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Information Gaps for Risk and Ambiguity

Russell Golman, Nikolos Gurney, and George Loewenstein
Carnegie Mellon University

We apply a model of preferences about the presence and absence of information to the domain of decision making under risk and ambiguity. An uncertain prospect exposes an individual to 1 or more information gaps, specific unanswered questions that capture attention. Gambling makes these questions more important, attracting more attention to them. To the extent that the uncertainty (or other circumstances) makes these information gaps unpleasant to think about, an individual tends to be averse to risk and ambiguity. Yet in circumstances in which thinking about an information gap is pleasant, an individual may exhibit risk- and ambiguity-seeking. The model provides explanations for source preference regarding uncertainty, the comparative ignorance effect under conditions of ambiguity, aversion to compound risk, and a variety of other phenomena. We present 2 empirical tests of one of the model's novel predictions, which is that people will wager more about events that they enjoy (rather than dislike) thinking about.

Keywords: ambiguity, gambling, information gap, risk, uncertainty

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This article derives both risk and ambiguity preferences from an underlying model of thoughts and feelings about information gaps that was initially developed to explain preferences for information (Golman & Loewenstein, 2018; Golman, Loewenstein, Molnar, & Saccardo, 2020). We argue that risk and ambiguity aversion primarily arise from the discomfort of thinking about unanswered questions about either outcomes or probabilities (over and above the effect of utility function curvature, which is modest at low stakes). Likewise, risk- and ambiguity-seeking occur in (rarer) cases in which thinking about these questions is pleasurable. The main focus of our model is, therefore, on when and how much people think about questions prompted by uncertainty, and the hedonic consequences of this focus of attention. We show that these thoughts and feelings about unanswered questions have implications for decision making under risk and uncertainty.

We define an *information gap* (Golman & Loewenstein, 2018) as a question that one is aware of but for which one is uncertain between possible answers, and propose that the attention paid to such an information gap depends on two key factors: salience, and importance.[1] The salience of a question indicates the degree to which contextual factors in a situation highlight it. Salience might depend, for example, on whether there is an obvious counterfactual in which the question can be definitively answered. The importance of a question is a measure of how much one's utility would depend on the actual answer. It is this factor—importance—which is influenced by actions like gambling on the answer or taking on risk that the information gap would be relevant for assessing.

In our model, gambling raises the importance of the gamble's associated questions (e.g., will I win, or what is my chance of winning?), which motivates one to wager on events which evoke questions that are enjoyable to think about and to not wager on events which evoke questions that are aversive to think about. A wide range of phenomena can be explained in such terms. For example, Lovallo and Kahneman (2000) find a strong positive correlation between willingness to accept a gamble and preference to delay resolution of that gamble so as to have more time to enjoy thinking about it. Lottery players often prefer to spread out drawings, perhaps in order to savor their thoughts about the possibility

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Russell Golman, Nikolos Gurney, and George Loewenstein, Department of Social and Decision Sciences, Carnegie Mellon University.
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Correspondence concerning this article should be addressed to Russell Golman, Department of Social and Decision Sciences, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA 15213. E-mail: rgolman@andrew.cmu.edu

[1] Golman and Loewenstein (2018) assumed that a third factor—surprise—contributes to attention when information is acquired; this assumption relates to information acquisition and avoidance (see Golman et al., 2020), but is unnecessary here. The effect of surprise on attention would, however, be relevant in situations in which the decision maker anticipates the hedonic consequences of observing the outcome of an uncertain prospect and not just the consequences of exposing oneself to this uncertainty.

of winning (Kocher, Krawczyk, & van Winden, 2014).[2] People are especially prone to insure against the loss of things they have an emotional attachment to (Hsee & Kunreuther, 2000), in our view because they find it unpleasant to think about losing these items. Financial professionals primed to think about the bust of a financial bubble become more risk averse (even with known probabilities in a laboratory setting) than those primed to think about a boom (Cohn, Engelmann, Fehr, & Maréchal, 2015). Self-reported feelings can be used to predict choice under risk in the laboratory (Charpentier, De Neve, Li, Roiser, & Sharot, 2016). And in natural settings, it has been argued, the discomfort of thinking about risky situations is perhaps the primary motive behind risk avoidance (Loewenstein, Weber, Hsee, & Welch, 2001; see also Tymula et al., 2012).

In the case of risk, in our model, the key question about which people are uncertain—the information gap—centers around the eventual outcome when the uncertainty is resolved. For example, when deciding whether to accept a fair odds bet on a coin toss, the information gap is whether the coin flip will come out heads or tails. Thinking about the coin turning up heads (or about it turning up tails) does not seem intrinsically pleasurable or painful, but we suggest that the feeling of uncertainty about this outcome is a source of discomfort. Thus, in our model, risk aversion (even with low stakes) arises from a desire to avoid thinking about such uncertainty. Moreover, the model predicts, there will be stronger risk aversion when the outcome depends on additional uncertainties, so there will be more pronounced aversion for compound lotteries. Our predictions of risk aversion (rather than risk seeking) require information gaps to be unpleasant to think about. Despite the discomfort associated with feelings of uncertainty, however, such information gaps may be pleasurable to think about if the events under consideration have intrinsically positive valence, in which case our model would predict risk seeking. We would predict risk seeking behavior, for example, by a basketball fan for a lottery determined by his favorite basketball player making a free throw.[3]

In the case of ambiguity, an additional key question comes into play: what the likelihoods are of obtaining different outcomes. When thinking about this question is aversive, then we expect people to be ambiguity averse; when pleasurable, they should be ambiguity seeking. Our model, therefore, provides an account of ambiguity avoidance and seeking that is different from existing accounts.

The most straightforward, novel prediction of our model is that people should be more willing to accept a risky or ambiguous gamble in situations in which they enjoy (rather than dislike) thinking about the uncertainties associated with the gamble. We test, and provide empirical support for, this novel prediction in two new studies reported in the article. In Study 1, we show that people wager more on a 50/50 bet between two good events than a 50/50 bet between two bad events, specifically comparing bets on hometown baseball players getting hits versus striking out. In Study 2, we show that people are more ambiguity tolerant for bets that are contingent on more desirable events, in this case considering bets on the rankings of educational programs at the university they attended, for programs thought to be more or less prestigious.

We then proceed to relate our model to the existing literature on risk and ambiguity and to distinguish our contribution. Next, we describe our theoretical framework. Then we present theoretical results, applying this model to decisions under risk, and subsequently we discuss ambiguity. Finally, we report experimental results supporting our theory, followed by our conclusions. A more formal mathematical treatment of our theory, including precise definitions, propositions, and proofs, is provided in the Appendix.

Relationship to Existing Literature

Our theoretical model is substantially different from prior theoretical work that has provided accounts of risk and ambiguity preferences that are inconsistent with expected utility over prizes (behavior such as low-stakes risk aversion [Rabin, 2000], the Allais [1953] common consequence and common ratio paradoxes, and the Ellsberg [1961] paradox). These other approaches typically incorporated departures from expected utility maximization, such as loss aversion (Kahneman & Tversky, 1979), nonadditive probability weighting (Quiggin, 1982), and imprecise (set-valued) probabilities (Gilboa & Schmeidler, 1989). In contrast to these other approaches, our model adheres to expected utility, albeit over beliefs rather than outcomes. Our departure from traditional expected utility is that people derive utility from beliefs in addition to outcomes, and their exposure to risk or ambiguity can impact the utility they derive from their beliefs.

Our model is not intended to be a mutually exclusive alternative to these other theories of risk and ambiguity preference, which capture important psychological mechanisms and can explain many well-established behavioral patterns (see, e.g., Bordalo, Gennaioli, & Shleifer, 2012; Köszegi and Rabin, 2006; Loomes & Sugden, 1982; Schmidt, Starmer, & Sugden, 2008; Tversky & Kahneman, 1992). Incorporating features from these theories would no doubt improve the predictive power of our model. For example, probability weighting and event weighting, in the case of ambiguity, as assumed by prospect theory, would still be necessary for us to account for the well-documented fourfold pattern of risk and ambiguity preferences (i.e., risk- and ambiguity-seeking behavior for unlikely gains or likely losses; Tversky & Kahneman, 1992; Wakker, 2010; Trautmann & van de Kuilen, 2015). For simplicity, however, we forego this and other behavioral assumptions and introduce utility of beliefs in an expected utility framework. With only this departure, we are still able to account for a wide range of anomalous phenomena under risk and ambiguity. No model, however, including ours, can account for the full range of anomalous patterns of risk and ambiguity preference.

Our account of ambiguity preference is related to an account proposed by Frisch and Baron (1988) according to which ambiguity aversion arises from the awareness that one is missing information that would help one to refine one's judgment of a

[2] When faced with a risk of painful electric shocks, people generally prefer resolving this risk in one fell swoop rather than through a drawn out process, seemingly to avoid thinking about the possibility of receiving these shocks (Falk & Zimmermann, 2017).

[3] The traditional theory deriving risk aversion from diminishing marginal utility, embellished with an assumption of belief-based utility such that a fan derives utility from his favorite player making a free throw, would predict the opposite pattern, i.e., that the fan would prefer to hedge the risk by betting against his favorite player.

gamble's probabilities.[4] Our account is similar to theirs in terms of focusing on awareness of missing information as the source of ambiguity preference. However, our account is more specific about how and why thinking about the information gap leads to ambiguity preference, allows for the idea that thinking about information gaps can be pleasurable, and makes the prediction that in these situations people will be ambiguity seeking.

In their superb review of the literature on ambiguity, Camerer and Weber (1992) feature prominently the notion, from Frisch and Baron (1988), that ambiguity can be thought of as "uncertainty about probability, created by missing information that is relevant and could be known" (p. 330).[5] Yet despite the prominence of awareness of missing information in their definition of ambiguity, in a later section of the review that summarizes many specific theories of ambiguity preference, not a single theory (nor class of theories) is based on the conception of ambiguity preference as a response to feelings about missing information. By deriving ambiguity preference from feelings about information gaps, our account is quite different from other explanations that have been proposed.

Some models aim to describe ambiguity preference but do not attempt to shed light on its underlying cause. These models are intended to represent ambiguity-averse (and sometimes ambiguity-seeking) preferences, but they are not meant to be explanations for these preferences, which are seen as fundamental. For example, ambiguity preferences have been captured by assuming nonadditive subjective probability weighting (as in Schmeidler's (1989), Choquet expected utility model or Tversky and Kahneman's (1992) cumulative prospect theory), or imprecise (set-valued) probabilities (as in Gilboa and Schmeidler's [1989] Maxmin expected utility model, Hurwicz's [1951] α-maxmin model (see also Ghirardato, Maccheroni, and Marinacci [2004] or Maccheroni et al.'s [2005] variational preferences model), or second-order risk aversion (toward distributions of outcomes) rather than reduction of compound lotteries (as in Segal's (1987, 1990) extension of rank dependent utility, Klibanoff et al.'s (2005) smooth model, or other recursive expected utility models (Ergin & Gul, 2009; Nau, 2006; Seo, 2009).[6,7] In contrast, we aim to derive ambiguity aversion—and, in specific situations, ambiguity seeking—by considering fundamental preferences for information as well as over outcomes.

In a study that provided neural support for our interpretation of ambiguity aversion, Hsu, Bhatt, Adolphs, Tranel, and Camerer (2005) scanned the brains of subjects as they made choices involving ambiguous and unambiguous gambles. The authors found that the level of ambiguity in choices correlated positively with activation in the amygdala, a brain region that has been connected by numerous studies to the experience of fear. The authors concluded that "under uncertainty, the brain is alerted to the fact that information is missing, that choices based on the information available therefore carry more unknown (and potentially dangerous) consequences, and that cognitive and behavioral resources must be mobilized in order to seek out additional information from the environment" (Hsu et al., 2005, p. 1683). Additional studies have found that decision making involving ambiguous gambles, and even the perception of ambiguity in the absence of decision making, correlates with activity in the posterior inferior frontal sulcus/posterior inferior frontal gyrus (Bach, Seymour, & Dolan, 2009; Huettel, Stowe, Gordon, Warner, & Platt, 2006), a region of the brain that has been independently identified as responsible for attentiveness to relevant information in a task switching paradigm (Brass & von Cramon, 2004). Consistent with our information gap account, this region of the brain responds to ambiguity when information (that could potentially be known) is hidden from the observer, but not under conditions of complete ignorance (Bach et al., 2009).

In building on a foundation of information preference, our model can help to explain when and why ambiguity preference takes different forms in different situations, including those that produce ambiguity seeking rather than aversion.[8] One line of research (Fox & Tversky, 1995) shows that people value ambiguous and unambiguous gambles with similar subjective probabilities quite similarly when the gambles are presented separately; it is only when the two types of gambles are compared to one-another that people become markedly averse to ambiguity. The observation that people are more ambiguity averse when making choices between ambiguous and unambiguous gambles can be explained by the information-gap account we propose by assuming that such comparisons tend to direct attention to a salient information gap: the unknown probability associated with the ambiguous gamble.

Another line of research (Heath & Tversky, 1991) shows that people actually like to bet on ambiguous outcomes—for example, a horse race—when they feel they are expert in the domain. People tend to be averse to ambiguity when they feel they are lacking information or expertise in a domain. The information gap account of ambiguity preference can easily account for these findings with a natural assumption that it is more pleasurable to think about issues one is more expert on. Betting in domains of expertise

[4] Similarly, Kovarik, Levin, and Wang (2016) proposed that apparent ambiguity aversion in the Ellsberg paradox arises from not wanting to think about complexity. Although our account resembles theirs, we would predict that raising the stakes in the Ellsberg gambles would lead to more ambiguity aversion, whereas their theory of complexity aversion predicts that magnifying prizes decreases its prevalence.

[5] Some models interpret ambiguity to mean that subjective odds cannot even be specified, but such a situation would be extreme. People make subjective probability judgments all the time. (Abdellaoui et al. [2011] made a similar argument.) In our view, the distinction between ambiguity and risk is the decision maker's awareness (and uncertainty) about sources of uncertainty. With the so-called known urn in the Ellsberg paradox, the only uncertainty is about which ball will be drawn, and there is unawareness of the mechanism that will determine it. With the ambiguous urn, the decision maker is aware of an additional uncertainty about the contents of the urn in the first place. This makes a subjective probability judgment about the color of the drawn ball uncertain, but not impossible.

[6] Nonadditive subjective probability weighting captures ambiguity aversion when the weights are supermodular (given linear weights for known probabilities), or, more generally, when the weights are more convex for ambiguous probabilities than for known probabilities (Wakker, 2010). These weights should not be interpreted as subjective probability judgments but merely as inputs into the decision model.

[7] Imprecise probability captures ambiguity aversion when the decision maker is cautious or pessimistic and considers worst-case scenarios. Yet in many real-world decision environments, there is so much uncertainty that worst-case scenarios would render a decision maker impossibly conservative.

[8] Ellsberg himself did not focus exclusively on ambiguity aversion. Reflecting on the origin of his paradox, he suggested that a pattern of ambiguity-seeking "will be much more frequent than the reverse in certain circumstances" and deserves "much more experimental and theoretical investigation than it has received" (Ellsberg, 2011).

increases the attention devoted to many questions about which one is confident, whereas betting on unfamiliar situations increases the attention placed on questions one is more uncertain about. We thus should expect people to have preferences over the source of uncertainty, generally preferring a familiar source to an unfamiliar source. In fact, people do prefer to bet on their vague beliefs in situations in which they feel especially competent or knowledgeable, but prefer to bet on chance when they do not (Abdellaoui, Baillon, Placido, & Wakker, 2011; Heath & Tversky, 1991; Keppe & Weber, 1995; Taylor, 1995; Tversky & Fox, 1995). Such "source preference" may also help explain the common observation of home bias, that is, relative overinvestment in one's own country's (French & Poterba, 1991; Kilka & Weber, 2000), company's (Choi, Laibson, & Madrian, 2005), and even locality's (Coval & Moskowitz, 1999) stock.[9]

Although our theory can account for Heath and Tversky's competence hypothesis, their competence hypothesis does not fully account for all the predictions that our theory makes. Our studies provide evidence in support of our prediction that people prefer to bet on events that they like thinking about, in situations in which they have no more knowledge about the high-valence bets than about the low-valence bets. Thus, the competence hypothesis cannot explain this pattern. Other explanations of ambiguity preference struggle to account for any of the observed patterns of source preference. For example, ambiguity aversion has been attributed to pessimism, that is, fear that the unknown probabilities will end up being unfavorable. Yet evidence suggests that people are often extremely optimistic in the face of uncertainty (Taylor & Brown, 1988; Weinstein, 1980). An account of ambiguity preference based on optimism and pessimism still requires an explanation (yet to be offered, as far as we know) for why people would be optimistic in those cases in which ambiguity seeking has been observed and why they would be pessimistic in those cases in which ambiguity aversion has been observed.

The enjoyment of thinking about questions within one's area of expertise could also account for the prevalence of risk-seeking in the absence of ambiguity, especially in the domain of gambling. Gamblers often believe they have expertise on the particular events they wager on. They notoriously obey superstitions about hot or cold tables in a casino and rely on "systems" for choosing their stakes, even though many would acknowledge that the house retains a mathematical edge. von Neumann and Morgenstern (1944) explicitly disregarded the utility of gambling in capturing risk preferences with expected utility (see also Luce & Raiffa, 1957), but others have tried to incorporate intrinsic preferences for or against gambling into an expected utility framework (e.g., Diecidue, Schmidt, & Wakker, 2004; Fishburn, 1980). They associate a cost or benefit with a specific profile of material outcomes and probabilities (i.e., a "lottery"). A realistic behavioral model of intrinsic preferences about gambling must acknowledge that such preferences depend on the situation that gives rise to the gamble (Budescu & Fischer, 2001). In our model, the utility or disutility of gambling is not attached to the risk inherent in a gamble, but instead to the source of that risk. Particular sources of uncertainty arouse specific beliefs about those uncertainties and specific feelings—positive or negative—about those beliefs.

Like other accounts of ambiguity aversion that draw a connection between risk and ambiguity preference by assuming that ambiguity preference reflects second-order risk aversion (Ergin & Gul, 2009; Klibanoff et al., 2005; Nau, 2006; Segal, 1987; Seo, 2009), our account also proposes that both phenomena stem from the same underlying cause. But, as we have already described, it introduces a novel mechanism involving thoughts and feelings about unanswered questions. We do not doubt that other mechanisms, such as utility function curvature or a precautionary principle, also play a role in risk and ambiguity preferences. Nevertheless, we, like Caplin and Leahy (2001); Epstein (2008) and Navarro-Martinez and Quoidbach (2016), believe that affective feelings about uncertainty (i.e., information gaps) critically affect risk and ambiguity preferences. We suggest that these preferences are driven, or at least influenced, by the desire to not draw attention to questions one does not like to think about.

Theoretical Framework

We use Golman and Loewenstein's (2018) question-and-answer framework and belief-based utility model. In this framework, we define an information gap as a question of which one is aware, but for which one is uncertain between possible answers. A person has probabilistic beliefs about possible answers to questions as well as about material outcomes (e.g., prizes in lotteries), and each of these questions may attract more, less, or no attention. A utility function is defined over cognitive states, which encompass a person's beliefs and the attention paid to them. The more a person is thinking about a question, the more it may affect his utility.

Attention is, in principle, observable (perhaps imperfectly) through eye tracking, brain scans, and/or self-reports, but as it is, in practice, difficult to observe, we specify some determinants of attention. The attention on a question is assumed to be strictly increasing in the question's importance and its salience, with a positive interaction here as well. That is, as a question becomes more important, it attracts more attention, especially if it is already highly salient. We characterize the importance of a question as a function of the distribution of utilities that would result from different answers to the question. If this distribution becomes more (or less) spread out, the question becomes more (or less) important. In other words, a question is important to the extent that different possible answers will make a person feel much better or much worse.[10]

Some assumptions about the utility function (spelled out in the Appendix) imply that the utility derived from a belief about a particular question depends on the valences of the answers that are considered possible and the amount of uncertainty in the belief, amplified by the attention given to the question. Golman and Loewenstein (2018) posited a fundamental preference for clarity, which means that more uncertainty in a belief decreases its utility (holding valence and attention fixed). Although entropy serves as a natural measure of the uncertainty in a belief, we need not make any assumptions quantifying uncertainty for our purposes here, and we simply assume that uncertainty (between answers having the same valence) offers less utility than certainty (about any one

[9] Abdellaoui et al.'s (2011) source method can accommodate any form of source preference in a revealed preference framework. Our model goes beyond revealed preferences and makes predictions about which sources of uncertainty people will or will not expose themselves to.

[10] The circularity here—importance depends on utilities, utility depends on attention, and attention depends on importance—is by design.

of these answers), holding attention fixed. However, although we believe that uncertainty in and of itself is aversive, we still allow uncertain beliefs to have positive utility if the answers considered possible have sufficiently high valence. We can identify as positive (neutral/negative) beliefs those for which increasing attention on the belief increases (does not affect/decreases) utility.

We assume that apart from belief-based utility we have expected utility over material outcomes. This assumption may well be unrealistically strong (it may preclude patterns of risk seeking for moderately likely losses or longshot gains, e.g., when the value function over prizes is concave), but it simplifies the model so we can focus on the impact of beliefs on utility. Thus, to the extent that our account can reconcile phenomena that a traditional expected utility model cannot, the explanation will feature the utility of beliefs.

Wagering on an uncertain event changes the chances of receiving various prizes, typically making them contingent on the answers to particular questions (e.g., about the outcome of the uncertain event).[11] Wagering has two effects on the cognitive state. First, it changes beliefs about the probability distribution of prizes conditional on beliefs about activated questions. Second, and less readily apparent, it impacts attention because the change in prizes affects the importance of any question on which the prize is contingent. We focus on the utility of these immediate consequences and in this article do not consider situations in which insufficient attention or overly obsessive attention to an information gap leads to subsequent suboptimal choices with additional downstream consequences.[12] We now apply our theory to predict preferences between risky or ambiguous bets.

Risk

Low-Stakes Risk Aversion

People tend to be risk averse, even over low-stakes lotteries (L'Haridon and Vieider, 2019; Starmer, 2000). The utility curvature needed to explain low-stakes risk aversion in a traditional expected utility model implies an absurd amount of risk aversion in high-stakes lotteries, such that, for example, an individual who at any wealth level rejects a 50/50 lottery to either gain $110 or lose $100 would have to reject a 50/50 lottery with a potential loss of $1,000, regardless of the potential gain (Rabin, 2000). Utility function curvature (i.e., diminishing marginal utility of money) almost certainly does play a role in risk aversion, but clearly something more is in play here, too. We suggest that betting on a lottery exacerbates the pain of thinking about an information gap by making it more important.[13]

To illustrate the information gap account for low-stakes risk aversion, consider a simplifying assumption that the value function for material outcomes is linear over monetary prizes. (Of course, diminishing sensitivity to larger monetary prizes would be realistic, but any differentiable value function can be well approximated by a linear function over a small neighborhood.) Consider a possible bet on a fair coin that could either pay x^* (win) or $-x^*$ (lose). The information gap here is a question about the outcome of the coin toss, whether it will be heads or tails. Assume the decision maker has no intrinsic preference for heads or for tails (apart from the preference to win the lottery, if the bet is accepted), assigning both outcomes neutral valence. Then the decision maker will strictly prefer rejecting the bet. (See Proposition 1 in the Appendix.) The intuition is that having to think about the outcome of the coin toss lowers utility because, according to our model, the uncertainty is aversive. Betting on the coin toss makes it more important, and the question of the outcome would then attract more attention. The same logic also implies that if the decision maker were forced to bet on the coin toss, he would strictly prefer smaller stakes.

A Preference for Certainty

The observed patterns of nonstandard risk preferences mostly seem to relate to a preference to avoid exposure to uncertainty relative to having certainty. The preference for certainty is well documented (Starmer, 2000) and follows naturally from the information gap account. The pain of thinking about an information gap leads to what might be called direct risk aversion, above and beyond the risk aversion that can result from utility function curvature or alternative sources (e.g., loss aversion or probability weighting) in existing behavioral decision theories (see O'Donoghue & Somerville, 2018 for a review of alternative sources of risk aversion). In our model, there is effectively a direct cost in the utility function simply from awareness of exposure to risk (i.e., from the existence of an information gap).[14] Direct risk aversion could underlie Gneezy et al.'s (2006) *uncertainty effect*, in which individuals value a risky prospect (say, a lottery between gift certificates worth $50 or $100) less than its worst possible realization (i.e., a $50 gift certificate for sure). (See also Simonsohn's (2009) replication of the uncertainty effect.) In our account, such extreme direct risk aversion would require the uncertainty to relate to highly negative beliefs. Of course, this state of affairs is rare. Given the empirical facts, we might speculate that people associate the particular task of paying for a lottery over gift

[11] Actually observing the outcome of a wager is a separate action, not part of our present analysis. Decisions involving a sequence of actions, such as wagering and then observing the outcome of the wager, can be analyzed with the framework presented in our foundational article (Golman & Loewenstein, 2018).

[12] For example, we expect most people would have little interest in wagering on the result of an esoteric science experiment, because most people do not enjoy paying more attention to obscure scientific hypotheses. However, a student who wanted to learn about the subject, but who found it difficult to motivate herself to read more about it, could choose to bet on such an experiment to generate an interest in the outcome and thus to spark some initial curiosity. For another example in the opposite direction, a sports fan who usually enjoys betting on sporting events could refrain from betting on a game that would be played the night before he was going to take an important test, recognizing that a betting interest in the game might make it impossible for him to stop watching even though he knows he should be studying instead. Although such stylized examples can be accommodated by our theory, we do not consider such specialized scenarios here when identifying behavioral patterns that we predict will hold generally.

[13] In a rare case in which an uncertain lottery is pleasant to think about, we would suggest that risk seeking arises from the same mechanism.

[14] Ambiguity involves even more awareness of uncertainty than simple risk, so the information gap account also implies that there is an even larger direct utility cost from exposure to ambiguity, assuming this additional uncertainty is unpleasant to think about. Analogous to the uncertainty effect for risk, Andreoni, Schmidt, and Sprenger (2014) found that many subjects evaluating compound lotteries with a component that may be ambiguous actually violate (first-order stochastic) dominance as if there is a direct cost just to considering ambiguity.

certificates with the danger of being suckered into a bad deal (Yang, Vosgerau, & Loewenstein, 2013), which might well be a highly negative belief (see Isoni, 2011; Prelec & Loewenstein, 1998; Weaver & Frederick, 2012).

Compound Risk Aversion

Seeing that people generally try to avoid exposure to an information gap, we might expect that compound lotteries—which expose an individual to multiple information gaps—are even more aversive. Indeed, the empirical evidence is clear that people do not reduce compound lotteries and typically value them lower than their reduced form versions (Abdellaoui, Klibanoff, & Placido, 2015; Armantier & Treich, 2015; Bernasconi & Loomes, 1992; Halevy, 2007; Spears, 2013;). This phenomenon poses a particular challenge to theories that do not allow for framing effects and that require the utility of a lottery to depend only on the possible outcomes and their probabilities. It is also a necessary consequence of the information gap account.

In this model, as long as the lotteries do not involve events with positive intrinsic valence, a compound lottery will be less preferred than an equivalent simple lottery. A lottery is traditionally defined as a known probability distribution over prizes. In our framework, we need to specify how the outcomes of the lottery depend on the answers to activated questions. We define a simple lottery as depending only on a single question that is believed to be independent of all other questions (i.e., beliefs about the answers to these questions are independent). Resolving uncertainty about this one question completely determines the lottery. We define a compound lottery as depending on multiple questions. Resolving uncertainty about a question corresponding to an early (i.e., nonterminal) stage of the compound lottery just exposes the decision maker to a new lottery based on updated beliefs. We seek to compare a compound lottery to a simple lottery when they are materially equivalent.

Our model predicts that if a compound lottery and a materially equivalent simple lottery both depend on the answers to questions with identical salience, and all of the possible answers have neutral valence, then the simple lottery will be preferred. (See Proposition 2 in the Appendix.) The intuition here is that the compound lottery (in contrast to the simple lottery) exposes the decision maker to additional information gaps. These information gaps are unpleasant to think about (because the answers are neutral, but the uncertainty is unpleasant). Putting a prize on the line, dependent on the outcome of the uncertain events, makes these information gaps more important. That makes the compound lottery worse than the simple lottery.

Ambiguity

Information gaps can be a source of ambiguity as well as risk. In our view, an ambiguous prospect is simply a special case of a compound lottery. People are simply aware of and uncertain about the question, "what are the probabilities of the various outcomes?" Despite having no information from which to form objective probabilities, we propose that the decision maker can form subjective probabilities, that is, introspective judgments of probability that satisfy the additivity law of probability (as in Segal [1987]; Seo [2009], or Ergin and Gul [2009]), but thoughts and feelings about this information gap affect choice under ambiguity. In fact, we define an ambiguous gamble as a compound lottery that is contingent on a question about the probabilities of the possible outcomes.

Ambiguity Aversion

Consider the preference for the known urn in Ellsberg's problem (Ellsberg, 1961; Trautmann & van de Kuilen, 2015). Even if you bet on the urn with the known proportions of balls, the proportion of balls in the other urn you could have selected is still the subject of an information gap. To explain the phenomenon in terms of our model, therefore, we propose that there is a relevant question for both urns: "What is the proportion of each colored ball?" and that the attention weight is relatively greater for the question relating to the urn you choose. This follows from the assumption that attention weight increases in a question's importance. One knows the answer to the question for the precisely specified urn, but not for the ambiguous one. According to our model, the desire for clarity, along with the desire to pay less attention to negative beliefs, would cause an individual to bet on the known urn rather than the ambiguous urn in the Ellsberg paradox. (See Corollary 1 in the Appendix.)

Recognizing feelings about information gaps allows us to explain the preference for betting on the known urn rather than on the unknown urn, even when the subjective probability judgment about the odds of winning a prize is the same for both urns. Crucially, our account relies on aversion to uncertainty rather than a distinction between objective and subjective probabilities. Thus, consistent with Halevy's (2007) experimental findings, our premise is that ambiguity preference goes hand in hand with preference over compound (objective) lotteries.[15] Additionally, consistent with Chew et al.'s (2017) experimental findings, we would predict that preference for an ambiguous gamble (over events with neutral valence) declines when there is more uncertainty about the probabilities. Similarly, we account for the fact that people prefer to bet on a single ambiguous urn than on the relationship between draws from two different ambiguous urns (Epstein & Halevy, 2018).

Context Effects

Note that our explanation of ambiguity preference is inherently context dependent. In the Ellsberg paradox, ambiguity aversion arises from a desire to not pay attention to a salient information gap, combined with the opportunity to shift attention in the desired direction by placing the bet on the known urn. The description of the two urns in comparison makes salient the difference in their composition, so the questions about the composition of the urns get nonnegligible attention weight. If, however, an individual is asked to price a bet on a draw from just one of the urns in isolation, the question of the composition of that urn is less salient, and so receives less attention weight. As long as the question is activated, we would expect some degree of ambiguity aversion, because taking a sure payment in lieu of the bet still does shift attention away from an uncertain prospect, but (because attention weight

[15] Ambiguity preference may nevertheless be more extreme than compound lottery preference if the ambiguity makes the uncertainty more salient.

exhibits increasing differences in salience and importance) we would expect the degree of ambiguity aversion to be less when pricing bets on isolated urns than when pricing bets on urns that can be compared. This is precisely the comparative ignorance effect that Fox and Tversky (1995) and, following them, Chow and Sarin (2001) documented.[16]

Proposition 3 in the Appendix suggests that the comparative ignorance effect is an example of a more general phenomenon whereby a more salient information gap generates stronger ambiguity aversion. Consistent with this pattern, in a hypothetical scenario involving unknown risks of a vaccine (a scenario that subjects can intuitively grasp), salient missing information about whether the risk was high or had been eliminated made subjects more reluctant to vaccinate than when the subjects faced the same risk presented with no salient missing information (Ritov & Baron, 1990).

Other context effects have been noted as well and can be explained by our theory.[17] Studies have found that ambiguity aversion is exacerbated when others can observe the choice (Curley, Yates, & Abrams, 1986) and reduced when no others (not even the experimenter) can observe whether the bet wins or loses (Trautmann, Vieider, & Wakker, 2008). The authors interpret this finding to mean that the preference to avoid subjecting oneself to unknown risks is related to a desire to avoid social disapproval. Our model does not capture social disapproval per se, but could accommodate this phenomenon by positing, plausibly we believe, that that the possibility of social disapproval makes the unknown composition of the ambiguous urn that much more important if the bet on this urn is chosen.

Source Preference

Our theory also helps explain those situations in which ambiguous prospects are, in fact, preferred to risky, but clearly defined, gambles. In our analysis of the Ellsberg paradox, the prediction of ambiguity aversion depends on shifting attention between single beliefs that all involve neutral answers but that vary in their certainty. In general, shifting attention to favorable issues or away from unfavorable issues should increase utility. That is, we predict a preference for betting on issues one likes thinking about and for not betting on issues one does not like thinking about. (See Proposition 4 in the Appendix.)

Proposition 4 implies that ambiguity-seeking behavior arises when information gaps are pleasurable to think about, that is, in special cases in which outcomes have high valence. For example, ardent sports fans may enjoy betting on the outcome of a game they look forward to watching (Paul & Weinbach, 2010). They would generally prefer to bet on their home team than on other teams, and especially in comparison to a team their home team is playing against (Babad & Katz, 1991; Morewedge, Tang, & Larrick, 2016). Similarly, people (who we assume generally find it pleasurable to think of themselves as smart) are willing to pay more for a bet that they answered a quiz problem correctly than for a bet that another person answered correctly, exhibiting this preference with even greater frequency than they judge their own answer as more likely to be correct (Owens, Grossman, & Fackler, 2014). Cases of pleasurable information gaps may often coincide with issues about which one has significant expertise. To the extent that people generally enjoy thinking about issues for which they have more expertise and dislike unfamiliar situations, Proposition 4 would account for Heath and Tversky's (1991) findings demonstrating a preference to bet on familiar rather than unfamiliar sources of uncertainty (see also Abdellaoui et al., 2011; Tversky & Fox, 1995).

Also consistent with our hypothesis that gambling is correlated with the valence of an issue is the fact that people become less willing to hold risky assets after realizing a loss (Imas, 2016), as the painful experience of a loss could make thinking about another risky asset more unpleasant (see also Callen, Isaqzadeh, Long, & Sprenger, 2014). This realization effect could lead to path dependent risk and ambiguity attitudes. Barberis (2013) suggested that such dynamic changes in ambiguity preference may amplify financial panics that begin with relatively modest declines in asset values.

Machina Paradoxes

Machina (2009) introduced two decision problems for which typical patterns of behavior violate the predictions of most models of choice under ambiguity, including Choquet expected utility, maxmin expected utility, α-maxmin, variational preferences, and the smooth model of ambiguity aversion (Baillon, L'Haridon, & Placido, 2011). As these paradoxes have been so challenging for models of ambiguity aversion to accommodate, we find it illuminating to show how they are compatible with our model of informational preference.

Machina's 50:51 example presents an urn holding 50 balls colored red or yellow (in unknown proportion) and 51 colored black or green (also in unknown proportion). Table 1 displays four bets, showing the payoffs contingent upon the ball drawn. We may take 0, 101, 202, and 303 to be prizes equally spaced on the utility scale, given one's beliefs.[18] An individual chooses between a_1 or a_2, then between a_3 or a_4. Both choices involve allocating prizes between yellow and black with the remaining prizes fixed, but the contexts vary in how these remaining prizes are fixed. Bets a_2 and a_4 allocate the larger prize to black rather than yellow, which, if the individual accepts the principle of insufficient reason, means greater expected value. Bets a_1 and a_3, on the other hand, reduce how much is at stake depending on the unknown proportions in the urn. While they each reduce the stakes by the same absolute

[16] Similarly, if an individual is presented with extraneous information that seems to relate to the ambiguous issue, but is not easily processed, this information activates additional questions about which the individual is uncertain. The individual can shift attention weight away from these uncertain beliefs by avoiding a bet on the ambiguous issue. Indeed, Fox and Weber (2002) found that such unhelpful information makes ambiguous bets appear less attractive.

[17] For an example in the domain of risk, lotteries that are presented with narrow bracketing (and thus, we believe, made more salient) generate stronger risk aversion (Anagol & Gamble, 2013; Bellemare, Krause, Kröger, & Zhang, 2005; Gneezy & Potters, 1997; Haigh & List, 2005). Proposition 3 of course implies that the salience of an information gap affects risk preferences as well as ambiguity preferences, in accord with this empirical pattern.

[18] Actually eliciting prizes that are equally spaced on the utility scale requires, according to our model, subjects to consider random distributions of prizes that are independent of their beliefs about activated questions. There is a leap of faith in believing that subjects do not activate a question concerning which prize they will actually receive. Our analysis is not disturbed, however, if we accept this merely as an approximation.

Table 1
Machina's 50:51 Example

	50 balls		51 balls	
Bets	Red	Yellow	Black	Green
a_1	202	202	101	101
a_2	202	101	202	101
a_3	303	202	101	0
a_4	303	101	202	0

amount, bet a_1 eliminates all dependence on these uncertainties, whereas bet a_3 does not. The typical preference, $a_1 > a_2$ and $a_3 < a_4$ (at least when the magnitude of the payoffs is tuned just right), reflects a willingness to forego some material payoffs (in expectation) in order to lessen one's exposure to the unknown when the remaining exposure is minimal, but not when the remaining exposure is significant.

According to our model, choosing a bet affects utility in two ways. It determines the prize distribution corresponding to one's subjective belief about activated questions, thus directly affecting the expected value of the eventual prize. But, additionally, to the extent the distribution of prizes depends on the answers to various activated questions, a bet affects the importance of these questions, which in turn affects the utility derived from one's beliefs about these questions. As with the Ellsberg paradox, it seems reasonable to assume that all possible compositions of the urn (consistent with the known 50:51 split) are subjectively judged to be equally likely and that an individual does not care about the actual proportion or about which ball is drawn apart from the corresponding material payoff (i.e., all answers have neutral intrinsic valence). Drawing a black ball is thus subjectively judged to have a $\frac{.5}{101}$ greater chance than a yellow. By construction, this means that bets a_2 and a_4 each offer a gain in expected value of.5 over bets a_1 and a_3, respectively. On the other hand, bets a_1 and a_3 would lessen the importance of questions about the composition of the urn relative to bets a_2 and a_4, respectively. This would decrease the attention weight on the uncertain belief about the composition of the urn—a negative belief because of the uncertainty. Decreasing the attention weight on a negative belief, of course, increases utility. Our assumptions do not specify precisely how much the attention weight decreases as the stakes are reduced, but it is quite reasonable to think that there is diminishing sensitivity of attention weight to how much is at stake corresponding to an uncertain belief. Thus, our model can easily accommodate a greater gain in utility when rendering an uncertainty completely moot than when partially drawing down a higher-stakes exposure (and merely limiting its importance somewhat). This would allow the pattern $a_1 > a_2$ and $a_3 < a_4$.

Machina's second paradox, the reflection example, involves a similar urn that is now balanced with 50 red or yellow balls and 50 black or green balls. Table 2 displays four bets, showing the payoffs in the case that each kind of ball is drawn. In this example, the prizes do not need to have equal utility increments, and it is fine to think of them as monetary payoffs. Once again, an individual first chooses between b_1 or b_2, then between b_3 or b_4. As in the 50:51 example, both choices involve allocating prizes between yellow and black with the remaining prizes fixed, and the contexts vary in how these remaining prizes are fixed. Bets b_1 and b_3 reduce the stakes that depend on the proportion of black to green balls but increase the stakes that depend on the proportion of red to yellow balls, relative to bets b_2 and b_4, respectively. Viewed alternatively, bets b_1 and b_4 eliminate exposure to one source of uncertainty while amplifying exposure to another, relative to bets b_2 and b_3. Empirically, the most common pattern of choices (exhibited by about half of subjects) is $b_1 > b_2$ and $b_3 < b_4$, with a sizable minority (slightly above a quarter of subjects) choosing the opposite, and relatively few violating reflection symmetry (L'Haridon & Placido, 2010).

An individual who judges all possible compositions of the urn to be equally probable would determine that the expected values of the prizes associated with these four bets are all equal. Thus, according to our model, the choice between bets would hinge on which bet placed less attention weight on uncertain, negative beliefs. Once again, our model does not specify precisely how much importance, or, in turn, attention weight, decreases as the stakes associated with an uncertain belief are drawn down, and there could well be heterogeneity across the population, so the model does not rule out any pattern of behavior in this example. Still, from this perspective, the typical pattern of behavior is not surprising. If, as we hypothesized in order to explain the 50:51 example, attention weight exhibits diminishing sensitivity to exposure to an uncertain belief, then eliminating a modest exposure entirely would have a greater effect than partially reducing a large exposure by the same amount. By the informational symmetry between the red/yellow composition and the green/black composition, the (negative) value of the (uncertain) belief about each should be equal. Accordingly, a greater reduction in attention weight would lead to a greater increase in utility, regardless of which uncertainty is rendered moot. That is, we would then predict $b_1 > b_2$ and $b_3 < b_4$. Thus, diminishing sensitivity of attention weight with respect to the stakes associated with an uncertain belief allows our model to accommodate both of Machina's paradoxes.

An Experimental Test of a Key Prediction

The acid test of a new theory is to generate and test predictions that other theories do not produce and that have not been previously tested. Here, we report two such tests of our theory. The key prediction of the theory is that people will be more willing to bet on, and will bet more on, uncertainties that they like to think about. Study 1 confirms this prediction in a domain of risk, and Study 2 confirms the prediction in the domain of ambiguity.

Table 2
Machina's Reflection Example

	50 balls		50 balls	
Bets	Red	Yellow	Black	Green
b_1	0	50	25	25
b_2	0	25	50	25
b_3	25	50	25	0
b_4	25	25	50	0

Study 1

We designed a lab-in-the-field study to see if people do, in fact, bet more money on uncertainties that they like to think about than uncertainties they do not like to think about. We identified hometown sports teams' performance as an issue that many people have strong feelings about; in particular, we examined participants' willingness to bet on baseball player performance during regular season play.

We assumed that Pittsburgh Pirates baseball fans like thinking about Pirates getting hits and dislike thinking about Pirates striking out. Our theory predicts that Pirates fans' willingness to bet on a gamble over which of two Pirates has more hits (positive-valence information gap) in a fixed period should be greater than their willingness to bet on a gamble over which of two Pirates has more strikeouts (negative-valence information gap) in the same fixed period.

Method

Participants. Participants were recruited at the 2017 Three Rivers Arts Festival, a free community fair held in downtown Pittsburgh. Of the 193 people that completed the study, 50% were men ($n = 96$), the average age was 36.57 (age range = 18–86), and 61% ($n = 118$) had at least a bachelor's degree.

Design and stimuli. We asked participants to complete a one-page study in which they were given an opportunity to place a bet on the performance of two local players. In our between-subjects design, participants were randomly assigned to one of two conditions: betting on which player would get more hits (the positive valence condition) or betting on which player would get more strikeouts (the negative valence condition). Specifically, participants in the positive valence condition could bet on whether Josh Bell or Josh Harrison (two of the top players on the Pirates that year) would get more hits during the 4-week period leading up to the All Star Game. The negative valence condition simply replaced "hits" with "strikeouts." (If they both were to get the same number of hits [or strikeouts respectively], the bet would neither win nor lose.)

Procedure. We gave participants a $25 credit to bet with and promised that one in every five participants would receive their balance (i.e., $25 plus or minus their bet, depending on whether they won or lost) in the form of an Amazon gift card emailed to them after the four weeks were up. We first elicited participants' familiarity with the two players (and informed subjects who had no idea who the players were that they were two of the top hitters for the Pirates). We then asked participants to decide and report how much they wanted to bet before knowing who they were betting on. We then determined the player that participants were betting on via a coin flip. (Participants first picked one of the two players to associate with heads and could make a clean flip of the coin themselves. If heads came up, their bet was for the player they picked. If tails came up, their bet was for the other player. This way there could be no doubt that the chances of winning the bet, before knowing who they were betting on, were 50/50.) After the bet was made, participants completed a brief set of demographic questions.[19]

Results

Figure 1 shows the average amount bet in each condition. As predicted, participants bet significantly more in the positive-valence condition than in the negative-valence condition. Table 3 presents regression analyses of willingness to bet on the two different gambles. Specification 1 simply regresses the amount bet on the study condition. Specification 2 includes demographic controls. A specification including measures of fandom is not included in the regression table because the fandom measure did not meaningfully impact the amount bet. (We had predicted that there would be an interaction effect, with more engaged fans being more sensitive to the difference between betting on hits and betting on strikeouts, but we did not find a significant interaction effect.) In short, our results show that study participants were willing to bet significantly more in the positive valence bet (hits) than the negative valence bet (strikeouts, which serves as the regression constant).

Discussion

Our finding of an increased preference to make bets when one feels better about the subject of the bets in this study is a demonstration of source preference for choice under risk. We designed the bets so that even though they depended on ambiguous events, randomness about which player subjects were betting on meant that the bets had a known 50% chance of winning when subjects were deciding how much to bet. Still, the bets differed in the events that would matter over the 4-week period while the uncertainty played out. In this context, the source preference cannot be attributed to the degree of ambiguity in the bets—there is none—but instead depends on how enjoyable it is to think about the different events playing out.

Study 2

We designed a second study to test for the same kind of source preference in the presence of ambiguity, that is, to test whether people are more ambiguity tolerant for bets that depend on higher valence events. Our goal was to create a choice environment resembling the Ellsberg paradox, but with the ambiguous bets depending on events that varied in valence rather than on the composition of an urn. People indicated their preferences between complementary ambiguous bets and 50/50 risky bets, and were thus classified as ambiguity-averse, ambiguity-neutral, or ambiguity-seeking for each source of ambiguity.[20] We then determined whether people are more often ambiguity-seeking (and less often ambiguity-averse) when the events they can bet on have higher valence.

[19] We have reported all measures, conditions, and data exclusions. Our sample size was determined by the number of subjects we were able to recruit during the arts festival and was finalized before we examined the data. The stimuli and raw data from both of our studies is available in the online supplemental materials.

[20] Classification as ambiguity-neutral means that behavior is consistent with being ambiguity-neutral, not that preferences are necessarily precisely ambiguity-neutral. Ambiguity neutrality thus captures any behavior that is not conclusively ambiguity-averse or ambiguity-seeking.

Method

Participants. Participants were 418 Carnegie Mellon alumni, recruited from a pool of alumni who had joined an e-mail list to participate in Carnegie Mellon behavioral decision research.[21]

Design and stimuli. For this participant pool, consisting of Carnegie Mellon alumni who continue to engage with university activities, we assumed that Carnegie Mellon's reputation as a top university is a source of pride. We thus chose to offer bets that depended on the rankings of educational programs at Carnegie Mellon in the next edition of *U.S. News and World Report* as events that would have higher or lower valence depending on the prestige of the particular educational programs involved. All bets were presented as a chance to win a $50 gift certificate from the Carnegie Mellon University (CMU) bookstore depending on some contingency.

To create complementary bets that both expose participants to a high-valence information gap, we selected two similar, highly regarded educational programs at Carnegie Mellon: Computer Systems and Programming Languages. Both programs are in the School of Computer Science, which is ranked No. 1 overall, and both programs are ranked No. 2 among similar programs in the United States in the current *U.S. News and World Report* rankings. Participants were given this information through a series of questions and answers. One high-valence bet was then constructed as, "Win the gift certificate if Computer Systems has a better rank than Programming Languages next year." The complementary high-valence bet was, "Win the gift certificate if Programming Languages has a better rank than Computer Systems next year." These two bets were presented alongside two 50/50 risky bets: "Win the gift certificate if a virtual coin flip (based on a random number generator) is heads" and "Win the gift certificate if a virtual coin flip (based on a random number generator) is tails." Participants ranked the four bets from most preferred to least preferred (allowing for ties). This choice was incentivized by telling participants that one out of every 10 participants would be eligible to receive the gift certificate based on their most preferred contingency, and that one of out every 100 participants would be eligible to receive the gift certificate based on their second most preferred contingency. We also informed participants that if Computer Systems and Programming Languages were to get the same ranking next year or if *U.S. News and World Report* does not release new rankings next year, then the virtual coin flip would determine if they win the gift certificate. In other words, if there were a tie, the choice was moot, so participants did not need to worry about it.

To create complementary bets that expose participants to a lower-valence information gap, we selected two similar educational programs that are not as highly ranked: Biological Sciences and Chemistry. Both programs are in the natural sciences, and both are ranked near No. 40 among similar programs in the United States in the current *U.S. News and World Report* rankings. In addition to giving participants this information, we added a statement that both programs "are in danger of falling out of the top 50 altogether" with the goal of creating a negative mindset about these programs. The bets were constructed in the same way as in the high-valence context, except that they were framed as winning if one program has a worse rank than the other (instead of better rank than the other). That is, one bet was described as, "Win the gift certificate if Biological Sciences has as worse rank than Chemistry next year," and the other as "Win the gift certificate if Chemistry has as worse rank than Biological Sciences next year." The preference elicitation was the same for these bets as for the computer science bets.

The information gap about the natural science departments' rankings has lower valence than the information gap about the computer science rankings for two reasons: (1) their rankings will not be as good as the computer science rankings and (2) the framing of the information gap, emphasizing the "danger of falling out of the top 50" and posed as which department will have a

Table 3
Regressions of Amount Bet on the Baseball Gamble

Variable	Amount bet in $US (DV) (1)	(2)
Hits	2.390* (1.128)	2.201† (1.145)
Age		−0.043 (0.036)
Education		−0.062 (0.369)
Male		1.110 (1.140)
Constant	17.429** (0.820)	18.883** (2.134)
Observations	193	187
R^2	0.023	0.037
Adjusted R^2	0.018	0.016
Residual *SE*	7.822 (df = 191)	7.768 (df = 182)
F	4.490* (df = 1, 191)	1.754 (df = 4, 182)

Note. DV = dependent variable. Specification (1) includes just the treatment condition; specification (2) includes demographic variables. All values are reported *M (SD)*.
† $p < .10$. * $p < .05$. ** $p < .01$.

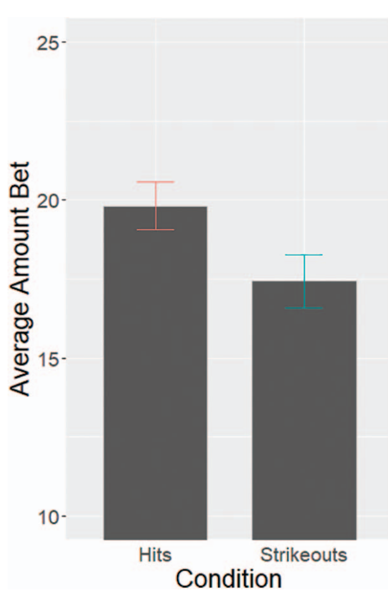

Figure 1. Average amount bet on gambles about hits and about strikeouts. See the online article for the color version of this figure.

[21] The sample size was determined by sending a mass email to this list and allowing one week for responses, in accordance with existing policies for use of this mailing list.

"worse rank," may induce a negative mindset about it. Our design does not permit us to disentangle these two distinct aspects of our manipulation, but we chose to include them together because they both lower the valence of the information gap about the natural science departments' rankings, and we wanted to use a strong manipulation. Participants indicated their preferences among both sets of bets on separate screens, with the order counterbalanced, in a within-subjects design.

Procedure. After the preference elicitations, participants also assessed the subjective likelihood of each of these ambiguous events using a slider with labels ranging from *extremely unlikely* to *extremely likely*. These responses were not incentivized. Finally, participants indicated how much they cared about CMU's ranking using a slider with labels ranging from *not at all* to *a great deal*. The subjective likelihood assessments let us check whether participants believe one bet is more likely to win than its complement, and the question about how much they care about CMU's ranking lets us investigate whether any effects we observe may be driven especially by participants who care more the issue.

Analysis. For both the computer science (higher-valence) bets and the natural science (lower-valence) bets (separately), we classify participants as ambiguity averse if they strictly preferred both risky bets to both (complementary) ambiguous bets, ambiguity seeking if they strictly preferred both (complementary) ambiguous bets to both risky bets, and ambiguity neutral (or possibly inconclusive) otherwise. Each participant was thus identified as one of $3 \times 3 = 9$ types, corresponding to one of three categories of ambiguity preference for each of the two contexts. Our classification is conservative in departing from ambiguity neutrality in that ambiguity preference needs to overcome any difference in subjective expected value (if subjective probabilities are not 50/50) to be detected. In other words, any behavior classified as ambiguity averse or ambiguity seeking is a clear violation of subjective expected utility, but on the other hand, an individual who had an actual nonneutral ambiguity preference might still report preferences consistent with ambiguity neutrality if he thought one bet was more likely to win than its complement.

Results

Figure 2 displays the results. The majority of participants were ambiguity averse for both sets of bets, consistent with typical behavior in the Ellsberg paradox. However, a nontrivial fraction of participants were ambiguity neutral or ambiguity seeking for both sets of bets. The most interesting behavior for the purpose of testing our hypothesis about source preference is different ambiguity preference across the two sets of bets. We see that 15.54% of participants are more tolerant of ambiguity for the computer science (higher valence) bets than for the natural science (lower valence) bets (summing the three lower-right cells in Figure 2), whereas only 8.62% of participants are less tolerant of ambiguity for the computer science bets than for the natural science bets (summing the three upper left cells in Figure 2). A Wilcoxon signed-ranks test with continuity correction indicated that participants were significantly more ambiguity tolerant for the higher-valence computer science bets than for the lower-valence natural science bets ($V = 3844$, $p = 7.61 \times 10^{-6} < .001$).

Figure 2. Proportion of participants classified by each ambiguity preference across the two sets of bets. See the online article for the color version of this figure.

One potential concern is that participants might not have considered both pairs of ambiguous bets to have similar subjective probabilities associated with them. Indeed, they reported a higher likelihood for "Computer Systems is ranked better than Programming Languages" than for the opposite ($M = 58\%$ vs. $M = 49\%$; note that we did not require their assessments to sum to 100%), but reported similar likelihoods for "Biological Sciences is ranked better than Chemistry" and its opposite ($M = 50\%$ vs. $M = 52\%$). Observing that the majority of subjects are ambiguity averse, we might worry that the shift toward ambiguity tolerance for the computer science bets could result from our conservative classification scheme missing some ambiguity aversion for the computer science bets and categorizing it as ambiguity neutrality (more so than for the natural science bets). For example, an ambiguity averse individual might still most prefer the bet on computer systems to be ranked better than programming languages if he believed this event were sufficiently likely, and this person would then appear to be ambiguity neutral for the computer science bets. We can address this concern by analyzing the data exclusively for participants who reported clear, nonneutral ambiguity preference for both sets of bets, that is, by comparing the bottom-right cell in Figure 2 to the top-left cell. We find that the asymmetry here is extreme, with quite a few participants behaving as if they were ambiguity averse for the lower-valence natural science bets and ambiguity seeking for the higher-valence computer science bets, but almost nobody displaying the opposite pattern. A two-tailed binomial test indicates that when restricting to the 35 participants who are ambiguity averse for one set of bets and ambiguity seeking for the other set, the proportion 33/35 who are ambiguity averse for the natural science bets and ambiguity seeking for the computer science bets is significantly higher than expected by chance 50% ($p = 4 \times 10^{-8} < .001$).

We observed that the distinctive pattern of displaying ambiguity aversion for the natural science bets and ambiguity seeking for the computer science bets was significantly more common for participants who first ranked the natural science bets and then ranked the computer science bets (24/211 participants) than for participants who saw this preference elicitation in the reverse order (9/207 participants; $p = .0103$), according to Fisher's exact test. However, there were no other significant order effects, and the effect dissipates if we include participants classified as ambiguity neutral for one of the bets (37/211 participants who first ranked the natural science bets were weakly more ambiguity tolerant for the computer science bets than for the natural science bets vs. 28/207 participants who first ranked the computer science bets were weakly more ambiguity tolerant for the computer science bets, $p = .2819$, according to Fisher's exact test). We did not anticipate any order effects, and it is possible that the one order effect we do observe is spurious. Such an order effect could arise due to a contrast effect in evaluating the valence of the bets, that is, if betting on the computer science departments' rankings feels more enjoyable in contrast to the unappealing bets on the natural science departments' rankings, but this is a post hoc explanation, and the evidence is inconclusive. We also look for an order effect in the proportions of clear shifts in ambiguity attitude that go in the predicted direction. For the participants who ranked the computer science bets before the natural science bets, nine of them shifted from ambiguity seeking for the computer science bets to ambiguity averse for the natural science bets, whereas only two of them shifted in the opposite direction from ambiguity averse to ambiguity seeking. For the participants who ranked the natural science bets before the computer science bets, 24 of them shifted from ambiguity averse for the natural science bets to ambiguity seeking for the computer science bets, and none shifted in the opposite direction. The proportions 9/11 and 24/24 are not significantly different ($p = .0924$), according to Fisher's exact test. Thus, the observed order effect, if it is real, does not appear to fully explain our primary finding that participants are more tolerant of ambiguity for the computer science bets than for the natural science bets.

If there are individual differences in how much our participants care about CMU's ranking in *U.S. News and World Report*, then we would expect a stronger effect (i.e., stronger source preference in ambiguity attitude) for participants who care more (i.e., who derive more utility from their beliefs about this issue). Indeed, this is what we find. We define an indicator Φ_{CS} that equals 1 if an individual is ambiguity seeking for the computer science bets, 0 if ambiguity neutral for these bets, and -1 if ambiguity averse for these bets, along with an indicator Φ_{NS} that equals 1 if an individual is ambiguity seeking for the natural science bets, 0 if ambiguity neutral for these bets, and -1 if ambiguity averse for these bets. We then run a simple linear regression to predict $\Phi_{CS} - \Phi_{NS}$ based on participants' self-reported score indicating how much they care about CMU's ranking. We find a significant relationship ($F(1, 409) = 4.441$, $p = .0357 < .05$), with an adjusted R^2 of .0083.[22] The regression predicts our measure of source preference to be

$$\Phi_{CS} - \Phi_{NS} = -.0360 + .0028(\text{ranking\_matters}),$$

with the variable ranking_matters being the self-reported score on a scale from 0 to 100 of how much the participant cares about CMU's ranking. Participants display stronger source preference (i.e., more tolerance of ambiguity for the higher-valence computer science bets than for the lower-valence natural science bets) when they report that they care more about CMU's ranking (i.e., when the information gaps associated with the bets have a greater impact on their utility). In summary, we have found strong evidence supporting our hypothesis that people are more tolerant of ambiguity stemming from higher valence information gaps.

Discussion

Heath and Tversky (1991) first demonstrated a source preference involving expertise or familiarity. Their experiments showed that people prefer to make bets when they are more knowledgeable about the subject of the bets. In contrast, our studies show that people prefer to make bets when they enjoy thinking about the subject of the bets. Of course, in many situations a subject that a person is knowledgeable about is one that the person enjoys thinking about and vice versa. In our studies, however, there is no reason to believe that people are more knowledgeable about the higher valence information gaps. Thus, Heath and Tversky's competence hypothesis cannot account for our findings.

[22] Note that seven participants did not report how much they care about CMU's ranking and were excluded from this analysis.

Conclusion

Preferences over beliefs (and the attention paid to them) create preferences for or against risky and ambiguous gambles. This information gap account of attitudes toward risk and ambiguity makes sense of low-stakes risk aversion, the difference between comparative and noncomparative responses to ambiguity vis a vis risk, and the sensitivity of ambiguity preference to the source of the uncertainty. It is consistent with empirically documented patterns of behavior that have been difficult for other theories to reconcile. We have established the following testable predictions:

Hypothesis 1: Individuals prefer to avoid actuarially fair lotteries that do not involve events that they particularly enjoy thinking about.

Hypothesis 2: Individuals prefer an equivalent simple lottery to a compound lottery that does not involve events that they enjoy thinking about.

Hypothesis 3: Individuals prefer to wager on uncertainties they enjoy thinking about (i.e., that depend on positive beliefs) than on objectively random events, but prefer such random bets to wagers that depend on negative beliefs.

Hypothesis 4: Individuals forced to choose among wagers that depend on negative beliefs prefer to wager on an uncertainty that is less salient.

Timing effects are not part of our formal model, and intuitions about the effects of time delay runs in both directions. From one point of view, it seems intuitive that the costs (or benefits) associated with thinking about negative (or positive) beliefs would scale with the amount of time that an individual spends thinking about them. To the extent the pleasures or pains of focusing on an information gap account for risk and ambiguity preferences, we should then expect that some time delay between exposure to uncertainty (risk or ambiguity) and resolution of that uncertainty would strengthen risk and ambiguity preferences. On the other hand, there is substantial evidence that the feelings associated with uncertainty are strongest right before uncertainty is going to be resolved (van Winden, Krawczyk, & Hopfensitz, 2011). This suggests that short- and long-term time discounting will dictate whether time delay strengthens or weakens risk and ambiguity preferences. Although we are reluctant to offer any general predictions about the effect of time delays, to the degree that time delay intensifies risk or ambiguity preferences, we would speculate that the effects would be stronger for people who discount the future less.

The primary determinant of risk and ambiguity preference in our model is how people feel when they think about questions about a gamble. These feelings are likely to be a function of a wide range of factors, including the outcomes, associated probabilities, the vividness of outcomes, the individual's feeling of expertise, any contextual factors (e.g., residual sadness or elation) which affect the individual's emotional reactions, and a variety of individual dispositional factors. Another tenet of our model is that feelings, and hence preferences, should depend on the salience of the unanswered questions—the information gaps. Salience is, in turn, likely to depend on situational factors, decision framing, and the existence of counterfactuals that highlight the information gaps. We have shown that these effects can make sense of a variety of already established empirical effects, and also provided new experimental evidence in support of a key, previously untested, prediction: people wager more about events that they enjoy (rather than dislike) thinking about.

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Appendix

Formal Theoretical Framework and Results

To begin, we represent a person's state of awareness with a (finite) set of activated questions $\mathcal{Q} = \{Q_1, \ldots, Q_m\}$, where each question Q_i has a set of possible (mutually exclusive) answers $\mathcal{A}_i = \{A_i^1, A_i^2, \ldots\}$. We let X designate a set of prizes. Denote the space of answer sets together with prizes as $\alpha = \mathcal{A}_1 \times \mathcal{A}_2 \times \ldots \times \mathcal{A}_m \times X$. A cognitive state can then be defined by a probability measure π defined over α (i.e., over possible answers to activated questions as well as eventual prizes) and a vector of attention weights $\mathbf{w} = (w_1, \ldots, w_m) \in \mathbb{R}_+^m$. We define a question as "activated" when its associated attention weight is greater than zero. A utility function is defined over cognitive states, written as $u(\pi, \mathbf{w})$.

The probability measure reflects a subjective judgment about the probability of the possible answers to the activated questions and of the prizes that may be received and satisfies the standard laws of probability. Material outcomes may correlate with answers about activated questions, and the answer to one question may provide information about the likelihood of different answers to another question. We can consider a marginal distribution π_i that specifies the probability of possible answers to question Q_i or π_X that specifies the probability over prizes.

The attention weights specify how much a person is thinking about each question and, in turn, how much the beliefs about those questions directly impact utility. The attention w_i on question Q_i is assumed to be strictly increasing in, and to have strictly increasing differences in, the question's importance γ_i and salience σ_i. To characterize the importance of question Q_i, we consider the probabilities of discovering any possible answer $A_i \in A_i$ (or, omitting answers thought to be impossible, in the support of the individual's belief about the question, $\text{supp}(\pi_i)$ and the utilities of the cognitive states $(\pi(\cdot \mid A_i), \mathbf{w})$ that would result from discovering each possible answer A_i. (We assume here for simplicity that belief updating after discovering answer A_i accords with Bayes' rule and that the attention weights do not change due to this discovery. Golman and Loewenstein (2018) assume that these attention weights are affected by surprise; all of our results are consistent with this assumption as well, but we neglect surprise for simplicity of presentation.) We assume that the importance γ_i of question Q_i is a function of the subjective distribution of utilities that would result from different answers to the question,

$$\gamma_i = \phi(\langle \pi_i(A_i), u(\pi(\cdot \mid A_i), \mathbf{w}) \rangle_{A_i \in \text{supp}(\pi_i)}), \tag{1}$$

that increases with mean-preserving spreads of the distribution of utilities and that is invariant with respect to constant shifts of utility. (Technically, importance is a fixed point of this equation, due to the circularity between importance and utility.)

We assume that utility takes the form $u(\pi, \mathbf{w}) = u_X(\pi_X) + \sum_{i=1}^{m} w_i v_i(\pi_i)$.[23] The first term describes the utility of a distribution over prizes and the remaining terms describe the utilities of beliefs about each activated question, amplified by the attention weights on each of these questions.[24] To stick to standard utility theory as closely as possible, apart from our belief-based utility terms, we assume that $u_X(\pi_X) = \sum_{x \in X} \pi_X(x) v_X(x)$.

We assume that the value of a belief (e.g., $v_i(\pi_i)$) depends only on the valences of the answers that are considered possible (e.g., $v_i(A_i)$ for all $A_i \in \text{supp}(\pi_i)$) and the amount of uncertainty in the belief.[25] Naturally, $v_i(\pi_i)$ is increasing in $v_i(A_i)$ for each $A_i \in \text{supp}(\pi_i)$.[26] We assume a "one-sided sure-thing principle," which holds that people always prefer a certain answer to uncertainty among answers that all have valences no better than the certain answer (holding attention weight constant). If for all $A_i \in \text{supp}(\pi_i)$ we have $v_i(\pi_i') \geq v_i(A_i)$, then $v_i(\pi_i') \geq v_i(\pi_i)$, with this inequality strict whenever π_i is not degenerate. This one-sided sure-thing principle operationalizes the assumption that uncertainty is aversive.[27] We assume that if $v_i(A_i)$ grows large for each $A_i \in \text{supp}(\pi_i)$, then $v_i(\pi_i) > 0$.

Making a wager can be modeled as an action a that acts on a given cognitive state $(\pi\ \mathbf{w})$ to determine a new cognitive state $(\pi[a], \mathbf{w}[a])$. It specifies a map from every answer set $\mathbf{A} \in \mathcal{A}_1 \times \ldots \times \mathcal{A}_m$ to a conditional distribution over prizes in $\Delta(X)$. Along with the prior judgment about the probability of each answer set, which is preserved by the action, this defines the new probability measure $\pi[a] \in \Delta(\alpha)$. The new attention weights $\mathbf{w}[a]$ are determined by new values of importance as described by Equation 1. Preference between actions is determined by their impacts on the cognitive state, in accordance with the utility function $u(a \mid \pi\ \mathbf{w}) = u(\pi[a], \mathbf{w}[a]) - u(\pi, \mathbf{w})$.

[23] Golman and Loewenstein's (2018) separability, monotonicity, and linearity properties would imply this form for the utility function.

[24] If we assumed that the utility of objective outcomes was fully captured by their impact on beliefs, the first term could be left out of the model.

[25] We abuse notation by referring to the valence of answer A_i as $v_i(A_i)$, a convenient shorthand for the value v_i of belief with certainty in A_i.

[26] More precisely, we assume that if there exists $\tau: \mathcal{A}_i \rightarrow \mathcal{A}_j$ such that $\pi_i(A_i) = \pi_j(\tau(A_i))$ and $v_i(A_i) \leq v_j(\tau(A_i))$, then $v_i(\pi_i) \leq v_j(\pi_j)$ with the latter inequality strict if the former inequality is. This is Golman and Loewenstein's (2018) label independence property.

[27] In contrast, Savage's (1954) sure-thing principle is based on the view that uncertainty is not intrinsically attractive or aversive.

(*Appendix continues*)

Low-Stakes Risk Aversion

Proposition 1

Assume v_X is linear over $\mathbb{R}$. Suppose question Q_1 is about the outcome of the coin toss, so that it is independent of other questions, it is believed to be a fair coin with $\pi_1(\text{H}) = \pi_1(\text{T}) = \frac{1}{2}$, and both heads and tails have neutral valence, that is, $v_1(\text{H}) = v_1(\text{T}) = 0$. Suppose bet b attaches prize x^* to heads and $-x^*$ to tails, so that $\pi_X^{\text{H}}[b](x^*) = \pi_X^{\text{T}}[b](-x^*) = 1$. Suppose not betting ($\neg b$) attaches prize 0 to both heads and tails, so that $\pi_X[\neg b](0) = 1$. There is a strict preference not to bet, $\neg b \succ b$.

Proof

Linearity of v_X implies that $u_X(\pi_X[b]) = u_X(\pi_X[\neg b])$. However, because bet b spreads out the utilities that would result from discovering either heads or tails, it increases γ_1, which implies that $w_1[b] > w_1[\neg b]$. By the one-sided sure-thing principle, we know that $v_1(\pi_1) < 0$ (regardless of whether the bet is taken) because the belief about the coin flip is not degenerate (i.e., because it is uncertain). Accepting the bet would increase attention weight on a negative belief and would thus lower utility, so $\neg b \succ b$. □

Compound Risk Aversion

Definition

Let Q_j be a question that is believed to be independent of all other questions. Given a sequence of prizes $x_h \in X$ with distinct valences, $v_X(x_{h_1}) \neq v_X(x_{h_2})$ for $h_1 \neq h_2$, suppose that an action a_j attaches prize x_h to answer A_j^h of question Q_j so that $\pi_X[a_j](x_h \mid A_j^h) = 1$ for all h. Then we say that action a_j exposes the decision maker to a simple lottery determined by the answer to question Q_j.

Let Q_i be a question, belief about which is pairwise dependent with belief about some other question $Q_{\tilde{\imath}}$. Given a sequence of prizes $x_h \in X$ with distinct valences, $v_X(x_{h_1}) \neq v_X(x_{h_2})$ for $h_1 \neq h_2$, suppose that an action a_i attaches prize x_h to answer A_i^h of question Q_i so that $\pi_X[a_i]\,(x_h \mid A_i^h) = 1$ for all h. Then we say that action a_i exposes the decision maker to a compound lottery determined by the answer to question Q_i (and contingent on question $Q_{\tilde{\imath}}$).

An action a_i that exposes the decision maker to a compound lottery is materially equivalent to an action a_j that exposes the decision maker to a simple lottery if they induce the same marginal probability distribution over prizes, $\pi_X[a_i] = \pi_X[a_j]$.

Proposition 2

Let action a_j expose the decision maker to a simple lottery determined by the answer to question Q_j, and let a materially equivalent action a_i expose the decision maker to a compound lottery determined by the answer to question Q_i. Suppose that the answers to any question jointly dependent with Q_i (including Q_i itself) as well as the answers to Q_j all have neutral valence. Suppose questions Q_i and Q_j both have the same salience, $\sigma_i = \sigma_j$. Then the simple lottery is preferred, $a_j \succ a_i$.

Proof

Denote by $\mathcal{Q}^E$ the set of all questions believed to be jointly dependent with question Q_i. Actions a_i and a_j determine probability measures $\pi[a_i]$ and $\pi[a_j]$ and attention weight vectors $\mathbf{w}[a_i]$ and $\mathbf{w}[a_j]$ such that

1. $\pi_{\mathcal{A}}[a_i](\cdot) = \pi_{\mathcal{A}}[a_j](\cdot)$;
2. $\pi_X[a_i](\cdot) = \pi_X[a_j](\cdot)$;
3. $w_i[a_i] = w_j[a_j]$ and $w_j[a_i] = w_i[a_j]$;
4. for any ν such that $Q_\nu \in \mathcal{Q}^E$, we have $w_\nu[a_i] \geq w_\nu[a_j]$ with strict inequality for $\nu = \tilde{\imath}$;
5. for any $\nu \neq j$ such that $Q_\nu \in \mathcal{Q} \backslash \mathcal{Q}^E$, we have $w_\nu[a_i] = w_\nu[a_j]$.

Condition 1 holds because instrumental actions determine prizes, but not beliefs. Condition 2 holds because the actions are materially equivalent. Condition 3 follows from the assumption that Q_i and Q_j have the same salience together with the observations that the same material importance is given to each question when the corresponding action is taken (because the questions have the same probability distributions and the actions attach the same prizes) and that neither question is important when the other action is taken. The crucially important Condition 4 applies because only question $\mathcal{Q}^E$ has dependence on $\mathcal{Q}^E \backslash \{Q_i, Q_j\}$, so only action a_i can increase the importance of these other questions. Last, Condition 5 holds because questions outside of $\mathcal{Q}^E$ are independent of both Q_i and Q_j.

Because questions Q_i and Q_j have the same probabilities (following from material equivalence) as well as the same (neutral) valences for all possible answers, it can be shown (using the assumptions of label independence and linearity with respect to attention weights) that the utility cost of an increase in attention weight on one is equal to the utility cost of the same increase in attention weight on the other.

Any uncertain belief about a question in $\mathcal{Q}^E$ must be a negative belief because certainty would be a neutral belief and the one-sided sure-thing principle applies. Thus, by the assumption of monotonicity with respect to attention weights, the increase in attention weight on question $Q_{\tilde{\imath}}$ that occurs for action a_i (according to Condition 4) causes a decrease in utility. □

(*Appendix continues*)

Definition of Ambiguity

An ambiguous gamble determined by the answer to question Q_i is a compound lottery determined by the answer to question Q_i that is contingent on the question "what is the probability distribution over answers to question Q_i?"

Ambiguity Aversion in the Ellsberg Paradox

Corollary 1

Let action a_j expose the decision maker to a simple lottery determined by the answer to question Q_j, and let a materially equivalent action a_i expose the decision maker to an ambiguous gamble determined by the answer to question Q_i. Suppose that the answers to any question jointly dependent with Q_i (including Q_i itself) as well as the answers to Q_j all have neutral valence. Suppose questions Q_i and Q_j both have the same salience, $\sigma_i = \sigma_j$. Then the simple lottery is preferred, $a_j \succ a_i$.

Proof

Corollary 1 follows from Proposition 2 about compound risk aversion and applies directly to the Ellsberg paradox. Consider Q_i to be the question of which ball is drawn from the ambiguously specified urn. Belief about this question depends on the belief about the composition of this urn. On the other hand, belief about Q_j—which ball is drawn from the known urn—is independent of all other beliefs.[28]

Salience Effect

Proposition 3

Let action a_i expose the decision maker to an ambiguous gamble (or compound lottery) determined by the answer to question Q_i and contingent on question $Q_{\tilde{\imath}}$. Suppose that the answers to any question jointly dependent with Q_i all have neutral valence. Consider two possible baseline cognitive states $(\pi, \mathbf{w})$ and $(\pi, \hat{\mathbf{w}})$ that have the same probability judgments but with different attention weights that result from question $Q_{\tilde{\imath}}$ being more salient in the latter state than in the former, that is, $\hat{\sigma}_{\tilde{\imath}} > \sigma_{\tilde{\imath}}$ and $\hat{\sigma}_\nu > \sigma_\nu$ for all other Q_ν.[29] Action a_i would be more preferable in the former cognitive state than in the latter, that is, $u(a_i \mid \pi, \mathbf{w}) > u(a_i \mid \pi, \hat{\mathbf{w}})$.

Proof

As in Proposition 2, bet a_i attached to question Q_i makes question $Q_{\tilde{\imath}}$ more important and thus increases the attention weight on a negative belief. By the assumption that attention weight exhibits increasing differences in salience and importance, the decrease in utility due to this effect is worse in cognitive state $(\pi, \hat{\mathbf{w}})$ when question $Q_{\tilde{\imath}}$ is more salient than in cognitive state $(\pi, \mathbf{w})$. □

Preference for Gambles Determined by High-Valence Events

Proposition 4

Let action a_j expose the decision maker to a simple lottery determined by the answer to question Q_j, and let a materially equivalent action a_i expose the decision maker to an ambiguous gamble (or compound lottery) determined by the answer to question Q_i. Suppose questions Q_i and Q_j both have the same salience, $\sigma_i = \sigma_j$. Suppose that the answers to question Q_i and/or the answers to some question(s) that are pairwise dependent with Q_i all have the same valence υ, but now allow this valence to be positive or negative. Suppose that the answers to any other questions believed to be jointly dependent with Q_i as well as the answers to Q_j all still have neutral valence. Preference for action a_i, that is, $u(a_i \mid \pi, \mathbf{w})$, is increasing in the valence υ. Moreover, for sufficiently high υ, the ambiguous gamble is preferred to the simple lottery, $a_i \succ a_j$.

Proof

By our construction, utility exhibits increasing differences in the value of a belief and the attention weight on it. For sufficiently high υ, even an uncertain belief will be a positive belief. In this case, increasing the attention weight on it increases utility, so the bet a_i becomes favored relative to a_j. □

[28] The belief that there is a one half chance of drawing a red ball and a one half chance of drawing a black ball from the known urn is determined by the belief about its composition, but this belief is held with certainty, and dependence on a probability zero/one event is impossible.

[29] Consider the latter cognitive state to result from joint evaluation of a_i alongside an action that exposes the decision maker to a materially equivalent simple lottery and consider the former cognitive state to result from isolated valuation of a_i.

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