the terminology from prospect theory. Any point above the reference point is seen as a gain and below it is seen as a loss.[56,57] Thus, the reference point enables a person to distinguish how good or bad an outcome is. In the coming decades, a process theory of reference point formation needs to be developed.

A first step in theory development may be to determine what a person's natural reference point is for different types of decisions. Tversky and Kahneman[14, p. 456] noted that "a diversity of factors determine the reference outcome in everyday life. The reference outcome is usually a state to which one has adapted; it is sometimes set by social norms and expectations; it sometimes corresponds to a level of aspiration, which may or may not be realistic." Fischhoff[58] presented people with different frames of a civil defense scenario and showed that it was possible to find the most natural reference point. However, he didn't find a strong correlation between the reference points that participants chose and the preferences they showed.

Current evidence identifies the following factors that can potentially serve as reference points: goals,[59] expectations,[60-62] aspirations,[63,64] social comparisons,[65] and counterfactuals and foregone alternatives.[66,67] Many of the above factors share similar qualities in some sense, which leads to a more general question: is there a psychological construct that serves as the direct antecedent of the reference point formation and through which all (or many) of these known factors serve as indirect reference point sources? If so, then we will be able to identify more sources of reference points while keeping the conceptual nature of the reference point integrated. In addition, we will be able to nudge decision makers by priming different reference points that could presumably lead to better decisions and accurate risk perception.

3.2. Do Psychological Distances (i.e., Time, Risk, Spatial Distance, and Social Distance) have Similar Effects on Decision-Making?

Prelec and Loewenstein[68] presented a seminal paper discussing the symmetric role of time and risk in decision-making, and they illustrated that there was almost a one-to-one correspondence between the decision biases involving these two factors. From a broader perspective, in the construal level theory literature[69-71] researchers have identified a similar effect of psychological distances on human decision-making, where psychological distances referred to four dimensions: temporal distance, spatial distance, social distance, and hypotheticality. They argued that anything that is not the direct experience of the here and now is a mental construct, and thus these dimensions may share some similar qualities. Existing work has shown that time and social distance share similar effects,[72,73] just as time (i.e., temporal distance) and risk (i.e., hypotheticality) may share some similar effects on decision making.[68,74] Based on the existing evidence, it is plausible to expect more symmetries among those psychological distances, not just mainly focusing on time and risk as has been done for the last several decades. So the future

challenges might be to work towards a unified theory of the impact of psychological distance on decision making and risk analysis.

3.3. Are Decision Makers Different in Terms of Decision Style and Decision Bias?

Individual differences (such as in people with different ages, socioeconomic groups, ethnicities, or personalities) can lead to differences in the way that risk information is processed,[75,76] including whether the focus is on economic or scientific vs. fairness or justice issues, which at-risk population is highlighted, and whether the focus is on potential gains or potential losses. Vaughan[50, p. 172-174] in *Risk Analysis* points out that the way a risk communication is articulated can be perceived differently by different groups involved in the risk communication (government experts, designated risk communicators, and community members with diverse socioeconomic or ethnic backgrounds), so the relative weight may differ across different groups when comparing economic factors versus health effects or long-term versus immediate consequences.

Fortunately many researchers have already noticed the importance of individual differences in decision-making. Therefore, tools are widely available to measure potential conceptual differences, such as decision competence,[77,78] domain specific risk attitude,[79] regulatory focus,[80] cognitive reflection test,[81] and the Decision Making Individual Differences Inventory.[82] Other than personality traits or decision-making characteristics, many other factors also play important roles in decision-making. Here we list some potential factors of particular significance for risk analysis and some examples of findings:

Ethnicity in general: Vaughan and Nordenstam[83] present three hypotheses for why ethnicity differences could lead to differences in risk perception judgments: “differences in prior experience

with or exposure to various hazards, dissimilar general beliefs about risk and uncertainty, and differences on various qualitative dimensions that influence nonexpert assessments of risk".

Profession and ethnicity: Vaughan[50, p. 177-178, 84] and Vaughan and Dunton[85] discuss a study within a Mexican immigrant farm laborer population facing chronic exposure to agricultural pesticides, in which it appeared that the broader socioeconomic context of exposure may be related to how likely a person will adopt self-protective behaviors in the workplace. Those who were in the lowest socioeconomic situations were the least likely to take self-protective actions, even if provided with risk information.

Age: As our large baby boom population ages, attention to differences in how older adults process information presented to them compared with younger adults will be of increasing importance for risk analysis messages. As decision makers age, their decreased cognitive capacity leads them to rely more on emotional reactions[86,87], search less information[88], and rely more on heuristic processing[89-91]. Additional research in behavioral decision theory is focusing on other differences due to a person's age.[92-94]

We believe the remaining challenge is to take the current and future knowledge about differences between groups, or individual differences within groups, to determine ways to improve decisions and behavior for those involved.

3.4. How Can we Help Biased Decision Makers?

Before addressing the existing work on this topic, we should observe that there are subtleties to consider before jumping to a conclusion that societal decision makers should set up the choice architecture to lead to the choice that is good for the public. For example, in the organ donor case

discussed above in section 2.3 a person (or the family of a deceased person) who may be somewhat coerced to accept an option that would not have been their true preference might indignantly protest or balk at the time the actual donation is to be made.

Putting the arguable objective of "helping" aside, we notice that two paths are generally available to help biased decision makers. First, researchers could help by appropriately designing messages, and the messages could be used to train decision makers to conform to normatively correct behavior.[95-97] Second, researchers could change the environment without the person learning of any bias or person-changing behavior, which means taking the decision bias as given and developing ways to enhance the welfare of the decision makers or the society in general.[58] We won't argue that one path is more useful or valid than the other. We believe that both of them can be beneficial to decision makers or the society, in some specific situations. Consequentially, we think two questions should be addressed.

3.4.1. Is There a Correct Way?

This is more of a philosophical question than a decision-making one. Taking different perspectives, decision makers may hold opposite opinions on the same description of a problem, and criteria for "correctness" are unclear. For example, it is a stylized fact that people do not put much money in equities (stocks). So, one proposed solution is to get people to save more and put it in equities since historically the performance of stocks has been better than the performance of bonds/fixed interest accounts. But if putting people's retirement funds in equities is proposed as the automatic default, some will argue that such a default is too risky. Company executives might worry if they automatically put someone in any specific investment the company would have problems when

the investment did poorly. For a more detailed discussion on choice architecture, refer to Johnson et al.[98]

3.4.2. Can We Debias, Assuming We Can Tell There is a Bias?

Some biases only happen in a between-subjects setting, which means when you present decision makers with two versions of the same scenario and allow comparisons, the decision bias will disappear. For example, in the classic Asian Disease problem setting, if both scenarios are presented to decision makers, after a careful reading, decision makers should be able to give consistent responses as they will easily find out that those two scenarios are essentially the same. There are also biases that can be debiased by psychological manipulation. For example, Wang et al.[97] explored ways to help decision makers avoid the uncertainty effect[99] by providing exogenous anchors or limiting cognitive resources.

Well-chosen problem representations can help overcome biases. Keller[96] studied the effects of three forms of problem representation on decision making under risk and found that visual representations and training were able to help people obey the Sure-Thing and Substitution Principles. However, surprisingly, some biases are so strong that they are hard to avoid even if decision makers know of them ahead of time. More interestingly, some decision biases can even counteract each other. Kahneman and Lovallo[100] demonstrate that overly risk averse "timid" choices can counteract overly confident estimates of the probability of success. They also suggest that decision makers should combine risky options in the loss domain and gains domain together when facing multiple decision problems to cancel out excess risk aversion in the isolated gains domain options and loss aversion in the isolated loss domain options. Montibeller, and Winterfeldt[101] provide a more comprehensive discussion on this topic.

3.5. How Do Different Designs of Messages Lead You to Different Choices?

This is basically asking for the process of decision-making under a specific message design or frame. We think paying more attention to the decision making process will be valuable for risk analysis and we can certainly borrow insights from psychology. Researchers have started to explore along this track.[56,102,103] Process data will be able to help researchers clarify many crucial concepts and thus may lead to brand new areas of research. Taking the anchoring and adjustment heuristic as an example, it turns out that the original experiment settings didn't actually trigger the anchoring and adjustment process and the only situation that will lead to anchoring and adjustment is when decision makers generate the anchor internally.[104] So, more psychological process data is needed.

3.6. Do Sensations Other than Vision Matter, and How?

For the last 30 years or so, most research has focused on only one way for presenting task information (i.e., using their vision, participants read text-based scenarios). However, cognitive psychology tells us that vision, touch, hearing, smell and taste all could deliver information. Human brains may perceive selected sensory information to form decisions, which opens a window for us to investigate the impact of sensory messages on decisions and risk perceptions. This will be especially important for risk analysts, since many risks engage multiple senses. For example, a Spanish speaking agricultural field worker in California may not be able to read pesticide warnings in English, but would be able to detect a noxious smell.[50,84,85] See Krishna[105] for examples of sensory research in consumer contexts. We believe more sensory research in risk communication/perception contexts should be conducted in the near future.

3.7. What Can We Learn from Neuroscience?

When talking about future directions of risk research, it is hard to avoid neural ones. Why? Simply because the brain forms risk perceptions and makes decisions. Research has shown that some of the observed decision biases have neural foundations. For example, Figner et al.[106] studied the neural basis of self-control and intertemporal choices. Tom et al.[107] studied the difference of neural activities between losses and gains, and found that areas such as midbrain dopaminergic regions and their targets had increasing activity in gains scenarios but decreasing activity in loss scenarios. Trepel et al.[108] summarized a broad set of existing literature related to many aspects of prospect theory in human imaging, lesion, neuropharmacology, and animal neurophysiology studies. The neural studies are appealing as they may help reveal the basic functions of our brain and the fundamental elements of decision-making. However, our current knowledge about our brains is still very limited. How far we can go in terms of decision related research is partially (if not totally) based on the available tools and understanding of brain functions. So far, most of the existing research on the neural basis of decisions is answering "how" questions. However, what we would really like to see (at least from decision making and risk analysis perspectives), is how it can help to improve decisions. The future research may fall in two branches. First, we would like to see more advanced studies on decision mechanisms from a neural perspective. Second, we expect to see more research that employs the findings from neural research to improve human decision-making.

4. DISCUSSION AND IMPLICATIONS FOR RISK ANALYSTS

Unlike theoretical research where questions proposed in this essay may not yet have a generalizable answer, for risk analysts in practice, many questions can be answered in a case-specific manner. For example, in a scenario where analysts can precisely describe the context, a

reference point is possibly predictable with some empirical data and it is also possible to know that one response from the message recipients is better than the others.

A number of practical questions should be asked when conducting a risk analysis: *What is the reference point?*, *What is the status quo?*, *What requires action?*, *Who takes the action?*, *What does the message tell decision makers or members of the public?*, *Is there a correct or incorrect message design?*, *Can we debias members of the public (or policy makers), assuming we can tell there is a bias from the provided message?*, and *Are there contrasting perspectives when thinking of general policies vs. specific actions for one person?*.

Consider a simplified Ebola example. The actual report from the World Health Organization reads as follows[109, p. 1]: "A total of 14,413 confirmed, probable, and suspected cases of Ebola virus disease (EVD) have been reported … there have been 5,177 reported deaths." This message can be framed in many different ways, assuming those who have not died are cured. The following messages provide a few examples:

"14,413 people contracted Ebola. 5,177 have died."

"14,413 people contracted Ebola. 9,236 have been cured."

"5,177 people have died of Ebola."

"9,236 people have been cured of Ebola."

"35.9% of Ebola patients have died."

"64.1% of Ebola patients have been cured."

Messages, such as pharmaceutical package inserts, that mention people dying may be framed in a loss domain, and ones that mention people being cured may be framed in a gains domain. Such framings can lead to different risk-taking or risk-avoiding behaviors and could lead to different

types and levels of emotional reactions. Messages that give absolute numbers of people may be understood and processed differently than ones that give percentages.

When authorities are trying to communicate risk messages to their recipients, they have plenty of options regarding the design of messages. Rigorous pretests should be used to elicit potential responses from recipients. A relatively small-scaled representative sample should be able to provide authorities with an indication of how people will respond to their messages. Given a clear objective of the message, an optimized design can be found and utilized to nudge responsive behaviors. Taking the Ebola case as an example, if the public health authorities would like to create some tension, motivating the general public to act on this incident, they should wisely select the framing that could lead to a relatively higher perceived risk; if the authorities would like to calm the general public down from panicking, they could select the framing that potentially leads to a relatively lower perceived risk.

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