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Distortion of Outcome and Probability Information in Risky Decisions

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ABSTRACT—Substantial evidence indicates that information is distorted during decision making. However, no studies have assessed the distortion of outcome and probability information in risky decisions or the effects of ambiguity on information distortion. We report two studies involving six binary decisions (e.g., banning blood donations from people who have visited England, because of "mad cow disease"). In Study 1, participants distorted their evaluations of outcome and probability information in the direction of their preferred decision alternative and used these biased evaluations to update their preferences. Participants also evaluated the utilities of possible outcomes more positively when the outcomes could follow only from the preferred alternative and more negatively when they could follow only from the competing alternative. In Study 2, we manipulated ambiguity by describing outcomes and probabilities using either point estimates or ranges of values. Results replicated those of Study 1, with no effects of ambiguity on information distortion.

KEYWORDS—Information distortion; Bidirectional reasoning; Implied dominance; Ambiguity; Precautionary principle; Decision analysis; Expected utility theory; Consequentialism; Multilevel modeling

A central premise of normative decision making is that choices should be made on the basis of unbiased assessments of relevant information (Baron, 1994; Clemen, 1996; Raiffa, 1968; von Winterfeldt & Edwards, 1986). Depending on the context, such information may consist of product attributes, legal evidence, medical symptoms, or the behavior of others in social or professional settings. In risky decisions, relevant information includes descriptions of possible outcomes and the probabilities of those outcomes.

Although these considerations do inform many decisions, there is substantial evidence that inferences also operate in the opposite direction. Specifically, when one decision alternative is favored over another, information is often evaluated as being more consistent with the preferred option than is warranted. Such *information distortion* or *bidirectional reasoning* has been observed in consumer decisions (Bond, Carlson, Meloy, Russo, & Tanner, 2005; Carlson & Pearo, 2004; Carlson, Meloy, & Russo, in press; Russo, Medvec, & Meloy, 1996, Russo, Meloy, & Medvec, 1998; Russo, Meloy, & Wilks, 2000), professional decisions (Russo et al., 2000), personnel and scholarship decisions (Bond et al., 2005; Simon, Krawczyk, & Holyoak, 2004), legal decisions (Carlson & Russo, 2001; Holyoak & Simon, 1999; Hope, Memon, & McGeorge, 2004; Simon, Pham, Le, & Holyoak, 2001; Simon, Snow, & Read, 2004), medical diagnoses (Walsten, 1981), and military decisions (Adelman, Bresnick, Christian, Gualtieri, & Minionis, 1997). Brownstein (2003) provides a recent review. Such biases are thought to reflect motivated reasoning (Kunda, 1990; Larrick, 1993), particularly the motivations to separate alternatives (Montgomery, 1983; Svenson, 1992, 1996) and to achieve consistency (Simon et al., 2004). They are also consistent with research on the *affect heuristic*, which indicates that people's early affective reactions to hazards and other stimuli influence related judgments and decisions (Alhakami & Slovic, 1994; Finucane, Alhakami, Slovic, & Johnson, 2000; Slovic, Finucane, Peters, & MacGregor, 2002, 2004). For example, the observed negative relationship between judgments of the risks and benefits associated with hazards appears to be mediated by initial affective reactions (Finucane et al., 2000).

The above studies provide convincing evidence for the distortion of attribute information and evidence, but the possible distortion of outcome and probability information in risky decisions has been largely overlooked. Bond et al. (2005) reported one study involving a hypothetical gamble, in which participants' evaluations of the low probability of winning (.025) and the large amount that could be won ($200) depended on order of evaluation, but the gamble did not

involve a possible loss and participants did not make a decision. More recently, DeKay, Patiño-Echeverri, and Fischbeck (2005) reported four studies on the distortion of the desirabilities (utilities) of possible outcomes in risky nonmonetary binary decisions. In several scenarios (e.g., responding to a dam-failure warning), participants often evaluated false positives (*FP*, e.g., evacuating when the dam did not fail) as better than true negatives (*TN*, e.g., not evacuating when the dam did not fail). This utility ordering ($U_{FP} > U_{TN}$) implies that an incorrect decision is better than a correct one in a given state of the world, and hence that the more protective (precautionary) option dominates the less protective option (e.g., that one should evacuate no matter how low the probability of dam failure). Written explanations and patterns among outcome ratings indicated that participants often based their evaluations of possible outcomes on the decisions that might lead to them. Accordingly, the prevalence of implied dominance decreased substantially when the emphasis on decisions was reduced. Despite methodological differences, these results are consistent with those from other research on information distortion. They are clearly at odds with the requirements of decision analysis and more general *consequentialist* theories of decision making (Frisch & Clemen, 1994).

The role of ambiguity in information distortion has also been largely neglected. Many studies have involved complex qualitative stimuli with wide latitude for interpretation, but Bond et al. (2005) reported that distortion also occurs for unambiguous quantitative probability and payoff information. Russo et al. (1998) observed lower distortion for more diagnostic product attributes (i.e., attributes that genuinely favor one alternative), but valence is not the same as the precision with which attributes are measured or described. Ambiguity (i.e., lack of precision) does not appear in Brownstein's (2003) list of 18 possible moderators of information distortion. However, because other research on ambiguity (e.g., Darling & Gross, 1983; Dunning Meyerowitz, & Holzberg, 1988; Hsee, 1995, 1996) suggests that biased processing is more likely when information is ambiguous, it is reasonable to expect that ambiguity might exacerbate information distortion. The *precautionary principle* (Commission of the European Communities, 2000; DeKay et al., 2002; O'Riordan & Cameron, 1994; Raffensperger & Tickner, 1999; Wingspread Conference, 1998) suggests another role for ambiguity. The principle asserts that the lack of scientific certainty (i.e., ambiguity) should not be used as a reason for postponing the protection of human health and the environment. If precautionary

tendencies are stronger when otherwise equivalent information is ambiguous, then the information may be distorted in that direction as well.

Finally, although participants in information-distortion studies typically judge several information items, repeated-measures analyses have usually not been employed. In some studies, observations have been treated as independent even though doing so inflates inferential statistics. In other studies (or in separate analyses in the same studies), judgments have been averaged within participants even though doing so obscures potentially interesting information and even though relationships that are evident in between-participants analyses may not hold for individual participants.

The two studies reported here were designed to address the three issues raised above. In both studies, we used scenarios like those in DeKay et al. (2005) to study information distortion in risky decisions, but we assessed participants' initial and emerging preferences and participants' evaluations of information (outcomes and probabilities) using methods similar to those in other studies cited above. These procedures allowed for a direct assessment of DeKay et al.'s (2005) claim that initial preferences bias the reported utilities of possible outcomes in such situations. In Study 2, we manipulated ambiguity by creating versions of our materials that used either point estimates or ranges for most of the information items. Finally, we used *multilevel modeling* to account for the nesting of observations within participants (Kreft & de Leeuw, 1998; Luke, 2004; Snijders & Bosker, 1999). More detail on this approach is provided in the results section of Study 1.

STUDY 1

Method

Participants

One hundred two people (40 undergraduates and 20 graduate students from Carnegie Mellon University and 42 nonstudents from a Pittsburgh community organization) participated for $30 cash or an equivalent donation to their organization. One nonstudent was dropped for failing to complete the study. The remaining participants were 18 to 61 years old (M = 27.4); 50.5% were female.

Procedures

After considering a practice scenario about the decision to carry an umbrella, participants in this computer-based study considered six other scenarios involving risky decisions, presented in the following order: (A) responding to a dam-failure warning; (B) banning the use of cellular phones by automobile drivers; (C) evacuating an airport because a screening machine had failed a reliability check; (D) avoiding milk from hormone-treated cows; (E) banning blood donations from people who have visited England, because of the risk of "mad cow disease"; and (F) banning genetically modified potatoes. For example, Scenario D was described as follows:

> Companies have developed hormones that increase the milk production of dairy cows. These increases result in lower milk prices for consumers. Some consumer and environmental groups claim that drinking milk from hormone-treated cows may cause cancer in humans, but the evidence is inconclusive. Imagine that the U.S. Food and Drug Administration requires that all milk from hormone-treated cows be labeled "This product comes from cows treated with hormones." Also imagine that you are the person who does the grocery shopping for your family.

After reading this description, participants indicated the strength of their initial preference for a course of action on a continuous scale with endpoints labeled *I strongly prefer buying it* and *I strongly prefer* ***not*** *buying it* (for Scenario D). The precautionary option appeared on the right, and the variable was scored –50 to 50.

Participants then selected and viewed five information items by clicking on a button for each question. All participants viewed the same information, but could view it in any order. For Scenario D, the questions and answers were as follows:

> What is the chance that milk from hormone-treated cows causes cancer? [Probability]
>
> The chance that milk from hormone-treated cows causes cancer is 1%.
>
> What happens if milk from hormone-treated cows causes cancer and I have bought this milk? [False negative]
>
> If milk from hormone-treated cows causes cancer and you have bought this milk, then for each member of your family, the chance that they would get cancer at some point in their life increases by 1 in 100,000.

What happens if milk from hormone-treated cows causes cancer and I have **not** bought this milk? [True positive]

If …, then you incur the cost of buying the more expensive milk that is not from hormone-treated cows. The risk of cancer does not increase for members of your family.

What happens if milk from hormone-treated cows does **not** cause cancer and I have bought this milk? [True negative]

If …, then the risk of cancer does not increase for members of your family.

What happens if milk from hormone-treated cows does **not** cause cancer and I have **not** bought this milk? [False positive]

If …, then you incur the cost of buying the more expensive milk that is not from hormone-treated cows. The risk of cancer does not increase for members of your family.

The information labels shown above (e.g., probability, false negative) were not shown to participants. Note the a positive decision is defined as taking the precautionary action, which in this case is not buying milk from hormone-treated cows. The probability information item refers to the probability of the *event of concern* (e.g., the probability that milk from hormone-treated cows causes cancer), but some outcomes of the decision may also include probabilities (e.g., the probability of actually getting cancer if the milk causes cancer).

After viewing each item, participants evaluated the extent to which that item favored either course of action on a continuous scale from *Strongly favors buying it* to *Strongly favors **not** buying it* (for Scenario D). The information was then moved up on the screen to join the scenario description and any previously viewed information, and participants updated their strength of preference for a course of action.

After viewing and evaluating the five information items, participants evaluated the desirability of the four possible decision outcomes (A = false negative, B = true positive, C = true negative, and D = false positive) by dragging the letters onto a continuous scale from *Worst possible outcome* to *Best possible outcome* (coded 0 to 100). Participants then chose their preferred course of action (a binary decision) and whether this choice would be different if the probability of the undesirable event (e.g., milk from hormone-treated cows causes cancer) were low enough or high enough. If participants responded that their choice was dependent on the

probability of the event (i.e., that their preferred course of action was not dominant), participants were asked for a threshold probability above which they would take the precautionary action. Participants answered all questions for one scenario before moving to the next.

Results and Discussion

Distortion of Probability and Outcome Information

Participants each made 30 judgments of the extent to which information favored the precautionary option (6 scenarios × 5 information items). We modeled these judgments as a function of participants' preferences for the precautionary alternative while controlling for scenario, information item, and viewing order. Because information distortion should depend on participants' current preferences (rather than their initial preferences), we used the preference judgments that were made immediately prior to viewing the information item in question. For example, when modeling whether evaluations of the third information item viewed were affected by participants' preferences, we used the preference judgments collected after the second information item had been evaluated (for the first information item viewed, participants' immediately prior preferences were the same as their initial preferences).

Because judgments of the extent to which information favored the precautionary option were not independent within participants (intraclass correlation = 0.084), we used multilevel modeling for these data (Kreft & de Leeuw, 1998; Luke, 2004; Snijders & Bosker, 1999). Multilevel models are appropriate for hierarchical data in which observations are nested within higher-level groups or contexts, as when students are nested within classrooms or schools, or when employees are nested within firms. In our study, repeated judgments were nested within participants. The particular model that we used allowed us to assess information distortion at the lower level (within participants) and the higher level (between participants) simultaneously. Specifically, we fit the following model:

$$\begin{aligned} &Information\,Favors\,Precaution_{ijk} = \gamma_0 + \gamma_1 Prefers\,Precaution\,Before(Mean)_i \\ &\quad + \gamma_2 Prefers\,Precaution\,Before(Deviation)_{ijk} + \gamma_3 Order_{ijk} + \sum_{l=1}^{4} \gamma_{4l} Information\,Item_{jl} \\ &\quad + \sum_{m=1}^{5} \gamma_{5m} Scenario_{km} + \sum_{l=1}^{4}\sum_{m=1}^{5} \gamma_{6lm} Scenario_{km} \times Information\,Item_{jl} + u_{0i} \\ &\quad + u_{2i} Prefers\,Precaution\,Before(Deviation)_{ijk} + r_{ijk}, \end{aligned} \tag{1}$$

where *i*, *j*, and *k* indicate the participant, the information item, and the scenario, respectively, and *l* and *m* indicate specific comparisons among information types and scenarios, respectively. *Prefers Precaution Before (Mean)* is the average of each participant's 30 preference judgments, collected immediately prior to the information evaluations. *Prefers Precaution Before (Deviation)* is the deviation of a preference judgment from the participant's mean. *Order* is the order in which a particular information item was viewed by a participant within each scenario (range = 1 to 5). *Information Item* and *Scenario* are sets of orthogonal contrast codes for categorical variables, multiplied to create the *Scenario* × *Information Item* interaction terms. In multilevel terms, *Prefers Precaution Before (Mean)* is a *level-2* predictor because it varied only between participants, whereas *Prefers Precaution Before (Deviation)*, *Order*, and the codes for *Information Type*, *Scenario*, and *Scenario* × *Information Item* are *level-1* predictors because they varied within participants.[1] u_{0i} is the error or unmodeled variability in the intercept for participant *i* (i.e., $\beta_{0i} = \gamma_0 + u_{0i}$); u_{2i} is the error or unmodeled variability in the slope for participant *i* (i.e., $\beta_{2i} = \gamma_2 + u_{2i}$); and r_{ijk} is the traditional error term. The γs and *u*s are considered fixed and random effects, respectively, with the extent of random variation in the intercept and slope described by the variances $\sigma^2_{u_0}$ and $\sigma^2_{u_2}$.

Results appear in Table 1. The coefficient for *Prefers Precaution Before (Mean)* indicates that participants who preferred the precautionary option were more likely to report that new information favored that option, $\widehat{\gamma_1} = 0.550$, $t(99) = 7.47$, $p < .0001$. The coefficient for *Prefers Precaution Before (Deviation)* indicates that this relationship also held within participants, $\widehat{\gamma_2} = 0.249$, $t(2896) = 10.19$, $p < .0001$. Because the variance associated with *Prefers Precaution Before (Deviation)*, $\widehat{\sigma^2_{u_2}} = 0.029$, was relatively small compared to $\widehat{\gamma_2}$, almost all participants had positive slopes. These results are evident in the model predictions for individual participants, as depicted in the left panel of Fig. 1. Overall, the model accounted for 45.7% of the level-1 variation and 60.0% of the level-2 variation in the dependent measure (estimated without the random slopes, u_{2i}, as suggested by Snijders & Bosker, p. 105).

[1] For simplicity, we have indexed the main sets of coefficients from γ_0 to γ_6 rather than using two separate indices for the level-1 (within-participant) and level-2 (between-participant) effects (e.g., we have γ_0, γ_1, and γ_2 rather than γ_{00}, γ_{01}, and γ_{10}).

Insert Table 1 and Fig. 1.

Although not evident in the 4-*df* test of *Information Item* in Table 1, mean judgments of the five information items were sensible. False negatives and true positives (outcomes in which the event of concern occurred) were generally rated as favoring the precautionary option ($M = 21.5$ and 7.7, respectively), whereas true negatives and false positives (outcomes in which the event did not occur) were rated as favoring the nonprecautionary option ($M = -13.3$ and -15.5, respectively). Ratings of probability information did not strongly favor either option ($M = 3.8$), although all five of these means were significantly different from zero at $p < .01$. Judgments of the extent to which information favored the precautionary option also varied with the *Scenario* and *Scenario* × *Information Item* contrasts (see Table 1). Such variation is to be expected and is of no great concern.

We expected participants' information judgments to be more strongly related to the preferences that participants held immediately before viewing the information than to the preferences that they held when they initially read the scenario. When initial preferences were used in place of immediately prior preferences, the coefficients for *Prefers Precaution Initial (Mean)* and *Prefers Precaution Initial (Deviation)* were significant, $\hat{\gamma} = 0.388$, $t(99) = 5.59$, $p < .0001$, and $\hat{\gamma} = 0.185$, $t(2888) = 5.59$, $p < .0001$, respectively, but smaller than those in the original model. When both sets of predictors were included in a single model for the last four information items viewed (the deviation predictors were redundant for the first item), immediately prior preferences were clearly better predictors than were initial preferences, $\widehat{\gamma_1} = 0.636$, $t(98) = 4.82$, $p < .0001$ for *Prefers Precaution Before (Mean)* and $\widehat{\gamma_2} = 0.227$, $t(2283) = 8.05$, $p < .0001$ for *Prefers Precaution Before (Deviation)*, compared to $\hat{\gamma} = -0.118$, $t(98) = -1.16$, $p = .2493$ for *Prefers Precaution Initial (Mean)* and $\hat{\gamma} = 0.063$, $t(2283) = 2.46$, $p = .0138$ for *Prefers Precaution Initial (Deviation)*.

The model in Table 1 did not assess whether the effects of preferences for precaution differed across information items and scenarios, as that would have required up to 58 additional interaction terms involving the two *Prefers Precaution Before* variables in combination with the *Information Type*, *Scenario*, and *Scenario* × *Information Item* contrasts. To assess such variation

in a more transparent manner, we regressed *Information Favors Precaution* onto *Prefers Precaution Before* and *Order*, separately for each combination of scenario and information item. The resulting coefficients for *Prefers Precaution Before*, which reflect only between-participant variation, appear in Table 2. Although there is substantial variation across analyses, all 30 coefficients were positive, and 29 were significant at the $p < .05$ level (the 30th approached significance).

Insert Table 2.

Holyoak and Simon (1999) and Simon et al. (2001) reported that the consistency among ratings of agreement with legal arguments was much greater after participants had considered all of the materials in a complex case than before they had considered those materials. For example, in Simon et al.'s (2001) studies, Cronbach's α increased from near zero at pretest to about .75 after all information had been considered and to .80 after a decision had been made (verdict was included as an item in the latter two assessments). Although there was no pretest in our study (it is hard to imagine a truly decision-free test involving the *Information Favors Precaution* variables), α values for consistency among the ratings of the five information items ranged from .62 to .74, depending on the scenario.

In summary, participants' evolving strength of preference among decision alternatives biased their evaluations of outcome and probability information in the direction of the preferred alternative. This relationship persisted when initial preferences were controlled, it was observed for all five information items and in all six scenarios, and it resulted in consistent ratings of the information items within scenarios.

Effects of Information Evaluations on Subsequent Preferences

The analyses in the previous section demonstrate that information was evaluated in a biased manner, but they do not indicate whether the biased evaluations affected subsequent preferences for decision alternatives. In this section, we assess whether participants' preferences after viewing and evaluating information were affected by their evaluations of that information, controlling for their earlier preferences. Although such an effect would not constitute an additional bias, it would allow the biases reported in the previous section to be carried forward in

the decision-making process. We fit the following multilevel model to assess the effect of information evaluations on subsequent preferences:

$$\begin{aligned}
&Prefers\,Precaution\,After_{ijk} = \gamma_0 + \gamma_1 Prefers\,Precaution\,Before\,(Mean)_i \\
&\quad + \gamma_2 Prefers\,Precaution\,Before\,(Deviation)_{ijk} + \gamma_3 Information\,Favors\,Precaution\,(Mean)_i \\
&\quad + \gamma_4 Information\,Favors\,Precaution\,(Deviation)_{ijk} + \gamma_5 Order_{ijk} + \sum_{l=1}^{4} \gamma_{6l} Information\,Item_{jl} \\
&\quad + \sum_{m=1}^{5} \gamma_{7m} Scenario_{km} + \sum_{l=1}^{4}\sum_{m=1}^{5} \gamma_{8lm} Scenario_{km} \times Information\,Item_{jl} + u_{0i} \\
&\quad + u_{2i} Prefers\,Precaution\,Before\,(Deviation)_{ijk} \\
&\quad + u_{4i} Information\,Favors\,Precaution\,(Deviation)_{ijk} + r_{ijk}.
\end{aligned} \tag{2}$$

Thus, participants' preferences immediately after evaluating an information item were predicted on the basis of the extent to which that item was judged to favor the precautionary option, controlling for participants' prior preferences. The intercept was allowed to vary randomly across participants ($\beta_{0i} = \gamma_0 + u_{0i}$), as were the coefficients for *Prefers Precaution Before (Deviation)* ($\beta_{2i} = \gamma_2 + u_{2i}$) and *Information Favors Precaution (Deviation)* ($\beta_{4i} = \gamma_4 + u_{4i}$).

Results are shown in Table 3. Not surprisingly, preferences after viewing an item were strongly related to preferences before viewing the item. In addition, the coefficients for *Information Favors Precaution (Mean)*, $\widehat{\gamma_3} = 0.069$, $t(98) = 1.84$, $p = .0686$, and *Information Favors Precaution (Deviation)*, $\widehat{\gamma_4} = 0.307$, $t(2895) = 14.75$, $p < .0001$, were both positive, although the within-participant effect was much stronger than the between-participant effect. The variance associated with *Information Favors Precaution (Deviation)*, $\widehat{\sigma^2_{u_4}} = 0.018$, was significant, but relatively small compared to the mean slope, $\widehat{\gamma_4}$.

Insert Table 3.

As expected, participants' evaluations of information—previously shown to be biased in the direction of the preferred decision alternative—affected participants' subsequent preferences for decision alternatives in the same direction. As noted earlier, this result does not provide additional evidence of biased processing because new information generally *should* be used to

update preferences. Even so, repeated updating on the basis of biased information evaluations can create positive feedback loops that serve to maintain or strengthen participants' initial preferences.

Effects of Initial Preferences on the Desirability of Outcomes

In addition to affecting judgments of the extent to which information favors one decision alternative over the other, initial preferences may also affect judgments of the desirability of the decision outcomes themselves (DeKay et al., 2005). Shortly, we will present a single multilevel model for all four possible outcomes of binary decisions (true positives, false positives, true negatives, and false negatives). However, the results of the full model are easier to interpret if we first present a set of four separate models, one for each possible outcome. The dependent measures in these separate models were participants' desirability (utility) ratings of the outcomes. We collected these ratings at the end of the study rather than immediately after each information item was evaluated because we wanted participants to compare the four possible outcomes to each other directly. The predictors in these separate models were participants' initial preferences for precaution and the usual contrasts for scenarios. Initial rather than updated preferences were used for consistency across the four models. Also, as noted above, updated preferences collected after the evaluation of information about the possible outcomes ought to reflect the desirability of those outcomes. For this reason, a fair test of the biasing effects of preferences on the desirability of outcomes must utilize preference judgments collected before the presentation of outcome information.

Partial results appear in Table 4. On average, false negatives were rated lowest (M = intercept = 8.2) and true negatives were rated highest (M = 87.6). This ordering makes sense. The ordering of true positives (M = 60.3) and false positives (M = 43.5) was surprising, however. Given that the precautionary action is taken (i.e., the decision is "positive"), participants preferred to be correct. Although this reasoning seems sensible at first blush, but being correct in such situations implies that the event of concern actually occurs. For example, given that milk from hormone-treated cows had been avoided, participants preferred that the milk cause cancer. Given that blood donations from people who had visited England had been banned, participants preferred that mad cow disease be transmissible via blood transfusions. This pattern held for five of the six scenarios. In the remaining scenario (dam failure), true positives (M = 47.6) were rated

as slightly worse than false positives (M = 49.3), but the results still implied that value of being correct was nearly enough offset the fact that one's home was "severely damaged" by the flood. Ignoring cases of dominance for the moment (see below), the appeal of a true positive relative to a false positive is consistent with regret theory (Bell, 1982; Loomes & Sugden, 1982) and decision affect theory (Mellers, 2000; Mellers, Schwartz, & Ritov, 1999) if the combination of the regret associated with a false positive relative to a true negative, $f(U_{FP} - U_{TN})$ (which is negative), and the rejoicing associated with a true positive relative to a false negative, $f(U_{TP} - U_{FN})$ (which is positive), is sufficient to balance or overcome the affect-free difference between a false positive and a true positive. But even if one acknowledges a role for such emotions in risky decisions, that's a lot of weight to place on counterfactuals.

Insert Table 4.

Of the eight tests for the effects of initial preferences on outcome utilities (two for each of the four possible outcomes in Table 4), four were significant at the $p < .05$ level and one approached significance. Although the signs of the coefficients were positive in four tests and negative in four others, these results actually tell a very consistent story. True positives and false positives can follow only from the precautionary option, whereas true negatives and false negatives can follow only from the nonprecautionary option. If possible outcomes are evaluated as more desirable if they could result only from one's preferred decision and as less desirable if they could result only from the opposite decision, then evaluations of true positives and false positives are expected to be positively related to initial preferences for precaution, whereas evaluations of true negatives and false negatives are expected to be negatively related to initial preferences for precaution (DeKay et al., 2005). This is exactly the pattern of results observed.

To assess this interaction between initial preferences and possible outcomes directly, we conducted a single multilevel model (not shown) in which the desirability of outcomes was predicted on the basis of *Prefers Precaution Initial (Mean)*, *Prefers Precaution Initial (Deviation)*, the usual codes for *Scenario*, and nine additional predictors. One new contrast code for possible outcomes compared true positives and false positives with true negatives and false negatives (*TPFP versus TNFN*), a second compared true positives to false positives (*TP versus FP*), and a third compared true negatives to false negatives (*TN versus FN*). Each of these contrasts was interacted with *Prefers Precaution Initial (Mean)* and *Prefers Precaution Initial*

(Deviation). All three of the contrasts for differences between mean ratings of the four outcomes were significant at the $p < .01$ level. More important, the two interactions involving *TPFP versus TNFN* were both positive and significant, $\hat{\gamma} = 0.355$, $t(2300) = 4.32$, $p < .0001$ for *TPFP versus TNFN* × *Prefers Precaution Initial (Mean)* and $\hat{\gamma} = 0.237$, $t(2300) = 5.50$, $p < .0001$ for *TPFP versus TNFN* × *Prefers Precaution Initial (Deviation)*, indicating that the relationship between initial preferences and outcome desirability depended on whether the outcome could follow from the preferred decision. The only other significant interaction, *TP versus FP* × *Prefers Precaution Initial (Deviation)*, indicated that the effect of initial preferences was more negative for true positives than for false positives, $\hat{\gamma} = -0.279$, $t(2300) = -4.94$, $p < .0001$.

The analyses in this section indicate that participants' initial preferences among decision alternatives—preferences expressed before the participants read specific information about the possible outcomes of those alternatives—were predictive of participants' subsequent evaluations of the possible outcomes. Outcomes that could result only from the initially favored decision alternative were viewed as more desirable, whereas those that could result only from the initially disfavored alternative were viewed as less desirable.

Effects of Initial Preferences on Implied Dominance

DeKay et al. (2005) reported that biases in the evaluation of outcomes can sometimes be large enough to imply that one decision alternative dominates the other. In particular, initial preferences for the precautionary option can lead participants to evaluate false positives as being better than true negatives, thereby implying that the precautionary option should be chosen regardless of the probability of the event of concern. Similarly, preferences for the nonprecautionary option might lead participants to evaluate false negatives as being better than true positives, implying that the nonprecautionary option should be chosen regardless of the probability of the event of concern ("event of concern" is perhaps a misnomer in this instance).

Whether one alternative dominates the other depends on the pattern of evaluations of the four possible outcomes. Of the 606 response patterns in this study (101 participants × 6 scenarios), 40 implied that the nonprecautionary option was weakly dominant ($U_{TN} \geq U_{FP}$ and $U_{FN} \geq U_{TP}$, with at least one inequality); 489 implied that neither option was dominant ($U_{TN} > U_{FP}$ and $U_{TP} >$

U_{FN}); 73 implied that the precautionary option was weakly dominant ($U_{FP} \geq U_{TN}$ and $U_{TP} \geq U_{FN}$, with at least one inequality); and 4 were of some other type.

We assessed the effects of initial preferences on implied dominance using a separate ordinal logistic regression model for each scenario, with the first three response patterns above in order of increasing preference for precaution. Results appear in Table 5. The coefficient for *Prefers Precaution Initial* was positive in all six scenarios and was significant at the $p < .05$ level in five scenarios, indicating that higher initial preferences for precaution were associated with higher probabilities that the precautionary option was weakly dominant and lower probabilities that the nonprecautionary option was weakly dominant. Although the corresponding odds ratios seem small (1.021 to 1.037), these are for 1-point increases on the –50 to 50 preference scale. For an odds ratio of 1.03, a 25-point increase in initial preference for precaution (less than one *SD*) yields an odds ratio of $1.03^{25} = 2.09$—an increase of 109% in the odds that a response pattern would be in the more precautionary dominance category (e.g., the highest category rather than one of the lower two). These results reflect only between-participant differences. Repeated-measures binary logistic regressions (Allison, 1999) yielded similar results for within-participant effects.

Response patterns implying that one decision alternative dominated the other were not accidental, at least when the precautionary option was dominant. When asked directly to indicate whether their preferred alternative might be different if the probability of the event of concern were higher or lower, participants said no in 179 out of 606 cases. According to this explicit measure, the nonprecautionary option was dominant in 19 cases, neither option was dominant in 427 cases, and the precautionary option was dominant in 160 cases. Logistic regression analyses like those for implied dominance yielded similar but much stronger effects of initial preferences when these explicit dominance categories were used.

Insert Table 5.

Summary

Participants in this study distorted their evaluations of outcome and probability information to favor the currently preferred alternative and then used these biased evaluations to update their preferences accordingly. In addition, they evaluated the utilities of possible outcomes more positively when the outcomes could follow only from the preferred decision alternative and more

negatively when the outcomes could follow only from the competing alternative. Frequently, such evaluations implied that one alternative dominated the other. All of these results are consistent with expectations based on previous research. In our second study, we assessed whether these findings depended on the ambiguity of the information provided.

STUDY 2

Method

Participants

One hundred two people from 10 Pittsburgh-area community organizations participated for $30 cash or an equivalent donation to their organization. Five participants were dropped for failing to complete the study. Those remaining were 29 to 87 years old (M = 45.9); 57.3% were female and 96.9% were nonstudents.

Procedures

Except for the random assignment of participants to the ambiguity and no-ambiguity conditions in this study, procedures were identical to those in Study 1. In the no-ambiguity condition, information about probabilities, true positives, false positives, and false negatives was presented as precise numerical point estimates when possible. For example, "the chance that they would get cancer at some point in their life increases by 4 in a million." In the ambiguity condition, point estimates were replaced by ranges. For example, "the chance … increases by between 2 in a million and 6 in a million." In other cases, 3% was replaced by 1% to 5%, 80% by 70% to 90%, 500 deaths by 200 to 800 deaths, 600 million dollars per year by 300 to 900 million dollars per year, and so on. Different adjustment factors were used to avoid repetition of numbers across scenarios. Information about true negatives was identical in the two conditions. In Scenario F, we changed potatoes to peaches to allow for greater price differences.

Results and Discussion

Distortion of Probability and Outcome Information

To the multilevel model in Eq. (1), we added a contrast-coded *Ambiguity* variable (ambiguity = 0.5, no ambiguity = –0.5) and the interactions of this variable with *Prefers Precaution Before (Mean)* and *Prefers Precaution Before (Deviation)*. The results in Table 1 and Fig. 1 indicate

that participants' evaluations of information as favoring one option or the other were positively related to their immediately prior preferences. These relationships were somewhat stronger than in Study 1, $\widehat{\gamma_1} = 0.736$, $t(93) = 13.27$, $p < .0001$ for *Prefers Precaution Before (Mean)* and $\widehat{\gamma_2} = 0.334$, $t(2781) = 12.42$, $p < .0001$ for *Prefers Precaution Before (Deviation)*. As before, they were stronger than analogous relationships involving initial preferences, and they remained large and significant when initial preferences were added to the model. The between-participants relationship was positive in all 30 combinations of information item and scenario, and significant at the $p < .05$ level in 29 combinations (it approached significance in the 30th combination; see Table 2). The effects of ambiguity and its interactions did not approach significance (see Table 1). Cronbach's α for consistency among the five *Information Favors Precaution* ratings ranged from .71 to .78, depending on the scenario.

Effects of Information Evaluations on Subsequent Preferences

We added *Ambiguity* and its interactions with *Information Favors Precaution (Mean)* and *Information Favors Precaution (Deviation)* to the model in Eq. 2. The coefficients for *Information Favors Precaution (Mean)*, $\widehat{\gamma_3} = 0.085$, $t(91) = 1.44$, $p = .1537$, and *Information Favors Precaution (Deviation)*, $\widehat{\gamma_4} = 0.386$, $t(2779) = 17.54$, $p < .0001$, were both positive, although the former did not approach significance (see Table 3). Effects involving ambiguity did not approach significance.

Effects of Initial Preferences on the Desirability of Outcomes

We added *Ambiguity* and its interactions with *Prefers Precaution Initial (Mean)* and *Prefers Precaution Initial (Deviation)* to the four multilevel models for predicting the desirability of possible outcomes. Six of the eight coefficients for initial preferences were significant at the $p < .05$ level (see Table 4). As before, the four coefficients for true positives and false positives were positive and the four coefficients for true negatives and false negatives were negative. False negatives were viewed as worse when information was ambiguous than when it was not, $\hat{\gamma} = -5.852$, $t(93) = -3.07$, $p = .0028$, but the effects of initial preferences were not moderated by ambiguity.

As in Study 1, we also used a single multilevel model to assess the interactions between initial preferences and possible outcomes in predicting the desirability of the outcomes. The two

interactions involving *TPFP versus TNFN* were again positive and significant, $\hat{\gamma} = 0.333$, $t(2215) = 3.47$, $p = .0005$ for *TPFP versus TNFN* × *Prefers Precaution Initial (Mean)* and $\hat{\gamma} = 0.262$, $t(2215) = 5.38$, $p < .0001$ for *TPFP versus TNFN* × *Prefers Precaution Initial (Deviation)*, indicating that the relationship between initial preferences and outcome desirability depended on whether the outcome could follow from the preferred decision. In one difference from Study 1, the *TN versus FN* × *Prefers Precaution Initial (Deviation)* interaction indicated that the effect of initial preferences was more negative for true negatives than for false negatives, $\hat{\gamma} = -0.096$, $t(2215) = -2.55$, $p = .0108$ (an interaction involving *TP versus FP* was significant in Study 1).

Effects of Initial Preferences on Implied Dominance

Participants' evaluations of the four possible outcomes again implied a dominant decision alternative in many instances. Of the 582 response patterns in this study (97 participants × 6 scenarios), 41 implied that the nonprecautionary option was weakly dominant, 407 implied that neither option was dominant, 106 implied that the precautionary option was weakly dominant, and 28 were of some other type (in 26 of these, $U_{TN} = U_{FP}$ and $U_{TP} = U_{FN}$).

We added *Ambiguity* and *Ambiguity* × *Prefers Precaution Initial* as predictors in the ordinal logistic regression models for predicting implied dominance in the six scenarios. The coefficient for *Prefers Precaution Initial* was positive in all six scenarios and was significant at the $p < .05$ level in four scenarios (it approached significance in one additional scenario; see Table 5). The effect of ambiguity was significant in only one scenario, and in no scenario did ambiguity moderate the effect of initial preferences. As before, repeated-measures binary logistic regressions yielded similar results for within-participant effects.

When asked directly about their preferred alternative, participants indicated that the nonprecautionary option was dominant in 18 cases, that neither option was dominant in 326 cases, and that the precautionary option was dominant in 237 cases. As before, logistic regression analyses like those for implied dominance yielded similar but much stronger effects of initial preferences when these explicit dominance categories were used.

Summary

The results of this study were remarkably similar to those of Study 1, despite differences between the samples of respondents. Contrary to expectations, there were no important effects

of the ambiguity manipulation. In particular, there were no significant effects of ambiguity on the extent of information distortion.

GENERAL DISCUSSION

The results of both studies demonstrate that outcome and probability information is inappropriately evaluated as favoring the preferred alternative in risky decisions and that these biased evaluations are subsequently used to update preferences. These findings extend previous research on information distortion and bidirectional reasoning to this important class of decisions. In addition, results indicate that judgments of the utilities of possible outcomes depend on the relationships between those outcomes and the decision alternatives. Outcomes that could follow only from the preferred decision alternative are evaluated more positively, whereas outcomes that could follow only from the competing alternative are evaluated more negatively. In extreme cases, such evaluations imply that one alternative dominates the other. These findings confirm DeKay et al.'s (2005) conclusions regarding the role of initial preferences for decision alternatives in the estimation of outcome utilities.

In some circumstances, bidirectional reasoning may be useful or adaptive. If one's premises (e.g., evaluations of possible outcomes in a decision analysis) imply a decision that seems counterintuitive or unwise, it is surely advisable to check the premises and revise them if they are invalid. But reflective equilibrium that results from conscious deliberation is not the same as consistency for consistency's sake. When the drive for consistency leads people to ignore tangible consequences, such as the costs associated with false positives, it does not appear so adaptive. If decisions are important (as the ones in these studies were intended to be), it is probably better to acknowledge and address the difficult tradeoffs rather than sweep them under the rug. Indeed, backwards inferences of the type reported here are antithetical to normative theories of decision making (e.g., expected utility theory) that are based on consequentialist principles. As a practical matter, such circular reasoning may undermine the usefulness of decision analysis as a method for making difficult decisions involving risk.

These results also pose a serious challenge to descriptive theories of the role of emotions in risky decision making. For example, DeKay et al. (2005) noted that regret theory (Bell, 1982; Loomes & Sugden, 1982), disappointment theory (Bell, 1985; Loomes & Sugden 1986), and decision-affect theory (Mellers, 2000; Mellers, Schwartz, Ho, & Ritov, 1997; Mellers et al.,

1999) cannot account for implied dominance. None of these theories includes a mechanism for reducing or reversing the difference between the desirabilities of two outcomes that result from different actions (e.g., evacuating or not) when a given state of the world occurs (e.g., when the dam does not fail). Indeed, the theorized effects of anticipated emotion work in the opposite direction, to increase $U_{TN} - U_{FP}$ and $U_{TP} - U_{FN}$. If such effects were present in our studies (which is certainly possible), the opposing effects of information distortion would have had to clear an even higher hurdle in order to create implied dominance. It remains possible that anticipated regret and disappointment play a role in the formation of initial preferences (e.g., by widening $U_{TP} - U_{FN}$ more than $U_{TN} - U_{FP}$, which would favor the precautionary option), after which information distortion comes into play. The reconciliation of theories of anticipated emotion with theories of information distortion and bidirectional reasoning should be a high priority for future research on risky choice.

Because our results are so consistent within and across studies, one might wonder whether they are due solely to uninteresting between-participants differences involving scale usage. For example, if some participants gave higher or lower ratings across the board, these response patterns might create positive relationships between preferences for alternatives and evaluations of information. However, this explanation cannot account for the within-participant differences evident in Tables 1 and 3 and in Fig. 1. Nor can it account for the between-participants result that immediately prior preferences were better predictors of information evaluations than were initial preferences, or for the between-participants result that relationships between initial preferences and outcome utilities were negative for true negatives and false negatives. Moreover, the average participant used 83% of the response scale for preference judgments and 90% of the response scale for judgments that information favors one of the two alternatives, making it difficult to argue that our findings reflect participants' use of consistently high or low ratings.

We were somewhat surprised by the absence of ambiguity effects on information evaluations in Study 2. The main effect of ambiguity on judgments that information favored the precautionary option was less than one hundredth of the range of the response scale, and the larger of the two nonsignificant interactions with preferences for precaution had a negative sign, contrary to expectations. One explanation for these results is simply that our manipulation was not strong enough. Ranges of 20 percentage points (e.g., 40% to 60%) and up to 7-fold

differences in risk (e.g., 1 in a million to 7 in a million) seemed large enough, but perhaps they were not. Although these data corroborate Bond et al.'s (2005) finding that unambiguous numerical probabilities and outcomes can be distorted, additional studies with wider ranges for ambiguous information may be warranted before ambiguity is dismissed as a potential moderator of information distortion.

Finally, our analyses illustrate the usefulness of teasing apart between-participants and within-participants effects in studies of information distortion. Our multilevel approach is not the only solution for repeated-measures data, but it does provide an appropriate framework for treating the individual judgment as the primary unit of analysis without assuming that multiple judgments from the same participant are independent. Researchers interested in tightly focused analyses of information distortion over the course of the decision process are likely to find repeated-measures approaches very valuable.

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TABLE 1
Multilevel Model Results for Predicting Judgments that Information Favors Precaution

	Study 1		Study 2	
	Parameter estimate	Significance test	Parameter estimate	Significance test
Fixed effects				
Intercept	0.814	$t(99) = 1.28$	5.981	$t(93) = 10.09$****
Prefers Precaution Before (Mean)	0.550	$t(99) = 7.47$****	0.736	$t(93) = 13.27$****
Prefers Precaution Before (Deviation)	0.249	$t(2896) = 10.19$****	0.334	$t(2781) = 12.42$****
Ambiguity			0.772	$t(93) = 0.65$
Ambiguity × Prefers Precaution Before (Mean)			–0.162	$t(93) = -1.47$
Ambiguity × Prefers Precaution Before (Deviation)			0.050	$t(2781) = 0.94$
Order	1.897	$t(2896) = 3.16$**	0.248	$t(2781) = 0.42$
Information Item		$\chi^2(4) = 811.3$****		$\chi^2(4) = 546.2$****
Scenario		$\chi^2(5) = 75.8$****		$\chi^2(5) = 23.0$***
Scenario × Information Item		$\chi^2(20) = 642.6$****		$\chi^2(20) = 642.6$****
Random effects (variance components)				
Intercept	26.127	$\chi^2(1) = 73.9$****	16.416	$\chi^2(1) = 25.1$****
Prefers Precaution Before (Deviation)	0.029	$\chi^2(1) = 63.8$****	0.041	$\chi^2(1) = 79.0$****
Residual	433.62		527.79	
R^2				
Level 1	.457		.422	
Level 2	.600		.838	

Note. Unstandardized coefficients and statistical tests are from maximum likelihood multilevel models fit using PROC MIXED in SAS, assuming variance-component covariance structures. For *Prefers Precaution Before (Mean)*, participants' means were centered relative to the overall mean. For *Prefers Precaution Before (Deviation)*, values were centered relative to individual participants' means. *Order* (the participant's viewing order) was centered relative to the overall mean. Orthogonal contrast codes were used for all categorical variables. Empirical standard errors were used for all t tests. χ^2 tests were conducted by comparing deviances of nested models. R^2 values are for models without random slopes, as suggested by Snijders & Bosker, p. 105).

**$p < .01$. ***$p < .001$. ****$p < .0001$.

TABLE 2
Unstandardized Regression Coefficients for Predicting Judgments that Information Favors Precaution on the Basis of Preference for Precaution, for Each Combination of Scenario and Information Item

	Information item				
Scenario	Probability	True positive	False positive	True negative	False negative
		Study 1			
Responding to dam-failure warning	0.269**	0.255***	0.361***	0.262**	0.299***
Banning use of cell phones by drivers	0.330****	0.538****	0.494****	0.515****	0.396****
Evacuating airport for security reasons	0.376****	0.337****	0.367****	0.303****	0.195**
Avoiding milk from hormone-treated cows	0.411***	0.334****	0.184*	0.283***	0.385****
Banning blood donors from England	0.274**	0.365****	0.404****	0.251**	0.395****
Banning genetically modified potatoes	0.372****	0.235**	0.164†	0.308**	0.510****
		Study 2			
Responding to dam-failure warning	0.440****	0.361****	0.549****	0.402****	0.316****
Banning use of cell phones by drivers	0.527****	0.550****	0.449****	0.450****	0.425****
Evacuating airport for security reasons	0.592****	0.469****	0.490****	0.274**	0.239***
Avoiding milk from hormone-treated cows	0.308*	0.606****	0.406****	0.319**	0.628****
Banning blood donors from England	0.392****	0.561****	0.278**	0.166†	0.438****
Banning genetically modified peaches	0.386****	0.442****	0.439****	0.229*	0.474****

Note. A separate regression was conducted for each combination of scenario and information type, with participant as the unit of analysis. In Study 1, *Information Favors Precaution* was regressed onto *Prefers Precaution Before*, controlling for *Order*. In Study 2, *Ambiguity* and the *Ambiguity* × *Prefers Precaution Before* interaction were also controlled.

†$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$. ****$p < .0001$.

TABLE 3
Multilevel Model Results for Predicting Participants' Preferences for Precaution after Participants had Evaluated Information

	Study 1		Study 2	
	Parameter estimate	Significance test	Parameter estimate	Significance test
Fixed effects				
Intercept	7.928	$t(98) = 29.00$****	14.004	$t(91) = 41.17$****
Prefers Precaution Before (Mean)	0.970	$t(98) = 34.47$****	1.003	$t(91) = 20.31$****
Prefers Precaution Before (Deviation)	0.658	$t(2895) = 31.03$****	0.563	$t(2779) = 21.85$****
Information Favors Precaution (Mean)	0.069	$t(98) = 1.84^{\dagger}$	0.085	$t(91) = 1.44$
Information Favors Precaution (Deviation)	0.307	$t(2895) = 14.75$****	0.386	$t(2779) = 17.54$****
Ambiguity			–0.075	$t(91) = -0.11$
Ambiguity × Prefers Precaution Before (Mean)			–0.064	$t(91) = -0.64$
Ambiguity × Prefers Precaution Before (Deviation)			–0.043	$t(2779) = -0.82$
Ambiguity × Information Favors Precaution (Mean)			0.095	$t(2779) = 0.80$
Ambiguity × Information Favors Precaution (Deviation)			0.036	$t(2779) = 0.83$
Order	1.743	$t(2895) = 4.42$****	0.809	$t(2779) = 2.92$**
Information Item		$\chi^2(4) = 27.5$****		$\chi^2(4) = 24.7$****
Scenario		$\chi^2(5) = 48.3$****		$\chi^2(5) = 26.0$****
Scenario × Information Item		$\chi^2(20) = 152.6$****		$\chi^2(20) = 170.5$****
Random effects (variance components)				
Intercept	0.911	$\chi^2(1) = 0.8$	3.135	$\chi^2(1) = 6.3$*
Prefers Precaution Before (Deviation)	0.027	$\chi^2(1) = 115.1$****	0.043	$\chi^2(1) = 207.8$****
Information Favors Precaution (Deviation)	0.018	$\chi^2(1) = 76.2$****	0.027	$\chi^2(1) = 145.9$****
Residual	198.18		226.84	
R^2				
Level 1	.759		.723	
Level 2	.965		.952	

Note. Multilevel models were fit as described in Table 1. For *Prefers Precaution Before (Mean)*, participants' means were centered relative to the overall mean. For *Prefers Precaution Before (Deviation)*, values were centered relative to individual participants' means. *Order* was centered relative to the overall mean. Orthogonal contrast codes were used for all categorical variables.

$^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$. $^{****}p < .0001$.

TABLE 4
Partial Multilevel Model Results for Predicting the Desirability of Possible Outcomes

	Possible outcome			
Fixed effects	True positive	False positive	True negative	False negative
		Study 1		
Intercept	60.307	43.489	87.626	8.225
Prefers Precaution Initial (Mean)	0.253**	0.144	–0.182*	–0.131†
Prefers Precaution Initial (Deviation)	0.055	0.223****	–0.101**	–0.074**
		Study 2		
Intercept	55.825	47.840	86.272	6.831
Prefers Precaution Initial (Mean)	0.133	0.155	–0.212*	–0.165**
Prefers Precaution Initial (Deviation)	0.171**	0.114**	–0.122***	–0.078*
Ambiguity	0.423	–1.720	5.406†	–5.852**
Ambiguity × Prefers Precaution Initial (Mean)	0.100	0.103	0.290	–0.084
Ambiguity × Prefers Precaution Initial (Deviation)	0.091	0.117	–0.077	0.002

Note. Multilevel models were fit as described in Table 1, with a separate model for each possible outcome. For *Prefers Precaution Initial (Mean)*, participants' means were centered relative to the overall mean. For *Prefers Precaution Before (Deviation)*, values were centered relative to individual participants' means. Orthogonal contrast codes were used for *Ambiguity* and for *Scenario*, which was controlled in each model. Tests of intercepts are not reported because the tests are not meaningful. Random effects for the intercepts and for the coefficient of *Prefers Precaution Initial (Deviation)* were also included, but the corresponding variances are not reported here.

†$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$. ****$p < .0001$.

TABLE 5
Parameter Estimates and Odds Ratios from Ordinal Logistic Regression Models for Predicting Implied Dominance in Each Scenario

	Scenario					
	Responding to dam-failure warning	Banning use of cell phones by drivers	Evacuating airport for security reasons	Avoiding milk from hormone-treated cows	Banning blood donors from England	Banning genetically modified potatoes or peaches
			Study 1			
Intercept 1	–2.392****	–1.938****	–2.503****	–1.217****	–3.364****	–2.587****
Intercept 2	4.031****	3.775	3.820****	3.345****	1.394****	3.257****
Prefers Precaution Initial	0.021 (1.021)	0.037*** (1.037)	0.027* (1.028)	0.020* (1.020)	0.024** (1.024)	0.031* (1.032)
Distribution of implied dominance	2, 87, 9	4, 80, 17	3, 87, 10	4, 72, 24	22, 74, 4	5, 87, 9
			Study 2			
Intercept 1	–1.138****	–1.671****	–1.990****	–0.947****	–2.096****	–1.994****
Intercept 2	4.195****	1.832****	3.506****	3.623****	1.822****	3.471****
Prefers Precaution Initial	0.027* (1.028)	0.013 (1.013)	0.027** (1.027)	0.023* (1.023)	0.014† (1.014)	0.028** (1.028)
Ambiguity	–0.395 (0.674)	0.273 (1.314)	–0.317 (0.729)	0.322 (1.379)	0.380 (1.462)	–1.580** (0.206)
Ambiguity × Prefers Precaution Initial	0.006 (1.006)	–0.003 (0.997)	–0.019 (0.981)	–0.025 (0.976)	0.000 (1.000)	0.020 (1.021)
Distribution of implied dominance	2, 66, 24	13, 63, 15	4, 75, 14	3, 63, 28	14, 68, 11	5, 72, 14

Note. A separate model was fit for each scenario, with participant as the unit of analysis. The proportional odds assumption could not be rejected at $p < .05$ in any model. *Prefers Precaution Initial* was centered relative to the mean, separately in each scenario. A contrast code was used for *Ambiguity*. The distribution of implied dominance gives the number of participants whose outcome utility ratings implied that the nonprecautionary option was weakly dominant, that neither alternative was dominant, or that the precautionary option was weakly dominant. Odds ratios appear in parentheses. Ratios greater than 1.0 mean that higher values of the independent variables were associated with higher probabilities that the precautionary option was weakly dominant and lower probabilities that the nonprecautionary option was weakly dominant. Wald χ^2 tests were used for statistical significance.

†$p < .10$. *$p < .05$. **$p < .01$. ***$p < .001$. ****$p < .0001$.

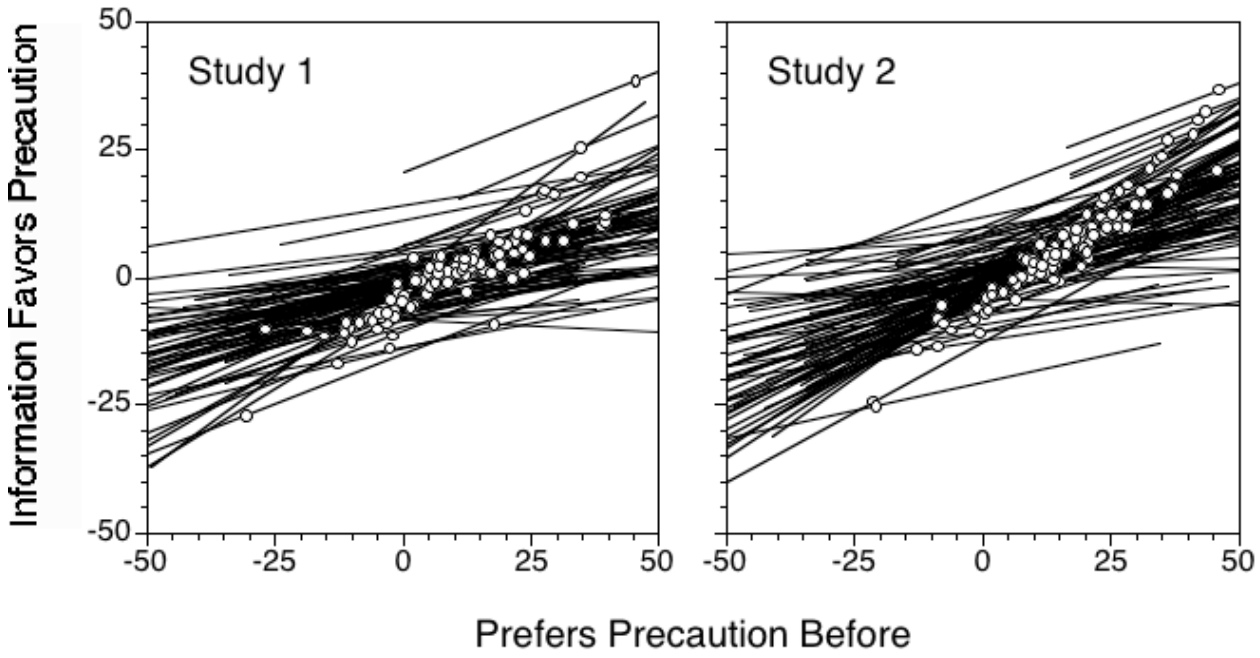

Fig. 1. Predicted judgments of the extent to which information favors the precautionary option (*Information Favors Precaution*) as functions of participants' immediately prior preferences for the precautionary option (*Prefers Precaution Before*), based on the results of the multilevel models in Table 1. There is a separate line for each participant, with the endpoints depicting the participant's minimum and maximum values for *Prefers Precaution Before* and with the open circle depicting the participant's mean value for *Prefers Precaution Before*. As is customary in multilevel modeling, each participant's predicted line is a weighted average of the line based on only that participant's data and the line based on the full sample. Predictions for Study 2 reflect the nonsignificant effects of *Ambiguity* and its interactions. *Order* was centered and the contrast codes for *Information Type* and *Scenario* were set to zero for these plots.