Ambiguity aversion in qualitative contexts: A vignette study

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Abstract

Most studies of ambiguity aversion rely on experimental paradigms involving contrived monetary bets. Thus, the extent to which ambiguity aversion is evident outside of such contexts is largely unknown, particularly in those contexts which cannot easily be reduced to numerical terms. The present work seeks to understand whether ambiguity aversion occurs in a variety of different qualitative domains, such as work, family, love, friendship, exercise, study and health. We presented participants with 24 vignettes and measured the degree to which they preferred risk to ambiguity. In a separate study we asked participants for their prior probability estimates about the likely outcomes in the ambiguous events. Ambiguity aversion was observed in the vast majority of vignettes, but at different magnitudes. It was predicted by gain/loss direction but not by the prior probability estimates (with the interesting exception of the classic Ellsberg 'urn' scenario). Our results suggest that ambiguity aversion occurs in a wide variety of qualitative contexts, but to different degrees, and may not be generally driven by unfavourable prior probability estimates of ambiguous events.

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Introduction

The world is replete with the unknown, yet people generally prefer some types of 'unknown' to others. Here, an important distinction exists between *risk* and *uncertainty*. As defined by Knight (1921), *risk* is a measurable lack of certainty that can be represented by numerical probabilities (e.g., "there is a 50% chance that it will rain tomorrow"), while *ambiguity* is an unmeasurable lack of certainty (e.g., "there is an unknown probability that it will rain tomorrow"). All other things being equal, humans generally prefer risk to ambiguity; they would rather be in a situation with "known unknowns" than one with "unknown unknowns." This phenomenon is known as ambiguity aversion.

A quintessential and well-studied example of ambiguity aversion is known as the two-colour Ellsberg task. In it, people are shown two urns which contain coloured balls and are told that drawing a red ball will earn $100. People prefer to place a bet on a "risky" urn that they know contains 50 red balls and 50 blue balls while avoiding betting on an "ambiguous" urn that contains red and blue balls in an unknown combination (Ellsberg, 1961; Fellner, 1961). This preference is incredibly robust (for a review see Camerer & Weber, 1992).

However, it is unclear how far it generalises to different situations. Most of the research on ambiguity aversion involves variants of the two-colour Ellsberg task or economic games involving pecuniary contexts outside of the lab that are well suited to the quantitative toolkit of the economist. Ambiguity aversion has been found in contexts such as asset markets (Füllbrunn, Rau, & Weitzel, 2014) and insurance (e.g., Kunreuther, Meszaros, Hogarth, & Spranca, 1995). While this work has been useful for understanding and modeling the rules that may underlie people's decisions (for a review of see Machina & Siniscalchi, 2014), these situations are still quantitative, involving bets and utilities quantified numerically (usually with money), often focusing on experts.

There is much less work investigating whether people show ambiguity aversion in more real-world contexts, especially those that are not as readily understood in quantitative terms. Moreover, the sparse literature that does exist yields somewhat ambiguous conclusions. On one hand, ambiguity aversion has been observed in medical contexts such as decisions to vaccinate children (when framed as acts of co-mission but not omission; Ritov & Baron, 1990), decisions relating to online phishing (Wang, 2011), and where to live based on health risks (Viscusi, Magat, & Huber, 1991). On the other hand, people sometimes appear to be *ambiguity seeking* in medical decisions depending on whether they are framed as gains or losses (Bier & Connell, 1994; Curley, Eraker, & Yates, 1984). Indeed, even within the economic games paradigm ambiguity aversion has not always been observed in the context of losses or lower-likelihood gains (Kocher, Lahno, & Trautmann, 2018; Baillon & Bleichrodt, 2015). Overall, there is mixed evidence as to whether ambiguity aversion arises in both losses and gains (Baillon & Bleichrodt, 2015; Moore & Eckel, 2003; Kocher et al., 2018). Given the widespread evidence that people treat losses and gains differently (see e.g., Kahneman & Tversky, 1979), perhaps differences in ambiguity aversion in qualitative situations for gains and losses is to be expected.

Overall, therefore, it remains uncertain to what extent ambiguity aversion occurs in more qualitative or "everyday" situations, as well as to what extent it holds for both losses and gains. A larger question, perhaps, is *why* we might expect it to hold: or, put another way, what makes people prefer risk over ambiguity in the first place?

One possibility is that people tend to make pessimistic assumptions about ambiguous options. The ambiguous and risky choices in the Ellsberg task, for instance, are only equal if one presumes that people follow the principle of indifference (Marquis de Laplace, Pierre-Simon & Truscott, 1951); if they presume that all possible outcomes are equally likely. Under this assumption, a risky decision in which the outcomes are assigned 50/50 probability is equivalent to an ambiguous two-choice scenario in which all options are equally likely. Ambiguity aversion is often seen as a departure from rationality that is worthy of study because it is assumed that, absent any information, people in fact do have a flat prior over all possible events. If, however, people naturally assume that "good" options are rarer than "bad" options, ambiguity aversion would be entirely rational. On this view, people are acting in accordance with utility theory from a subjective probability or Bayesian sense — that is, ambiguity aversion can be consistent with utility theory as a normative model 'given what one knows' (Frisch & Baron, 1988, p. 149).

There is some evidence to support the idea that people evaluate ambiguous options unfavourably. Pulford (2009) found that highly optimistic people showed a significantly smaller amount of ambiguity aversion than less optimistic, both when they knew the generating process behind the ambiguity was randomly determined and when it could be influenced by the experimenter. Keren and Gerritsen (1999) found that people thought that a decision maker choosing a precise option was likely to have a more successful bet than a decision making choosing an ambiguous option. From a Bayesian perspective, this makes sense if people assume that omitted information is biased against them, and thus form pessimistic or unfavourable priors. Indeed, such pessimistic priors for ambiguous events may arise from 'negativity bias' more generally (Rozin & Royzman, 2001). Consistent with this, ambiguity aversion is reduced in situations where participants have evidence against pessimistic priors. For example, in experimental scenarios that allow people to verify that an ambiguous option is actually random and not biased against them, they display less ambiguity aversion (Güney & Newell, 2015). However, this is not the case when the probabilities are simply described to them; people must *experience* the probability distribution (Curley, Young, & Yates, 1989).

Why might people have pessimistic priors? One possibility derives from the theory of comparative ignorance, which suggests that ambiguity aversion arises when a person feels less competent. Thus, ambiguity aversion emerges when the context invites comparisons to more unambiguous events or more competent individuals (Fox & Tversky, 1995). In the opposite manner, when the context does not invite a comparison to more competent individuals — such as when the probability distribution underlying payoffs becomes clearly 'unknowable' to everyone involved — ambiguity aversion is reduced (Chua Chow & Sarin, 2002; Moore & Eckel, 2003).

Pessimistic priors might also arise less from a feeling of incompetence than from a suspicion about the data generating process. For example, consider the "tennis match" scenarios discussed by Gärdenfors and Sahlin (1982). In Match A, the reasoner must decide how to bet between two players that they know are extremely evenly matched. In Match B, they know nothing at all about the players, and in Match C they have been told that one of the players is strongly favoured but they do not know which one. In all of these scenarios, the reasoner strictly has a 50% of winning the bet, but one might forgive them for being suspicious about being asked to place a bet in Match C. When competing against

others — or, more broadly, when you are suspicious about the reason you are being asked the question in the first place — ambiguity aversion may be reasonable, because the things you do not know can be used against you. It is unclear to what extent people default to approaching all ambiguous situations with a certain level of caution for this reason.

Overall, then, we are left with two main questions. First, how robust is ambiguity aversion? Specifically, do people show ambiguity aversion in a variety of (not necessarily monetary) everyday situations, for both losses and gains? Second, does the degree of ambiguity aversion depend on people's prior beliefs about the ambiguous scenarios?

We answer these questions in two pre-registered experiments.[1] In the first, participants were presented with vignettes asking them to decide between 'risky' and 'ambiguous' scenarios presented as either gains or losses in various qualitative domains (e.g., work, family, love, friendship, exercise, study and health). Our question was whether ambiguity aversion would vary across domain or gain/loss direction. In the second study, we asked a separate set of participants to share their prior beliefs about each of these scenarios. Our question was whether these priors were predictive of variation in ambiguity aversion across the scenarios.

Experiment 1

Method

Participants. 1206 participants from the United States of America (605 female, 597 male, 3 other, 1 NA; $M_{age} = 39.85$, $SD = 11.09$, range: 18–75 years) were recruited through Amazon Mechanical Turk. 76 of them failed at least one of two pre-registered attention checks, leaving 1130 in the final sample (578 female, 549 male, 2 other, 1 NA; $M_{age} = 40.06$, $SD = 11.09$, range: 18–75 years). Both experiments in this paper were approved by the Human Research Ethics Committee of the Melbourne School of Psychological Sciences (Ethics ID 1953838.1).

Materials. Stimuli consisted of 24 vignettes consisting of qualitative descriptions of situations with two possible outcomes. Each vignette asks participants to choose between two situations, each corresponding to different hypothetical possibilities about the probability of these outcomes. For the RISKY situation, each outcome has a probability of exactly 50%, while for the AMBIGUOUS situation, the probability for each outcome is unknown. For illustration, we reproduce one vignette below, but all 24 vignettes appear in the Appendix.

> You have two friends, X and Y. You have a strong crush on X and no romantic interest at all in Y. A mutual friend of yours, Bob, tells you that he heard that either X or Y was interested in you but doesn't remember which one it was. Which of the following situations would you rather be in?
>
> A. There is a 50% chance that person X is interested and a 50% chance that person Y is interested.

[1] Experiment 1 was preregistered at `https://aspredicted.org/blind.php?x=yq37vw`. Experiment 2 was formulated after the conclusion of Experiment 1, but the method and all analyses were preregistered at `https://aspredicted.org/blind.php?x=3b3rx6`. The data and code necessary to recreate all analyses in this paper can be found on the Open Science Framework website at `https://osf.io/28azp`.

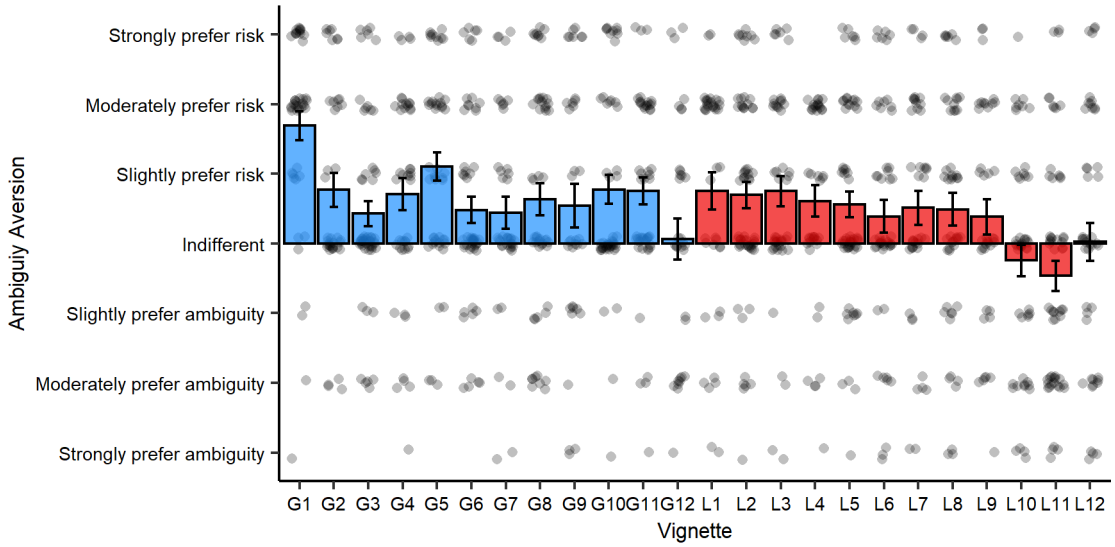

Figure 1. Ambiguity aversion rating for each of the 24 vignettes (x axis). Each dot represents the response given by one participant, and the bars represent the mean ratings for each vignette (gains in blue and losses in red). Error bars represent standard error. A majority of the vignettes showed ambiguity aversion, with participants preferring the riskier option over the ambiguous option. However, there was substantial variation in the strength of this preference across vignettes.

> B. Either person X or person Y is interested but the exact probability for each is unknown.

In this example, A corresponds to the RISKY situation and B corresponds to the AMBIGUOUS situation, but the order of each was randomised for each participant. The vignettes were constructed so as to span a variety of different life domains such as work, family, love, friendship, exercise, study and health. We also varied the gain/loss DIRECTION: twelve vignettes were presented as gains, as in this example, and twelve were presented as losses. Where possible, the gain and loss vignettes were designed to match each other as closely as possible except for the gain/loss direction. Where this was not possible, the topics of the vignettes were chosen so that each domain (e.g., work, health, etc.) was represented a similar amount across the gain and loss conditions.

Two of the 24 vignettes (G1 and L1) were urn-based ones as found in Ellsberg (1961); these were included in order to ensure that the classic ambiguity aversion effect could be replicated with our method and sample.

Procedure. Our design was between-participant, so each person rated only one of the 24 vignettes. The experiment began by asking participants to report their age and gender, after which they read the following instructions on how to complete the experiment:

> You will be presented with two short, life-like scenarios which we call 'vignettes'. After reading each vignette, you will be shown two different possibilities for what the true underlying situation in the vignette is. For each vignette we are interested in which of these two situations ***you would rather be in***. You will answer on a scale from "I would definitely rather be in situation A" to "I would

definitely rather be in situation B" with "I am indifferent about which situation I would rather be in" in the middle.

Participants were then presented three questions checking their comprehension of the instructions; they were required to answer each correctly before proceeding. After completing a practice trial, each participant was randomly assigned to one of the 24 vignettes. This resulted in sample sizes for each vignette ranging from 33 to 62. Participants were then asked "Which of the following situations would you prefer to be in?" The two options, labelled A and B, were randomly assigned to either the RISKY or AMBIGUOUS situation. Participants responded on a 7 point Likert scale in which 1 was 'Definitely A', 7 was 'Definitely B', and 4 was 'No preference.'

Exclusion Criteria. Although all participants were paid, we pre-registered two exclusion criteria which were used to exclude data from the analysis. First, during the practice trial participants were given a vignette in which option B is clearly preferable to option A (see Appendix). Participants that did not respond that they definitely, probably or slightly preferred option B were excluded on the grounds that they failed to understand the task or were not paying attention. Second, following completion of the main vignette, participants were asked "what was the last question about?" and asked to choose the correct option out of four possibilities. Participants who answered incorrectly were excluded on the grounds that they failed to read the vignette carefully enough.

Results

Figure 1 shows the degree of preference for ambiguity for each of the 24 vignettes separately. On average, people showed ambiguity aversion for the clear majority of the vignettes, but the degree of the aversion varied. In order to quantify this as well as determine what factors drove ambiguity aversion, we modelled preferences using ordinal logistic regression. The outcome variable was the answer participants gave to the "which situation would you prefer to be in?" question, recoded so that +3 indicated a strong preference for the RISKY option (ambiguity aversion), 0 indicated indifference, and -3 indicated a strong preference for the AMBIGUOUS option. According to the preregistered plan, we compared the following models:

1. Model containing only an intercept[2]
2. Model containing intercept plus a parameter for DIRECTION condition. If preferred to model 1, this suggests participants are systematically acting differently for gain vignettes than for loss vignettes.
3. Model containing intercept plus a parameter for response order. If preferred to model 1, this suggests participants are systematically choosing either the first or the second option presented, regardless of its content. We do not expect this to happen; this is just a precautionary check.

[2]Ordinal regression models do not have one intercept parameter, but instead have $C - 1$ cut-point parameters, where C is the number of categories and the cut-points are thresholds used to differentiate the adjacent levels of the response variable. For simplicity we refer to this as the intercept throughout. C does not vary between models.

4. Mixed-effect model containing intercept, a parameter for DIRECTION condition, and a random intercept for each vignette. If preferred to model 2, this suggests that ambiguity aversion varies substantially across individual vignettes, over and above variation due to gain/loss direction.

All analyses were carried out under both frequentist and Bayesian paradigms, and results were qualitatively identical in each. The frequentist analysis used the `clm` and `clmm` functions from the R package `ordinal` (Christensen, 2019), and the model selection metric was the Aikake Information Criterion, or AIC (Akaike, 1974). For Bayesian analyses, the R package `brms` (Bürkner, 2017) was used with default priors.[3] The Leave-one-out Information Criterion calcluated via Pareto Smoothed Importance Sampling (Vehtari, Simpson, Gelman, Yao, & Gabry, 2019) was used as a the model selection metric for Bayesian models. The purpose of model selection metrics such as LOOIC and AIC is that they penalise more complex models, thus guarding against overfitting.

The results are shown in Table 1. Because Model 4 is preferred overall, we infer that gain/loss direction had a significant effect and that there is also significant variation among the vignettes. Furthermore, since Model 3 was outperformed by all models, the order of response did not appear to affect ambiguity aversion (as expected).

As pre-registered, in order to ascertain whether the classic ambiguity effect was replicated with our version of the Ellsberg urn task, we compared Models 1 and 2 using only the two vignettes involving urns (G1 and L1). Model 2 (AIC = 278.55, LOOIC = 278.47) was preferred to Model 1 (AIC = 285.17, LOOIC = 285.05). This suggests that people showed a greater aversion to ambiguity for gains than for losses. Two-tailed one-sample wilcox signed rank tests revealed that both the gain urn vignette ($V = 840$, $p < .001$), and the loss urn vignette ($V = 416$, $p = 0.012$) showed significant ambiguity aversion, thus replicating the classic two-colour Ellsberg task ambiguity aversion effect.

Table 1
Model evaluation for Experiment 1

Model	Description	Pseudocode	AIC	LOOIC
1	Intercept only	`AA ~ 1`	3,973.75	3,973.91
2	Intercept & DIRECTION parameter	`AA ~ direction + 1`	3,964.19	3,964.28
3	Intercept & order parameter	`AA ~ order + 1`	3,975.24	3,975.19
4	Intercept, DIRECTION, and random intercept by vignette	`AA ~ direction + 1 + (1|vignette)`	**3,943.56**	**3,929.42**

Note. AIC (Akaike Information Criterion) is reported for frequentist instantiations of models, and LOOIC (Leave-one-out Information Criterion) is reported for Bayesian instantiations of models. Pseudo code is reported according to `lme4` syntax. `AA` = Ambiguity aversion rating. `direction` = DIRECTION condition, i.e., gain or loss. `order` = the response order, i.e., whether AMBIGUOUS and RISKY options were assigned to options A or B. The preferred model (Model 4) is the one with the lowest AIC and LOOIC, indicated in bold.

[3] This corresponds to an improper flat prior over the reals for all fixed predictors, a half-t distribution with 3 degrees of freedom, and a scale parameter of 2.5 for intercept (i.e., cutpoints) and random-effect standard deviation parameters.

Discussion

In Experiment 1, our goal was to investigate how robust the phenomenon of ambiguity aversion is, and specifically whether we would see it when judgments were qualitative rather than monetary and in scenarios similar to those that might be found in real life. We found that participants did show ambiguity aversion in most scenarios, but the degree of ambiguity aversion varied by scenario. We also found that scenarios involving gains would resulted in greater ambiguity aversion than scenarios involving losses. We were also able to replicate classic ambiguity aversion effects in the 'urn' scenarios using our methodology (Ellsberg, 1961; Fellner, 1961).

Interestingly, the scenarios that exhibited the highest ambiguity aversion in their respective gain-or-loss domains were the 'urn' scenarios (G1 and L1). This may suggest that the magnitude of the ambiguity effect estimated from previous studies that used such scenarios may be inflated relative to more 'real-life' situations. More generally, we found that there was significant variation in the magnitude of ambiguity aversion across these scenarios. This is perhaps not a surprise as we made no special effort to control for factors that might affect ambiguity aversion, since our goal was to determine the robustness of the effect across those factors. However, it does raise the question of why this variation occurred. Motivated by the literature suggesting that ambiguity aversion may be driven by pessimism about the ambiguous scenario, we designed Experiment 2 to test whether prior beliefs about the probability of success in each scenario predicted the degree of ambiguity aversion in that scenario.

Experiment 2

Method

Participants. 721 people from the United States of America (393 female, 323 male, 4 other, 1 NA; M_{Age} = 41.05, SD = 11.48, range: 19–78 years) were recruited through Amazon Mechanical Turk. 38 of them failed at least one of two pre-registered attention checks, leaving 683 participants in the final sample (375 female, 304 male, 3 other, 1 NA; M_{Age} = 41.05, SD = 11.40, range: 19–76 years).

Materials. The vignettes were the same as used in Experiment 1.

Procedure. The procedure was the same as Experiment 1 except insofar as detailed here. After providing demographic information, reading experiment instructions and completing a practice trial, participants were randomly shown one of the 24 vignettes, and asked "If you had to guess, what is the probability of outcome X and outcome Y?"

This was designed to elicit point estimates of participant priors about the outcomes in the vignettes. Because the two events were mutually exclusive and collectively exhaustive, participants responded on a slider between 0% and 100% ; if one bar was moved, the other would automatically change to accommodate the above constraints. The starting point was randomised for each person to start at 0 for one outcome and 100 for the other outcome. Participants were forced to click the slider before continuing to ensure that they did not simply leave the value at the default outcome without adequate consideration of the question. After continuing, they were then asked, "How confident are you in your answer to the previous question?" They responded on a scale ranging from 0 ("Not at all confident") to 4 ("Extremely confident").

Exclusion Criteria. As in Experiment 1, there were two exclusion criteria. First, during the practice trial participants were given a vignette in which outcome A was clearly described to be more likely than outcome B. Participants responded on the slider as above. People who assigned a prior probability for A of 50% or less were excluded on the grounds that they failed to understand the task or were not paying attention. The second exclusion criterion was the same as in Experiment 1, based on responses to a question about what the previous scenario was about.

Results

Descriptives. Figure 2A shows the prior probabilities assigned by participants for each of the vignettes. The y axis shows the difference in probability between the favourable and unfavourable events in the vignette. For instance, for the vignette described above, the favourable event would be person X being interested and the unfavourable one would be person Y being interested; the difference in probabilities reflects how much more likely the person thinks it is that X is interested. Thus, a difference of greater than zero means the participant is relatively optimistic about the situation, while a negative difference means they are pessimistic and believe that the unfavourable outcome is more likely. Visual inspection of Figure 2A reveals that there was some variation across vignettes, with none showing striking levels of either pessimism or optimism. The exception was the urn-based gain vignette (G1), which participants were highly pessimistic for, rating the unfavourable event as 50% more likely than the favourable one.

Figure 2B shows the corresponding confidence ratings for each vignette, illustrating that participants rated themselves as moderately to very confident overall, with G1 not being unusual. There was no significant correlation between confidence ratings and prior probability percent difference, $r = .038$, $t(681) = 1.01$, $p = .315$ or between confidence ratings and absolute prior probability percent difference, $r = .031$, $t(681) = 0.82$, $p = .414$.

In order to quantify the extent to which prior probabilities and/or confidence on each vignette predicted ambiguity aversion, we compared several linear regression models. The outcome variable in all models was the degree of ambiguity aversion for each vignette obtained in Experiment 1. A key predictor variable was "percentage difference" (PRIORS) shown on the y axis of Figure 2A and calculated as $P(F) - P(U)$ where F is the favourable outcome and U is the unfavourable outcome.[4] This measure was then averaged across participants to obtain one value for each vignette. The other predictor variables were DIRECTION, as in Experiment 1 (whether the vignette depcited a gain or loss) and CONF, which reflects the mean confidence rating for each vignette (averaged across participants).

Before conducting the main analysis, in order to ensure that there were no confounding effects due to the randomised start point of the slider bar, we compared an intercept-only model to a model containing a 'starting point' parameter. The intercept-only model had a

[4]This analysis deviates from our pre-registration in one way. The pre-registered analysis uses odds ratios between the favourable and unfavourable outcomes as the dependent variable, but upon doing the analyses we realised that this approach has two problems we did not originally consider. The first is that odds ratios are undefined when the denominator is 0. This occurred numerous times in our data. Secondly, and relatedly, the measurement properties of the odds ratio are heavily skewed, making it not ideal for use in a regression. We therefore used the percentage difference rather than the odds ratio, but in all other ways followed the pre-registration precisely.

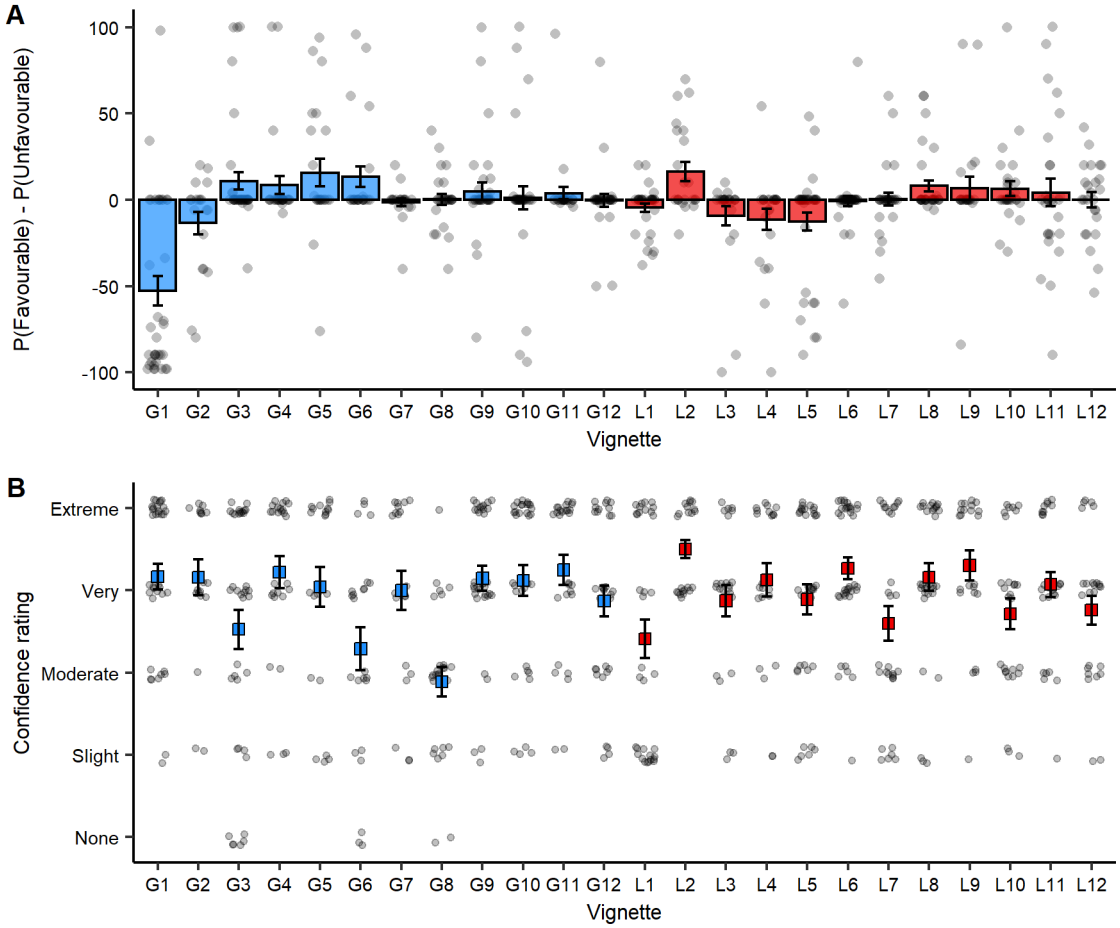

Figure 2. (A) Prior probability ratings for each of the 24 vignettes (x axis). Each dot represents one participant, and the bars represent means for each vignette (gains in blue and losses in red). Error bars represent standard error. The y axis reflects the difference between people's prior probabilities of the favourable event and the unfavourable event. Thus, a positive value indicates optimism about the unobserved events. There was some variation across vignettes but no strong tendency toward optimism or pessimism, with the exception of the urn vignette (G1) for which people were very pessimistic. (B) Confidence ratings for each vignette. Confidence varied but was usually high.

better fit (AIC = 6,661.31, LOOIC = 6,662.89) than the model that included a parameter for slider bar starting point (AIC = 6,663.29, LOOIC = 6,664.80). This indicates that the randomised starting point of the slider bar had no systematic effect on participant responses; as a result, all subsequent models exclude it as a parameter.

We created the subsequent models by systematically increasing model complexity to take into account three possible predictors of interest: DIRECTION (as gain or loss), PRIORS (the percentage difference, calculated as described above), and CONF (the confidence people had in their priors). As before, we used AIC as the model selection metric for the frequentist analysis and LOOIC for the Bayesian equivalent. Analyses were carried out as in Experiment 1 with the exception that the frequentist analysis used the `lm` function from Base R (R Core Team, 2020). The models we considered are:

1. Model containing only an intercept
2. Model containing intercept plus a parameter for DIRECTION condition.
3. Model containing intercept, a parameter for DIRECTION condition, and a parameter for PRIORS.
4. Model containing intercept, a parameter for DIRECTION condition, and a parameter for PRIORS, allowing an interaction between the DIRECTION and the PRIORS.
5. Model containing intercept, a parameter for DIRECTION condition, and a parameter for CONF.
6. Model containing intercept, a parameter for DIRECTION condition, and a parameter for CONF, allowing an interaction between the DIRECTION and the CONF.
7. Model containing intercept, a parameter for DIRECTION condition, a parameter for PRIORS, and a parameter for CONF.

Table 2 shows the model selection metrics of the fitted regression models predicting vignette ambiguity aversion. The best-fitting model was Model 3, which contained parameters for DIRECTION condition as well as the PRIORS. This model showed moderate fit, adjusted $R^2 = .319$, $F(2, 21) = 6.39$, $p = .007$, and both DIRECTION condition, $\beta = -.31$, $t(22) = -2.18$, $p = .041$, and PRIORS, standardised $\beta = -0.47$, $t(22) = -2.74$, $p = .012$, were significant predictors. Figure 3A shows the relationship between ambiguity aversion and the PRIORS for each of the 24 vignettes, along with the linear regression lines from the best-fitting model.

Although this analysis appears to indicate that ambiguity aversion is related to PRIORS, an investigation of the model residuals suggests that that this effect was heavily dependent on vignette G1, the gain-direction two-colour Ellsberg task vignette, which had high influence (Cook's $D = 1.15$, standardised $\text{DFBeta}_{intercept} = 0.58$, standardised $\text{DFBeta}_{priors} = -1.8$), high leverage ($h = 0.690$) and was a multivariate outlier (Mahalanobis distance = 15.25). To ascertain whether our findings were dependent on this observation, we redid all analyses with it removed. Table 3 shows the metrics for all models on the dataset without vignette G1, and Figure 3B shows the relationship between ambiguity aversion and PRIORS when G1 is removed as well. Both demonstrate that when G1 is not included, the effect of the priors disappears. The best fitting model is now the model with only DIRECTION as a predictor (Model 2), although the overall fit is poor: adjusted $R^2 = .076$, $F(1, 21) = 2.81$, $p = .109$.

Discussion

The goal of Experiment 2 was to determine whether the ambiguity aversion ratings from Experiment 1 were related to the prior probability that people assigned to outcomes. We found that when we excluded an outlier vignette (G1), there was no observed relationship between people's priors and the degree of ambiguity aversion. That said, it is possible that we would have observed an effect had we been able to do an individual-level rather than aggregate-level analysis: perhaps an individual's ambiguity aversion might be predicted by *their specific* priors even if the overall ambiguity aversion at a vignette level is not predicted by the mean priors for that vignette. Our data do not permit us to rule this possibility out, since we only designed Experiment 2 after having run Experiment 1. However, a

Table 2
Model evaluation for Experiment 2

Model	Description	Pseudocode	AIC	LOOIC
Preliminary models				
1	Intercept only	`AA ~ 1`	29.96	31.21
2	Intercept & DIRECTION parameter	`AA ~ direction + 1`	27.90	29.11
Point prior models				
3	Intercept, DIRECTION, & PRIORS parameters	`AA ~ direction + priors + 1`	**22.55**	**24.25**
4	Intercept, DIRECTION, & PRIORS parameters, and interaction	`AA ~ direction*priors + 1`	24.55	27.72
Confidence rating models				
5	Intercept, DIRECTION, & CONF parameters	`AA ~ direction + conf + 1`	28.80	29.48
6	Intercept, DIRECTION, & CONF parameters, and interaction	`AA ~ direction*conf + 1`	30.48	31.57
Combined point priors and confidence rating model				
7	Intercept, DIRECTION, CONF, & PRIORS parameters	`AA ~ direction + priors + conf + 1`	23.56	25.20

Note. AIC (Akaike Information Criterion) is reported for frequentist instantiations of models, and LOOIC (Leave-one-out Information Criterion) is reported for Bayesian instantiations of models. Pseudocode is reported according to `lme4` syntax. `AA` = Mean vignette ambiguity aversion rating taken from experiment 1. `direction` = DIRECTION condition, i.e., gain or loss. `priors` = mean percentage differential (prior probability of favourable event minus prior probability of unfavourable event) for each vignette. `conf` = Mean vignette confidence rating. The preferred model (Model 3) is the one with the lowest AIC and LOOIC, indicated in bold.

small subset ($n = 18$) of our participants who happened to complete both experiments (eight months apart) were randomly assigned to the same vignette each time. Within this sample there was no significant relationship between their prior estimates and the degree of ambiguity aversion exhibited, $r = 0.23$, $t(16) = 0.96$, $p = .352$, although we note the small sample size. Future work might address this limitation by obtaining within-subject estimates of both priors and ambiguity aversion, although in order to avoid demand effects it would be important to obtain them at distinct times. Regardless, the lack of relationship we observed between priors and ambiguity aversion at least suggests that if there is a link between the two, it is not obvious or consistent across people.

What do our results suggest about vignette G1? It is a variant of the classic two-colour Ellsberg task, presented with a gain framing. For it alone, we observed both a large amount of ambiguity aversion and very pessimistic priors. It seems plausible that in this case the two may be related, especially because the vignette describes the situation as taking place in a casino. This is consistent with the 'comparative ignorance' hypothesis which proposes

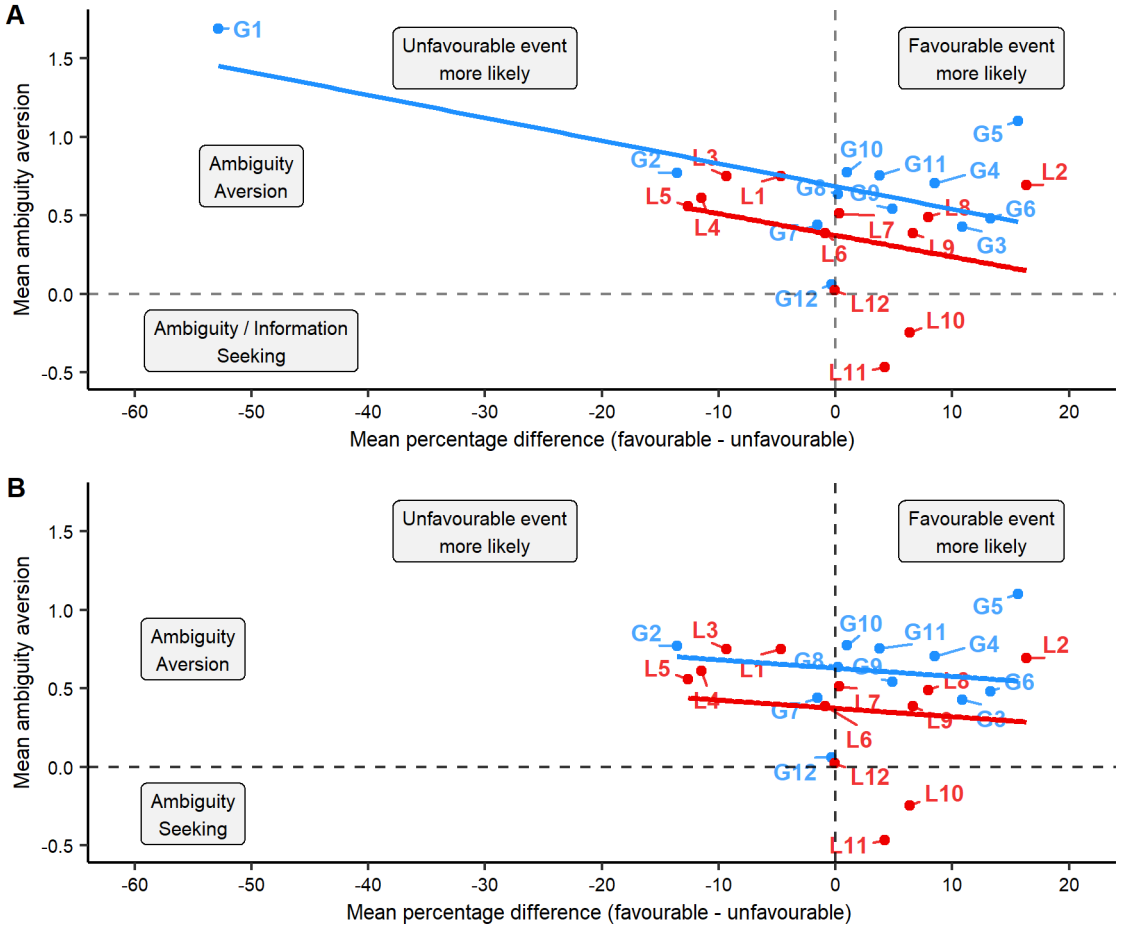

Figure 3. The relationship between the mean ambiguity aversion rating for each vignette (x axis) and the PRIORS, i.e., the mean prior probability percent difference of that vignette (y axis). Each dot point is one vignette. (A) Full data set. Regression lines of best fitting model for gains (blue) and losses (red) appear to show a relationship between PRIORS and ambiguity aversion. (B) Data set excluding vignette G1. Regression lines of best-fitting model illustrates that without it, there appears to be no relationship between PRIORS and ambiguity aversion.

that ambiguity aversion is produced by a comparison with less ambiguous events or with more knowledgeable individuals (Fox & Tversky, 1995). It is also consistent with sensitivity to data generation, as in the scenarios proposed by Gärdenfors and Sahlin (1982). The urn scenario, especially if it occurs in a casino, may cause people to assume that any unknowns are likely to be "stacked against" them, and thus to prefer the known risks.

Overall, our results suggest no single obvious cause for ambiguity aversion. Many vignettes showed strong ambiguity aversion but also had favourable prior estimates (the top right quadrant of Figures 3A and 3B). This suggests that ambiguity aversion in general is not driven by pessimistic priors, and may thus be considered irrational in that sense (i.e., when assuming utility theory as a normative model). This is consistent with theories of ambiguity aversion which view it as evidencing a departure from rationality as prescribed by utility theory (e.g., Al-Najjar & Weinstein, 2009), even when viewed from a subjective probability or Bayesian perspective (c.f., Frisch & Baron, 1988)

Table 3
Model evaluation for Experiment 2 without vignette G1

Model	Description	Pseudocode	AIC	LOOIC
Preliminary models				
1	Intercept only	`AA ~ 1`	20.45	21.31
2	Intercept & DIRECTION parameter	`AA ~ direction + 1`	**19.57**	**20.54**
Point prior models				
3	Intercept, DIRECTION, & PRIORS parameters	`AA ~ direction + priors + 1`	21.17	22.05
4	Intercept, DIRECTION, & PRIORS parameters, and interaction	`AA ~ direction*priors + 1`	21.83	24.29
Confidence rating models				
5	Intercept, DIRECTION, & CONF parameters	`AA ~ direction + conf + 1`	21.06	21.65
6	Intercept, DIRECTION, & CONF parameters, and interaction	`AA ~ direction*conf + 1`	22.98	24.51
Combined point priors and confidence rating model				
7	Intercept, DIRECTION, CONF, & PRIORS parameters	`AA ~ direction + priors + conf + 1`	22.55	25.51

Note. AIC (Akaike Information Criterion) is reported for frequentist instantiations of models, and LOOIC (Leave-one-out Information Criterion) is reported for Bayesian instantiations of models. Pseudocode is reported according to `lme4` syntax. `AA` = Mean vignette ambiguity aversion rating taken from experiment 1. `direction` = DIRECTION condition, i.e., gain or loss. `priors` = mean percentage differential (prior probability of favourable event minus prior probability of unfavourable event) for each vignette. `conf` = Mean vignette confidence rating. The preferred model (Model 2) is the one with the lowest AIC and LOOIC, indicated in bold.

More generally, we did find that ambiguity aversion was a robust phenomenon. This is consistent with a large existing body of work (Keren & Gerritsen, 1999) but extends it to show that it occurs even in qualitative situations across a wide variety of topics. The fact that it did not *always* occur is consistent with research showing that ambiguity seeking or neutrality sometimes arises (Kocher et al., 2018; Baillon & Bleichrodt, 2015), although we did find that the degree of ambiguity aversion was stronger for gains than losses (Curley et al., 1984). It remains unclear what factors predict when exactly ambiguity aversion will emerge. In part this is because our vignettes were not designed to include or control for all the factors that may effect ambiguity aversion, such as the utility of outcomes. This was intentional and a necessary first step, as our primary goal was to evaluate the robustness of the effect. For that it was necessary to capture the range of situations where it might occur in the real world, where situational factors will vary considerably, rather than to limit that range by trying to control for a small set of specific factors. Future work will consider scenarios that more tightly control and measure such factors, including not just prior beliefs about the outcomes but also familiarity with the situation and utility of the outcomes (see e.g., Shou & Olney, 2020 for initial work in that direction).

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Appendix A
Vignettes

Gain Vignettes

Vignette G1

At a casino, there is an urn on the table which contains 1000 balls. Each of these 1000 balls is either red or yellow. You are to randomly select one of these balls from the urn and, if you select a red ball, you will win $1000. Which of the following situations would you prefer to be in?

A. There is a 50% chance that the selected ball will be red, and a 50% chance the selected ball will be yellow.
B. The selected ball will be red or yellow, but the exact probability for each is unknown.

Vignette G2

Your friend has set you up on a blind date. When you arrive at the arranged meeting place you notice that there are two people who fit the general description that your friend has given to you. You find one of these people, person X, extremely attractive; while the other person, person Y, is of only average attractiveness. Which of the following situations would you prefer to be in?

A. There is a 50% chance that person X is your date, and a 50% chance that person Y is your date.
B. Either person X or person Y is your date but the exact probability for each is unknown.

Vignette G3

You have just been offered a promotion at work along with the choice of becoming head of department X or head of department Y. Your boss tells you that his boss is planning on heavily supporting only one of these departments, but he does not know which one his boss has in mind. Which of the following situations would you rather be in?

A. There is a 50% chance that department X will be highly supported and a 50% chance that department Y will be highly supported.
B. Either department X or department Y will be highly supported but the exact probability for each is unknown.

Vignette G4

Your child has extreme talent and interest in two things: X and Y. You have heard that in a few years a local rich person is planning on funding a very generous scholarship for talented young people in either X or Y. However, at this point they have not decided whether to support X or Y. In order for your child to be eligible they will need to receive specialised training starting now, and the skills are sufficiently time-consuming that they need to pick just one. Which of the following situations would you rather be in?

A. There is a 50% chance that X will get the generous scholarship, and a 50% chance that Y will get the generous scholarship.
B. Either X or Y will get the generous scholarship, but the exact probability for each is unknown.

Vignette G5

You have a stock portfolio of two stocks: X and Y. You get a call from your stockbroker who advises you that he has received a reliable tip that only one of your stocks is about to skyrocket in value, although he doesn't know which one. Unfortunately, you must sell one of the stocks immediately because of a recent medical emergency. Which of the following situations would you prefer to be in?

A. There is a 50% chance that stock X will skyrocket and a 50% chance that stock Y will skyrocket.
B. Either stock X or Y will skyrocket in value but the exact probability for each is unknown.

Vignette G6

You are currently unemployed, but have just been offered two jobs from two different companies: company X and company Y. You have heard that one of them is in line to receive a great deal of investor funding within the next year, but you don't know which one. Which of the following situations would you rather be in?

A. There is a 50% chance that company X will receive significant investor funding and a 50% chance that company Y will recieve significant investor funding.
B. Either company X or company Y will receive significant investor funding but the exact probability for each is unknown.

Vignette G7

You are in the market to buy a house and have identified two that you really like, X and Y. Your real estate agent tells you that the local government is planning on building an amazing school in the neighbourhood of either X or Y, which would greatly increase its property values (and is also very appealing to you since you are planning a family). Unfortunately no decision has been made at this point about where it will be built, and you need to put an offer in now in order to get either house. Which of the following situations would you rather be in?

A. There is a 50% chance that the school will be built in neighbourhood X, and a 50% chance that it will be built in neighbourhood Y.
B. The school will be built in either neighbourhood X or neighbourhood Y but the exact probability for each is unknown.

Vignette G8

You have two friends, X and Y. You have a strong crush on X and no romantic interest at all in Y. A mutual friend of yours, Bob, tells you that he heard that either X or Y was interested in you but doesn't remember which one it was. Which of the following situations would you rather be in?

A. There is a 50% chance that person X is interested and a 50% chance that person Y is interested.
B. Either person X or person Y is interested but the exact probability for each is unknown.

Vignette G9

You are a competitive runner. Your coach has recently returned from a sports science conference and advises you that she has been informed of two new training protocols: protocol X and protocol Y. Each of these training protocols has been shown to result in significant and long-lasting improvements, but they each work for different people. Unfortunately, it is so far impossible to determine ahead of time which people will benefit from which. The protocols are are mutually exclusive (i.e. they can't both be completed at the same time): you must choose one. Which of the following situations would you prefer to be in?

A. There is a 50% chance that training protocol X will help you and a 50% chance that training protocol Y will help you.
B. Either training protocol X or Y will help you but the exact probability for each is unknown.

Vignette G10

You are invited to two parties on the same night. You have heard that the person you are romantically interested in is definitely attending one of them, but you don't know which one. Unfortunately, the parties are three hours away from each other, so you cannot attend both. Which of the following situations would you prefer to be in?

A. There is a 50% chance that this person will be at a party X and a 50% chance that they will be at party Y.
B. The person will be at either party X or party Y but the exact probability for each is unknown.

Vignette G11

You have one day left of your vacation, and within a few hours' driving distance from your hotel are two different wildlife preserves: preserve X and preserve Y. There is a rare bird, one of the only ones of its kind, that has been spotted in both X and Y. The bird cannot be in two places at once and you do not have time to go to both. Which of the following situations would you prefer to be in?

A. There is a 50% chance that the rare bird is at preserve X, and a 50% chance that the rare bird is at preserve Y.
B. The rare bird is at either preserve X or preserve Y, but the exact probability for each is unknown.

Vignette G12

You are a medical student and final exams are two weeks away. You have recently been told about two study drugs, drug X and drug Y, which if taken during study can significantly improve memory retention. Both drugs have been shown to work very well, but each works for different people. Unfortunately, it is so far impossible to determine ahead of time which people will benefit from which. Further, both drugs are slow acting, so you only have time to try one before your exams commence. Which of the following situations would you prefer to be in?

A. There is a 50% chance that drug X will improve your memory retention, and a 50% chance that drug Y will improve your memory retention.
B. Either drug X or drug Y will improve your memory retention, but the exact probability for each is unknown.

Loss Vignettes

Vignette L1

At a casino, there is an urn on the table which contains 1000 balls. Each of these 1000 balls is either red or yellow. You are to randomly select one of these balls from the urn and, if you selct a red ball, you will lose $1000. Which of the following situations would you rather be in?

A. There is a 50% chance that the selected ball will be red, and a 50% chance the selected ball will be yellow.
B. The selected ball will be red or yellow, but the exact probability for each is unknown.

Vignette L2

Your friend has set you up on a blind date. When you arrive at the arranged meeting place you notice that there are two people who fit the general description that your friend has given to you. You find one of these people, person X, extremely unattractive; while the other one, person Y, is of average attractiveness. Which of the following situations would you rather be in?

A. There is a 50% chance that person X is your date, and a 50% chance that person Y is your date.
B. Either person X or person Y is your date, but the exact probability for each is unknown.

Vignette L3

You have just been offered a promotion at work along with the choice of becoming head of department X or head of department Y. Your boss tells you that the CEO of the company is planning on slashing the budget of only one of these departments, but your boss does not know which one the CEO has in mind. Which of the following situations would you rather be in?

A. There is a 50% chance that department X's budget will be slashed and a 50% chance that department Y's budget will be slashed.
B. Either department X's budget or department Y's budget will be slashed but the exact probability for each is unknown.

Vignette L4

Your child has extreme talent and interest in two things: X and Y. You have heard that the local schools are planning on discontinuing programs in either X or Y in a few years due to lack of funds; however, at this point they have not decided which one to eliminate. You don't have the funds to get your child private lessons, so their only option is through the schools. Neither your nor your child wants to start something that they will have to stop. Which of the following situations would you rather be in?

A. There is a 50% chance that programs in X will be discontinued, and a 50% chance that programs in Y will be discontinued.
B. Programs in either X or Y will be discontinued, but the exact probability for each is unknown.

Vignette L5

You have a stock portfolio of two stocks: stock X and stock Y. You get a call from your stockbroker who advises you that he has received an anonymous tip that one of your stocks is about to plummet in value, while the other will continue to grow steadily. Due to taxation and investment regulations, you can only sell one of these stocks. Which of the following situations would you rather be in?

A. There is a 50% chance that Stock X will plummet and a 50% chance that Stock Y will plummet.
B. Either stock X or Y will plummet in value, but the exact probability for each is unknown.

Vignette L6

You work at a bank and are moving to a new city that has two branches of this bank, branch X and branch Y. Your boss is willing to transfer you to either X or Y in your new city. However, The bank's CEO has announced that within two years one of these branches will be closed because the city is only big enough to sustain one branch. The employees of the closed branch will be made redundant. Which of the following situations

would you rather be in?

A. There is a 50% chance that branch X will be closed, and a 50% chance that branch Y will be closed.
B. Either branch X or Y will be closed, but the exact probability for each is unknown.

Vignette L7

You have developed an insect infestation in your house. The inspector tells you it is either species X or species Y. He cannot tell which one without further tests, but he is certain that it is not both because they are very territorial and will fight each other off. An infestation of species X will ruin the structural integrity of the house and cause it to plummet in value. Species Y, however, is completely benign and will impose no costs (financial, aesthetic, or otherwise) to your property. Which of the following situations would you rather be in?

A. There is a 50% chance that the infestation is of species X and a 50% chance that the infestation is of species Y.
B. The infestation is of either species X or Y, but the exact probability for each is unknown.

Vignette L8

You are on a hike in the remote wilderness when you are bitten by a snake; the bite happened so quickly that you could not determine the species. Only two species of snake exist in the area in which you are hiking: species X and species Y. A bite from species X is possibly lethal, while a bite from species Y is harmless. Which of the following situations would you rather be in?

A. There is a 50% chance that the bite is from species X and a 50% chance that the bite is from species Y.
B. The bite is from either species X or Y, but the exact probability for each is unknown.

Vignette L9

Your computer has a virus. A consultant tells you that it is either of type X or type Y; he cannot tell without further tests, but he is certain that it is not both because they cannot operate on the same machine. Virus type X will require your computer to sit at the shop for weeks in order to fix, while Y can be removed in less than an hour. Which of the following situations would you rather be in?

A. There is a 50% chance that your computer has virus X, and a 50% chance that your computer has virus Y.
B. Your computer has either virus X or Y, but the exact probability for each is unknown.

Vignette L10

On a routine doctor visit, you learn that your body has acquired a pathogen with two possible variants: variant X and variant Y. Your doctor cannot determine which it

is without further tests, but he is certain that it is not both because each one kills the other. Variant X is potentially deadly while variant Y is somewhat benign. Which of the following situations would you rather be in?

A. There is a 50% chance that the pathogen is variant X and a 50% chance that the pathogen is variant Y.
B. The pathogen is either variant X or Y, but the exact probability for each is unknown.

Vignette L11

You have left your car in an uncovered airport carpark while you are travelling to a far away city for work. Since you left, you have heard news that a large hailstorm has struck near the airport but you have not been able to determine exactly where. If this hailstorm hit the airport carpark, your car has probably sustained serious and costly damage (you are uninsured). Which of the following situations would you rather be in?

A. There is a 50% chance that the hailstorm has struck your car, and a 50% chance that it hasn't.
B. The hailstorm either struck your car or it didn't, but the exact probability for each is unknown.

Vignette L12

You are the five-term mayor of your city and you are again running for re-election, coming to the end of a long campaign against a surprisingly powerful challenger. You have scheduled a meeting with your campaign manager to talk about your prospects of losing the election. Which of the following situations would you rather be in?

A. There is a 50% chance that you will lose the election, and a 50% chance that you will not.
B. You will either lose the election or you will not, but the exact probability for each is unknown.

Appendix B
Exclusion Criteria

Experiment 1

You are on holidays when you hear news that the river near your home town has experienced serious flooding. Which of the following situations would you rather be in?

A. Your house is close to the river.
B. Your house is far from the river on a hill.

Experiment 2

You are planning on attending an outdoor, uncovered event this afternoon and you are interested in knowing whether it will rain. The weather forecast from multiple sources says that it is very likely to rain. Further, you look out the window and see heavy, dark, threatening rain clouds overhead. Both of these pieces of information lead you to believe that it is much more likely to rain than it is not to rain.

If you had to guess, what is the probability that it will rain and the probability that it will not rain?