Smarter in the Long-Term:

Diminishing Ambiguity Aversion in a Repeated Ellsberg Urn Task

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Abstract

Decision makers confront situations every day in which probabilistic information is unclear or unknown. When selecting between options with known probabilities and options with unknown probabilities, ample research indicates that people prefer the former. Yet empirical studies on ambiguity aversion have been limited to single drawing events, in which subjects make one-off decisions between a risky prospect and an ambiguous prospect. Largely unexplored is whether individuals in a repeated decision making setting become more tolerant of ambiguity in a manner consistent with expected utility theory. The present study gave 201 subjects a classic Ellsberg-urn choice between a gamble with a known probability of winning and a gamble with an unknown probability. Willingness to pay was assessed across 5 draws, and a moderate decrease in ambiguity aversion was found. Implications for the competence hypothesis of ambiguity aversion and discussed, along with avenues for future research.

Introduction

An Irish proverb advises, “Better the devil you know than the devil you don’t.” Most people follow this strategy when deciding between known and unknown prospects. We opt regularly for established, trusted brands over unfamiliar brands when shopping for consumer goods (Lassar et al, 1995). When choosing between two hotels, we are likely to attend the one with favorable online reviews than an alternative with no reviews (Sparks and Browning, 2011).

Decision makers rarely know the exact probabilities of potential outcomes. Ambiguity aversion is the robust tendency, in decisions involving risk or uncertainty, to prefer options in which the probabilities of the potential outcomes are known over options in which the probabilities of the potential outcomes are unknown. Our dislike of ambiguity is strong; individuals avoid ambiguous bets even when they are told their chances of winning are better for the ambiguous choice, or when the ambiguous choice has a higher payoff (Keren and Gerritsen, 1999; Trautmann et al, 2008). They will also pay sizeable premiums to avoid ambiguity (Camerer and Weber, 1992). While most studies have identified a dislike of ambiguity in student subjects, it has also been observed among actuaries, lawyers, businesspeople, physicians, and stock brokers (see Zamir and Teichman, 2014). Ambiguity preferences merit extensive research, as they have an established role in law (Mukerji, 1998), macroeconomics (Hansen & Sargent, 2007), finance (Bossaerts et al., 2009; Dimmock et al., 2013; Dow & Werlang, 1992), strategic management (Amit & Schoemaker, 1993; Barney, 1991), and politics (Ghirardato & Katz, 2000; Ghirardato & Marinacci, 2002).

Compared to the economic concepts of "risk" and "risk aversion," there is less agreement on how to model or define "ambiguity" or "ambiguity aversion" (see Machina and Siniscalchi, 2013 for an extended review of proposals). Psychologists often define ambiguity in a pragmatic way based on how it affects an individual's mental processing. A basic definition introduced by Fellner (1961) and extended by Frisch and Baron (1988) states, "Ambiguity is uncertainty about probability, created by missing information that is relevant and could be known." People are uncomfortable when they lack knowledge important to their situation. One effect of this feeling is that it makes people reluctant to accept either side of a bet (Heath and Tversky, 1991). Frisch and Baron (1988) argued that ambiguity aversion might be the result of people transferring a heuristic that is often beneficial—don't bet when you lack information other people might possess—to other circumstances in which their anxieties are baseless.

A distinction is usually made between decision-making under certainty, in which the actor knows in advance the outcome that will follow the choice of any available option, and decision-making in which the actor is uncertain of the outcome. Decisions with uncertainty are subdivided further into decisions under *risk*, in which the actor, though uncertain of the outcome, knows the outcome probabilities for the available options, and decisions under *uncertainty*, in which the actor lacks knowledge of the outcome probabilities.

Economists often model risky and ambiguous decisions using subjected expected utility theory (SEU). The model implies that individuals behave as if they have calculated the "expected utility" of each possible choice, and selected the option that they believe has the highest expected benefit. SEU is calculated by taking the utility of each option and multiplying it by its probability. To illustrate, consider a gamble that has an even chance of winning $50 or $100. The expected utility of this gamble is as follows: EU= ½ X U(50) + ½ X U(100).

The Relationship between risk and ambiguity attitudes

Classical economics often conceptualizes risk and ambiguity as two factors along the same spectrum, based on the level of certainty (see Knight, 1921; Einhorn and Hogarth, 1985; Frisch and Baron, 1988). Under this framework, a risky decision is characterized by knowing the exact probabilities for the possible outcomes, and an ambiguous decision is characterized by having unknown probabilities. Yet some researchers (e.g. Kahneman and Tversky, 1982; Teigen, 1994) have argued that there may be qualitative differences between risk and ambiguity. They group uncertain probabilities into two forms based on the location or source of the uncertainty: external and internal. External uncertainty refers to the event being unknown in the external world, such as which ball will be drawn from an urn containing 50 black balls and 50 white balls. Internal uncertainty reflects our “internal” knowledge state, or relative ignorance. An example of internal uncertainty is an ambiguous urn containing 100 balls but in an unknown color ratio. The type of uncertainty present in this urn is qualitatively different than that found in the known, 50-50 urn above (Brun and Teigen, 1990). People’s choices under certainty seem to depend on both the degree of uncertainty as well as the subjective precision with which it can be assessed. To illustrate, Heath and Tversky (1991) found that roulette wheels and other chance setups can seem more ambiguous than probabilities based on an individual’s knowledge.

Empirical research has indicated that risk and ambiguity aversion are distinct types of preferences, and that there are separate parameters for each (see Borghans et al. 2009). Studies employing tests of both risk and ambiguity attitudes have failed to find correlations between the two (e.g. Cohen et al. 1985, Curley et al. 1986, Hogarth and Einhorn, 1990). Moreover, fMRI studies have revealed distinct neural signatures for decision making under risk and decision making under ambiguity (Huettel et al. 2006). Yet creating and testing a theoretical framework that accounts for both types of preferences has been difficult (see discussion in Keren and Gerritsen, 1999), and no model has survived thorough empirical scrutiny.

Classic Ellsberg-Paradox Framework

The term "ambiguity" to denote a particular type of uncertainty originated with Daniel Ellsberg in his 1961 paper. To illustrate, Ellsberg proposed two thought experiments which are still widely employed in ambiguity research today. One is the Three-Color Ellsberg Paradox, in which there is an urn containing 90 balls. Exactly 30 of these balls are known to be red, and each of the remaining 60 balls are either black or yellow. The exact proportion of black/yellow balls is unknown, and could be anywhere from 0:60 to 60:0. The balls are mixed in the urn so that no one ball is more likely to be drawn than another. Decision makers are told that a ball will be drawn from the urn, and they are presented with two pairs of gambles based on the color of a drawn ball.

Gamble A	Gamble B
Receive $100 if ball is red	Receive $100 if ball is black

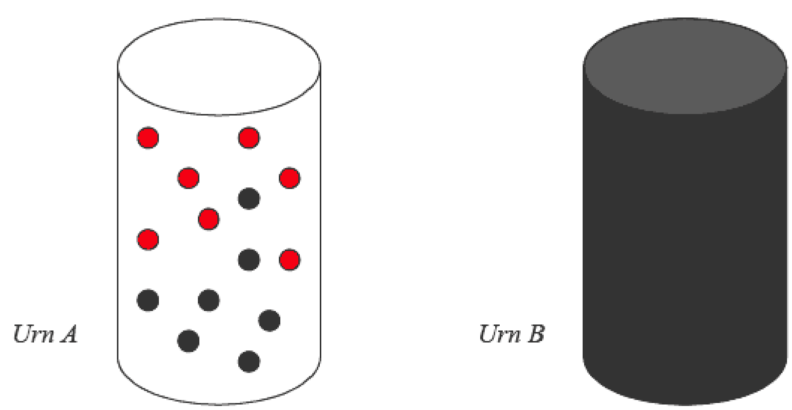
Gamble C	Gamble D
Receive $100 if ball is red or yellow	Receive $100 if ball is black or yellow

Ellsberg predicted that decision makers would usually prefer Gamble A over Gamble B, as well as Gamble D over Gamble C. This pattern has been termed the *Ellsberg Paradox*, and has been confirmed in numerous empirical studies with real decision makers (e.g. Fellner, 1961; Becker and Brownson, 1964; MacCrimmon, 1968; Slovic and Tversky, 1974; Curley and Yates, 1989).

Yet this preference is out-of-line with Subjective Expected Utility (SEU) theory, which suggests that since the outcomes are the same across the gambles, a utility maximizer should favor Gamble A over Gamble B only if she believes that a red ball is more likely to be drawn than a black ball. If drawing a red or black ball was perceived as equally likely, there would be no preference between the bets. Likewise, one should favor Gamble C over Gamble D only if she believes that a red or yellow ball is more likely to be drawn than a black or yellow ball. If one is likelier to draw a red ball than a black ball, then drawing a red or yellow ball is also likelier than drawing a black or yellow ball. Therefore, if a decision maker favors Gamble A over Gamble B, SEU theory states that she will also favor Gamble C to Gamble D. And if a decision maker favors Gamble B to Gamble A, she should also favor Gamble D to Gamble C.

In other words, Gamble A assures a known probability 1/3 of winning $100, while Gamble B's probability of winning is unknown, and could be anywhere from 0 to 2/3. Despite the range [0,2/3] having a midpoint of 1/3, decision makers seem to favor the known to the unknown probability. Likewise, Gamble D assures a 2/3 likelihood of winning, while Gamble C's probability of winning could be anywhere from 1/3 to 1. Still, decision makers favor the known probability bet, a preference known as ambiguity aversion, since both Gambles B and C involve ambiguity. Decision makers who are indifferent between Gambles A and B as well as Gambles C and D are considered *ambiguity neutral*, and those favoring Gamble B over A as well as Gamble C over D are considered *ambiguity seeking*.

In a second thought experiment, Ellsberg proposed the Two-Urn Paradox. Urn A contains exactly 50 black and 50 red balls, and Urn B contains 100 black and red balls in an unknown proportion. Decision makers are asked to choose a color (red or black) and an urn (A or B) and then draw a ball blindly from the selected urn, winning $100 if the ball ends up being of the selected color. A majority of people surveyed strictly favor the known Urn A over the ambiguous Urn B, regardless of the selected color.



Ellsberg's Two-Urn Paradox. Graphic from Dupuy and Grinbaum (2005)

Like the preferences seen in the Three-Color Paradox, the preferences here also violate the axioms of SEU theory. To illustrate, suppose a decision maker selects red and strictly favors Urn A over B. Since the likelihood of drawing a red ball from Urn A is ½, SEU theory assumes that she must have assigned a subjective probability less than ½ to drawing a red ball from Urn B, otherwise Urn A ought not be strictly favored for drawing a red ball. The decision maker's subjective probability of drawing a black ball from Urn B must be greater than ½, since the ball drawn needs to be either red or black, and the two probabilities must consequently sum to unity. SEU theory states that she should thus favor drawing a black ball from Urn B over drawing a red ball from Urn A, and the strict favoring of Urn A for drawing a red ball must thus have contradicted her own preferences. SEU theory was violated when the decision maker failed to maximize SEU.

Explaining Ambiguity Aversion: The Competence Hypothesis

A growing body of literature has indicated that the main driver of ambiguity preferences may be the decision maker's confidence in his knowledge about the topic (e.g. Frisch and Baron, 1988; Heath and Tversky, 1991; Fox et al., 2002; Klein et al., 2010). Known as the *competence hypothesis*, this explanation for ambiguity attitudes posits that children come to realize they perform better in situations they have more knowledge about than in situations they don't understand. This intuition carries over to situations in which the likelihoods of winning are no longer better in the familiar tasks than in the unfamiliar tasks. In addition to the monetary payoffs of bets, decision makers are impacted by the credit or blame caused by the outcome. Mental payoffs of pleasure or embarrassment can come from self-judgment or from being judged by others. When betting on a chance event, the outcome is attributed to luck. Yet when a person is betting on her own judgment and does not understand the issue well, failure will be attributed to her ignorance, whereas success will often be attributed to chance. When decision makers are "experts" at a task, success is usually attributed to knowledge, while failure sometimes to chance. The competence hypothesis argues that decision makers are highly attuned to the pleasures and embarrassments their decisions may invoke, and this drives their preferences when dealing with ambiguous probabilities.

In a series of experiments comparing individuals' willingness to bet on their uncertain beliefs with their willingness to bet on random events, Heath and Tversky (1991) found support for the competence hypothesis, showing that people bet on their vague beliefs when they feel especially competent or knowledgeable, but otherwise prefer to bet on chance. In one of Heath and Tversky's tests, subjects chose among bets involving three sources of unknowns: the winner of professional football matches, the winner of various states of the 1988 presidential election, and the results of random draws from an urn with a known ratio of desired balls. The subjects who said they knew a lot about football but not much about politics preferred betting on football games rather than on chance events that they considered equally likely. However, they preferred to bet on chance events as opposed to political events that they considered equally likely. The opposite pattern was seen in subjects who felt knowledgeable about politics but not football, choosing politics over chance and chance over football.

According to Fox and Tversky (1995), ambiguity aversion is caused by a comparison with more familiar sources of uncertainty or more competent individuals, and is less pronounced when no explicit comparison exists. The comparison makes the relative competence of the decision maker more salient. Chow and Sarin (1999) replicated the finding that the preference for known probabilities decreases when no explicit comparison is made, and showed that the preference is increased when subjects are told that another subject or group of subjects is assessing the other bet. Subjects preferred to bet on known probabilities over “unknowable” probabilities (i.e. the probabilities are unknown to anyone), and they preferred to bet on “unknowable” probabilities over “unknown” probabilities (i.e. they are told that someone else knows the probabilities). However, Fox and Weber (2002) have demonstrated that one’s level of confidence can still affect ambiguity preferences when subjects are not given a direct comparison between a known and an ambiguous prospect. Specifically, they demonstrated that even when just one prospect is judged, its attractiveness can be manipulated by simply asking the subject a question about a comparable event that the subject has more or less knowledge about, or by offering diagnostic information that is unusable to the subject. People are more attracted to uncertain bets when they have just been asked about a less familiar event than when asked about a more familiar event.

Providing further support for the competence hypothesis, people are more averse to ambiguity when they feel ignorant, such as when they are told to think about more intelligent people, or when they are overloaded with information that they do not know how to apply (Du and Budescu, 2005; Fox and Weber, 2002). However, when they feel more familiar with the task at hand, they avoid ambiguity less and may even become ambiguity seeking (Fox and Weber, 2002). An individual’s tolerance of ambiguity is also impacted by her level of optimism, with highly optimistic subjects showing less ambiguity aversion than subjects with less optimism (Pulford, 2009).

The competence hypothesis argues that ambiguity about probability is just one of several forces that affect competence and make individuals less likely to gamble. For instance, individuals prefer to bet on future events than on past events, since ignorance of past events can undermine their confidence (Rothbart and Snyder, 1970; Brun and Teigen, 1990). Additionally, they also prefer to bet on their skill rather than on chance (Cohen and Hansel, 1959; Langer, 1975).

Motivation for the Present Study: Why experience may change ambiguity preferences

Existing research on ambiguity has gauged preferences by presenting individuals with a risky prospect and an ambiguous prospect. The two prospects are equally attractive under expected utility theory, and individuals are asked to choose one. After making their selection, the individuals' preferences toward ambiguity are labeled, and no subsequent decision trials are run. To our knowledge, no existing studies have assessed how ambiguity preferences may be updated and altered if individuals were given additional trials of risky versus ambiguous prospects. Yet there are compelling reasons to believe that ambiguity preferences may change as individuals learn more about the ambiguous prospect and update their mental probability estimates for it.

Generally speaking, individuals are prone to many mistakes when assessing probabilistic information involving uncertainty (Kahneman and Tversky, 1984; Koehler, 1996; Newell et al., 2007). Yet a number of studies have demonstrated that their errors can be prevented by altering how the probabilistic information is presented (Cosmides and Tooby, 1996; Hertwig et al, 2004; Krynski and Tenenbaum, 2007; Stanovich and West, 2000). Most existing research on ambiguity aversion has presented probabilistic information through explicit descriptions, leading to subjects making false inferences about the information (see Curley et al, 1989). As observed in other economic errors people make, expressing probability distributions in a more intuitive form could make the information more usable to subjects, and ambiguity aversion might decrease. One intuitive form is to provide subjects with opportunities to experience the probability distributions. Hogarth (2001) has called these opportunities "kind" environments, wherein the nuances of a decision are made more apparent thus enabling better reasoning (Hogarth, 2001; Hogarth and Soyer, 2011). People may be capable of dealing with ambiguous probabilities, and our cognitive architecture may simply be better equipped for doing so in repeated gambles than in one-off gambles.

This hypothesis is supported by existing research in repeated market conditions. Various "anomalies" have been observed in individual choice behavior (see Camerer, 1995; Starmer, 2000). At face value, these anomalies can seem troublesome to decision theorists and applied economists. But many of them were demonstrated only in one-off decisions. Binmore (1999) states that anomalous behavior is economically important only if it also exists in situations of repeated decision making, and individuals are provided with adequate incentives and feedback on decision outcomes. Montgomery and Adelbratt (1982) found that subjects given detailed information about the expected value of various gambles usually neglected to use this information when making single choices, but they maximized expected value when repetitions were permitted. Some of the subjects even commented that numerical calculation was unimportant to gambles played just once. Wedell and Böckenholt (1994) showed that one type of expected utility violation, preference reversal, was significantly lowered under repeated gambles, and most subjects explained their repeated choices (but not their single choices) by attaching probabilities to observed outcomes. Similarly, DeKay and Kim (2005) and Keren (1991) found that individuals did not violate expected utility theory (primarily certainty and possibility effects) in repeated choices, despite violating them in single choices. The elimination of the certainty effect in a repeated task is intriguing, since ambiguity avoidance has been linked to the certainty effect (see Keren and Gerritsen, 1999). Essentially, a risky bet containing explicit probabilities is overweighed with regards to an ambiguous bet, even when the latter is subjectively perceived to have an equal probability. The literature largely agrees that decision makers obey the predictions of normative expected utility theory more often in repeated games than single games.

Prediction

Existing research suggests two factors that may affect how people respond to ambiguity in a repeated task. The first is the competence hypothesis, in which repeated experiences with the ambiguous prospect could result in subjects feeling more familiar and competent, leading to ambiguity-neutral or -seeking behaviors (Curley et al., 1986; Heath and Tversky, 1991). The second factor comes from the literature on how experience affects risk taking, which shows that people underweight rare outcomes when analyzing their samples (Erev et al., 2008; Hertwig and Erev, 2009; Hertwig et al., 2004; Jessup et al., 2008; Ungemach et al., 2009). For example, imagine that a risky prospect offers a 10% chance of winning $5 and a 90% chance of winning nothing. The rare outcome of $5 would be the result only in a small number of experiences. Having repeated experiences could lower the attractiveness of this prospect, since decision makers would realize that winning $5 is unlikely. But when experiencing a risky prospect that offers a 90% chance of winning $5 and a 10% chance of winning nothing, the rare outcome is winning nothing. The $5 gain will be the outcome in most of the gambles, and experiencing it would increase its attractiveness. In our experiment, people will adjust their preference for the ambiguous urn based on how frequently they see favorable draws from that urn.

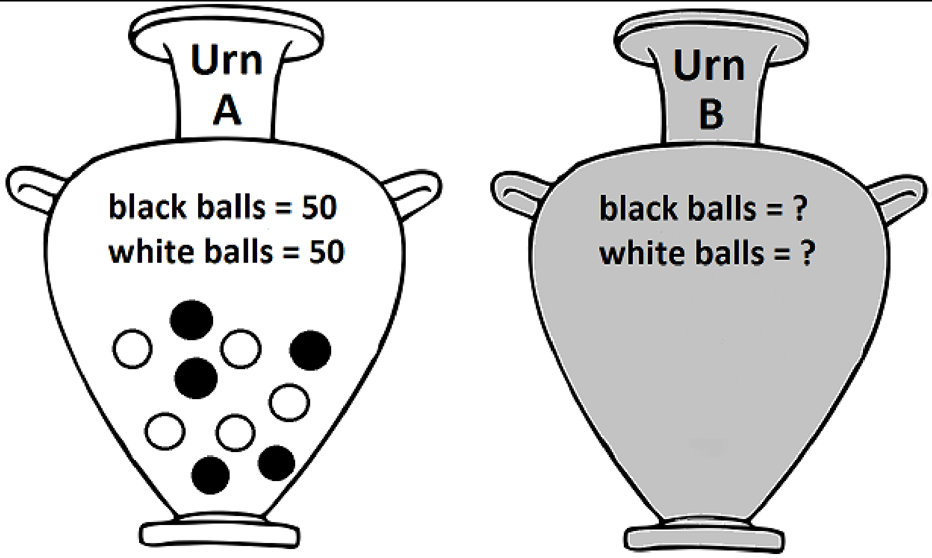
We predict that the ambiguous prospect will be more attractive relative to the known-probability risky prospect when there is a high perceived probability of winning, and less attractive when there is a low perceived probability of winning. Specifically, experiencing favorable draws from the ambiguous urn will lead to subjects betting more money on that urn in subsequent trials. Ambiguity aversion will decrease once subjects observe a favorable draw from the ambiguous urn.

Most studies on ambiguity attitudes have asked subjects to make a strict selection of one of the two urns. Since this study aims to assess preferences across repeated trials, using willingness to pay (WTP) may better gauge preference nuances than a strict selection criterion. Standard consumer theory suggests that identical rankings would be elicited if subjects' preferences were instead gauged via a separate monetary valuation of each prospect (see procedure in Becker et al., 1964). However, research has indicated that ambiguity aversion decreases when subjects are asked for their willingness to pay or willingness to accept, as opposed to making strict selections (Fox and Tversky, 1995; Chow and Sarin, 2001; Du and Budescu, 2005). Nonetheless, ambiguity aversion is still present in studies eliciting WTP. For reference, Fox and Tversky (1995) elicited WTP in an Ellsberg-style task and found the mean WTP to be $24.34 for the known (50-50 chance) prospect and $14.85 for the ambiguous prospect.

Method

201 subjects were recruited on MTurk and presented with a repeated Ellsberg 2-Urn task. After indicating their consent to participate, subjects were shown a graphic and text describing the task, and stated their WTP. All subjects observed a total of 5 draws (with replacement) from each urn, and WTP was elicited before each draw.

Imagine that there are two urns, and they each contain exactly 100 balls. In Urn A, there are exactly 50 black balls and 50 white balls. In Urn B, each of the balls is either black or white, but we do not know the ratio of black balls to white balls. However, we know that the total number of balls in Urn B is 100. Suppose you are offered the chance to play the following game: A ball will be randomly drawn from an urn. If the ball is black, you win $100. If the ball is white, you win nothing. After the ball is drawn and you are told the color, it will be placed back into the urn. You can play this game 5 times for each urn. What is the most you would pay to play? If the ball drawn is black, you will win $100.

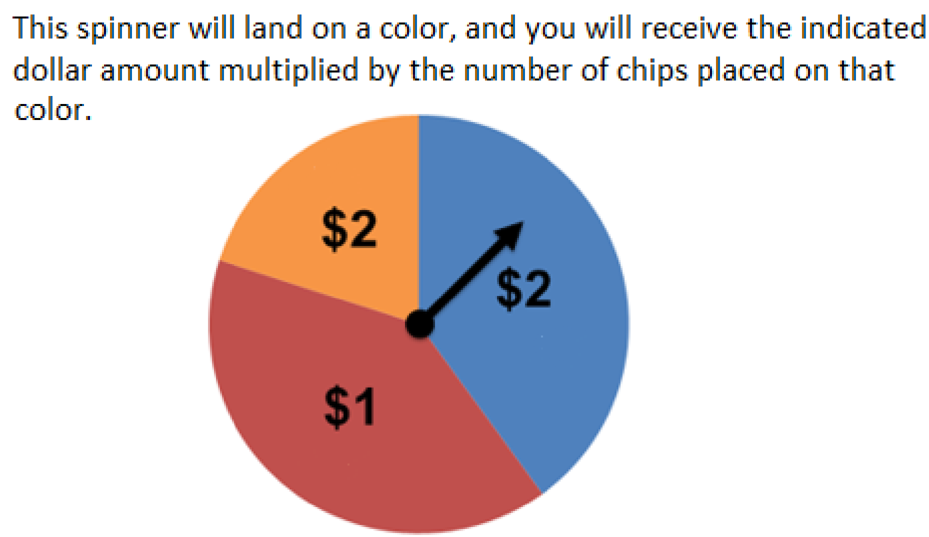


To play the game with Urn A, I would be willing to pay up to $______, but no more.
To play the game with Urn B, I would be willing to pay up to $______, but no more.

Figure 1: Task description and graphic presented to subjects

Upon indicating WTP, subjects were told the outcome of both draws, and that the balls were placed back into their respective urns for the next draw. The experiment was not “fixed” to yield any particular probability distribution for the ambiguous urn. Rather, all possible distributions were equally likely, and subjects were randomly assigned a distribution. Thus, in theory, subjects could be presented with an ambiguous urn probability distribution in which all the balls are black, or all white. Subjects with an identical WTP for both urns were labeled “ambiguity neutral” for that gamble, while subjects with a higher or lower WTP for the risky urn compared to the ambiguous urn were labeled “ambiguity averse” or “ambiguity seeking,” respectively.

To gauge possible relationships between risk and ambiguity attitudes, subjects completed a brief task at the end of the experiment. The task was designed by Shane Frederick at the Yale School of Management.



If you had 100 chips, how many would you bet on each color?

___ Blue
___ Red
___ Orange

Figure 2: Risk aversion task presented to subjects

Results

To adjust for outliers, the top and bottom 5% of the data were eliminated, and an analysis was conducted with the remaining 181 subjects. There was clear ambiguity aversion in the first draw WTP (see figure 3), with median amounts of $20 and $5 for the risky and ambiguous urns, respectively. Based on first draw WTP, 130 subjects were labeled ambiguity averse, 38 ambiguity neutral, and 13 ambiguity seeking. By the fifth draw, subjects were somewhat more tolerant of the ambiguous urn, with median amounts of $20 and $10 for the risky and ambiguous urns, respectively. Based on fifth draw WTP, 85 subjects were labeled ambiguity averse, 59 ambiguity neutral, and 37 ambiguity seeking.

	1st Draw	**5th Draw**
Subjects Ambiguity Averse	130	85
Subjects Ambiguity Neutral	38	69
Subjects Ambiguity Seeking	13	37
Mean WTP--Known Urn	$29	$26
Mean WTP--Ambiguous Urn	$17	$19
Median WTP-- Known Urn	$20	$20
Median WTP--Ambiguous Urn	$5	$10

Figure 3: Results comparing 1st and 5th draw outcomes

An independent samples t-test was conducted to compare WTP for the ambiguous draw and the outcome of the previous ambiguous draw. After the first draw, there was a significant difference in WTP for those seeing a favorable first draw (M= 17.80, SD= 23.28) than those seeing an unfavorable first draw (M= 14.32, SD= 18.58); t(179)= 1.106, p= .048. When subjects experienced favorable outcomes in both of the first two draws, they had higher WTPs for the third draw (M= 22.40, SD= 26.82) than subjects experiencing only one or no favorable draws (M=15.97, SD= 19.46); t(179)=1.75, p=.02. The sample size of subjects observing favorable outcomes in all of the first three or four draws was too small to yield significance. Subjects experiencing a total of at least 3 favorable draws over the course of the experiment had higher WTPs for the 5^{th} draw (M= 21.72, SD= 24.74) compared to subjects experiencing fewer than 3 favorable draws (M=18.16, SD= 29.63), but the increase was insignificant; t(178)= .801, p= .72. Subjects experiencing at least 2 favorable draws also had higher WTPs for the 5^{th} draw (M= 21.83, SD= 30.32) compared to subjects experiencing fewer than 2 favorable draws (M= 13.71, SD= 21.59), but this increase was also insignificant; t(178)= 1.8, p= .11.

There was some evidence for recency effects, as subjects experiencing consecutive favorable draws often had higher WTPs in subsequent draws.

	Designation in Next Draw			
	# Subjects	Amb. Averse	Amb. Neutral	Amb. Seeking
Fourth Draw if first 3 draws favorable	28	9	6	13
Fifth Draw if first 4 draws favorable	14	1	3	10
Fifth Draw if any 3+ draws favorable	60	18	18	24

Figure 4: Ambiguity preference based on favorability of previous draws

Analysis of the risk aversion task yielded averages of 46, 31, and 23 for the blue, red, and orange spaces, respectively. As a proxy for risk aversion, the total number of chips placed on the red and orange spaces were added together. Independent t-tests were run comparing this quantity to WTP, but the results were not significant. A linear regression test also failed to find significance.

	Blue	Red	Orange
Mean	46	31	23
Median	40	33	20
Mode	40	40	20

Figure 5: Results of risk task

Discussion

The present study found a moderate decrease in ambiguity aversion in a repeated Ellsberg urn task. The higher WTPs found in subjects with prior favorable draws suggests that subjects made mental probability updates in a utility maximizing framework. The general decline in ambiguity aversion provides support for the competence hypothesis. After just the first draw, subjects experiencing a favorable outcome had higher second draw WTPs than subjects experiencing an unfavorable outcome. Interestingly, subjects seemed to be affected more by the timing of favorable draws than by the total number of favorable draws. The highest WTPs were found in subjects experiencing multiple favorable draws in a row. The increase in WTP upon experiencing two favorable prior draws was only statistically significant if experienced sequentially, as opposed to being separated by unfavorable draws. This finding aligns with previous research on the sheer strength of the recency effect in long term gambling (Hertwig et al. 2006).

While ambiguity aversion decreased for subjects with favorable prior draws, the change was only moderate overall. It is interesting that only 40% of subjects experiencing 3 favorable draws were ambiguity seeking on the final draw. This may be due to the length of the experiment and the limited ability of subjects to create probability estimates for the ambiguous urn. 5 draws is likely too small of a sampling experience for subjects to gain a large increase in subjective competence. Yet the fact that subjects become more tolerant of ambiguity provides reason to suspect that a longer sampling experience would produce even greater tolerance. It may also find that subjects repeatedly reverse their preferences throughout the experiment, which would demonstrate a high level of sensitivity to new information. While many subjects in the present experiment switched from being ambiguity averse to ambiguity seeking, few subjects made repeated switches between preferences.

This experiment was unable to find relationships between risk aversion and ambiguity preferences. Previous empirical research has been unsuccessful in devising a model to conceptualize both types of preferences. If risk and ambiguity aversion are indeed distinct, additional work is needed to establish a model for choice under uncertainty.

Updating mental probabilities in a long-term task aligns with the findings of Montgomery and Adelbratt (1982) on behaviors violating expected utility theory. Participants in their study made numerical calculations in repeated gambles but not in single gambles, and many subjects explicitly stated their belief that accounting for probabilities is inapplicable to single gambles. It seems many people feel that probability mainly applies in the long run. In our experiment, people might feel that the uncertainty present in the ambiguous prospect is somehow eradicated or lessened when the prospect is repeated, making probabilities appear to be more relevant.

While this study addresses how ambiguity preferences may become more consistent with the predictions of expected utility theory in a repeated game, the setup did not allow for actual gains or losses, and thus cannot account for the potential role of loss aversion in influencing ambiguity preferences. One avenue for future studies is to provide individuals with mixed ambiguous gambles involving potential losses in addition to gains, to expose subjects to the possibility of losing some of the money they have earned. Some research has indicated that decision makers select ambiguous options more frequently in such circumstances (Cohen et al, 1985; Goldsmith and Sahlin, 1983). People are more sensitive to losses than to gains, and Tversky and Kahneman (1992) estimated that individuals weight losses 2.25 times as heavily as gains, relative to the status quo point, so that the disutility of losing $100 is over twice the utility of gaining $100. When there are mixed gambles involving potential losses and gains, the probability of loss becomes more important for subjects. Often, the probability of loss is smaller in a repeated gamble than in an equivalent single gamble, which may be why decision makers are less likely to violate normative principles of expected utility theory in repeated risky gambles (Thaler et al, 1997; Tversky and Bar-Hillel, 1983).

Additional studies can also increase the number of draws from the urns, and examine whether (and if so, how) people account for the gradual turning of an unknown prospect into a known prospect. Such studies could also provide insight for designing a model linking risk and ambiguity in decisions under uncertainty.

Conclusion

For many "anomalies" in economic decision making, an individual's performance more closely conforms to the predictions of expected utility theory when the game is played in a repeated setting than in a one-off setting. This study has demonstrated this effect in the realm of ambiguous gambles. While individuals have an inherent dislike of ambiguity, its impact on decision making is reduced when subjects are allowed to learn more about the ambiguous prospect through experience. Future research should examine the role of losses and gains on preferences, as well as expand the total number of draws allowed. These insights could have wide-ranging applications given the prevalence of decisions involving uncertainty.

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