Judgment and Decision Making, Vol. 7, No. 4, July 2012, pp. 383–389

Ambiguity aversion in a delay analogue of the Ellsberg Paradox

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Abstract

Decision makers are often ambiguity averse, preferring options with subjectively known probabilities to options with unknown probabilities. The Ellsberg paradox is the best-known example of this phenomenon. Ambiguity has generally been studied in the domain of risky choice, and many theories of ambiguity aversion deal with ambiguity only in this context. However, ambiguity aversion may occur in other contexts. In the present experiment, we examine the effects of ambiguity in intertemporal choice. Subjects imagine they are expecting a package and must choose between two delivery options. Some delivery times are exact. Others are ambiguous, with delivery possible over a range of dates. This problem was structurally identical to the Ellsberg paradox. Subjects showed the same pattern of responses as in the traditional Ellsberg paradox, with each delivery service preferred when it was the unambiguous option. Ambiguity aversion is not specific to risk, but can also occur in other domains.

Keywords: Ellsberg paradox, decision making, ambiguity, risk, delay, choice.

1 Introduction

When faced with a decision, a logical first question is, "What will happen if I do this? Will this investment make money? If I get this treatment, will I get better?" Frequently these are not questions that can be answered with certainty. Thus, the second question concerns probabilities, "What are the chances this investment will make money? If I get this treatment, what is the probability I will get better?"

Often these questions cannot be answered with any degree of certainty, either. While sometimes we can make subjectively good estimates of the probabilities of various outcomes, at other times we must make decisions under ambiguity: decisions for which we feel we lack knowledge that is required for a subjective estimate of the probability.

Many real-world decisions are ambiguous. To apply Expected Utility Theory (EUT), the normative theory of risky choice, to these ambiguous situations, decision makers must produce a subjective estimate of the absent probabilities (regardless of whether they feel that they have sufficient information to do so). According to Expected Utility theory, a decision maker should evaluate a gamble by multiplying the probability of each outcome by a numerical measure of the goodness of the outcome, the *utility*. The sum of the resulting numbers is the expected utility of the gamble, and the decision maker should choose the gamble for which this value is higher. Because it can be derived from defensible axioms, and because no other system will result in better aggregate outcomes over time, EUT is considered to be the normative theory of decision making (von Neumann & Morgenstern, 1944; Ramsey, 1926; Savage, 1954).

Initially it was assumed that, in addition to being normative, EUT also described actual decisions. However, challenges soon arose to the suggestion that EUT is a descriptive theory of choice. One of the earliest objections was made by Ellsberg (1961), who proposed what is now known as the Ellsberg paradox:

> Suppose an urn contains 90 balls. 30 are red, and the other 60 are some combination of black and yellow. You are not told how many of the balls are black and how many are yellow, only that together they total 60 balls.
>
> Now suppose you are going to draw a ball and gamble on the outcome. Consider this pair of gambles. Which would you prefer?
>
> *Pair One*
> Red Gamble: Win \$100 if ball is red
> Black Gamble: Win \$100 if ball is black
>
> Now consider a second pair of gambles. Again, which would you prefer?
>
> *Pair Two:*
> Red Gamble: Win \$100 if ball is red or yellow
> Black Gamble: Win \$100 if ball is black or yellow

According to EUT, a decision maker should choose the same outcome in both gamble pairs. To do otherwise

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would violate the *sure-thing* principle, which states that changing an outcome common to two gambles should not change a decision maker's preference between them. If a decision maker prefers the Red Gamble to the Black Gamble in Pair One, it implies the decision maker thinks that there are more red balls than black balls. However, if there are more red balls than black balls, there must be more total red and yellow balls than total black and yellow balls, and the decision maker should prefer the Red Gamble to the Black Gamble in Pair Two as well. A symmetrical argument demonstrates that decision makers who prefer the Black Gamble in Pair Two should prefer the Black Gamble in Pair One. Adding the common outcome of winning $100 if a yellow ball is drawn should not change whether the decision-maker prefers to bet on the red or the black ball.

However, Ellsberg found that decision makers prefer the Red Gamble in the first pair, but prefer the Black Gamble in the second pair. This pattern of choices violates the sure-thing principle and is thus inconsistent with EUT. Instead, a decision maker which shows this pattern of choices is displaying *ambiguity aversion*—in each pair, preferring to gamble on a known number of balls to gambling on an unknown number. Subsequent experiments have confirmed Ellsberg's intuition, both about the pattern of choices shown in the Ellsberg paradox and about ambiguity aversion more generally (Becker & Brownson, 1964; MacCrimmon & Larsson, 1979; Slovic & Tversky, 1974).

Ellsberg discussed ambiguity strictly in terms of risky choice, and subsequent work has generally followed this lead: ambiguity is defined as an unknown *probability* — that is, a probability for which the decision maker feels that she does not have enough information to make a subjective estimate. However, it seems possible that ambiguity aversion may be a more general phenomenon, not constrained to risky choice. Specifically, analogous phenomena may occur in the in the realm of intertemporal choice, choices made about outcomes that occur at different times. A wide variety of real-world decisions can be described as intertemporal choices, including saving/investment decisions and preventive health behaviors. For example, an investor must choose between spending a small amount of money now and saving the money to have a larger amount of money later. In many cases, the length of time that will pass before receiving the outcome cannot be estimated with any degree of accuracy, the equivalent to ambiguous probabilities in risky choice. The present experiment examines whether the effects of ambiguity in the domain of delay are similar to the effects of ambiguity on risky choice. Is there an equivalent to the Ellsberg paradox in the domain of intertemporal choice?

1.1 Intertemporal choice

Intertemporal choice refers to choices made about outcomes that occur at a future date. A variety of real-world decisions can be described as intertemporal choices, most notably saving/investment decisions and preventive health behaviors.

Normatively, future outcomes should be evaluated using an exponential discounting function (Samuelson, 1937). However, as in risky choice, the normative theory of intertemporal choice does not seem to describe a variety of commonly shown decision patterns. For example, decision makers show a disproportionate preference for outcomes that are immediate over outcomes that are delayed (Green, Fristoe, & Myerson, 1994; Kirby & Herrnstein, 1995).

Many of the biases shown in intertemporal choice are similar to those shown in risky choice (Chapman & Weber, 2006; Prelec & Loewenstein, 1991). The existence of parallels between risky and intertemporal choice led us to wonder whether decision makers display ambiguity aversion in intertemporal choice, just as they do for risky choice.

1.2 Ambiguity and intertemporal choice

What does it mean for a delay to be ambiguous? The term "ambiguity" can be somewhat ambiguous in itself. Camerer and Weber (1992) note that one can distinguish between two sources of ambiguity: ambiguity over outcomes and ambiguity over probabilities. Ambiguity over outcomes means the decision maker lacks information about the outcomes of the decision, while ambiguity over probabilities occurs when the decision maker lacks information relevant to probabilities of the outcomes. Choices with ambiguity over probabilities are a subset of choices with ambiguity over outcomes, which also include risky choices where the probabilities are given and choices where the probability of each outcome is given but the exact size of each payout is not (Ho, Keller, & Keltyka, 2002).

Camerer and Weber (1992) also note that there are two major conceptions of ambiguity (among those who accept the concept of ambiguity at all). The first is to express an ambiguous quantity in terms of a *second-order probability*, a probability distribution of possible values of the ambiguous quantity. In the Ellsberg paradox, the decision maker doesn't know how many of the 60 balls are black and how many are yellow, but he may have a belief about the probabilities of the various possible distributions: for example, he may think that it is most likely that there are a roughly equal number balls of each color than that they all yellow or all black. According to this conception of ambiguity, ambiguous decisions are in principle re-

https://doi.org/10.1017/S1930297500002734 Published online by Cambridge University Press

Table 1: Ellsberg Paradox gambles: Risk.

Ellsberg Paradox	Option One	Option Two
Classic	*Urn with 90 balls, 30 red and 60 black or yellow*	
Level One	$100 on red ball	$100 on yellow ball
Level Two	$100 on red or black ball	$100 on yellow or black ball
Expanded	*Urn with 120 balls, 30 red and 90 black, yellow, or green*	
Level One	$100 on red ball	$100 on yellow ball
Level Two	$100 on red, black, or green ball	$100 on yellow, black, or green ball

ducible to unambiguous risky decisions, by reducing the compound gambles into single-stage gambles. The second conception of ambiguity described by Camerer and Weber (1992) is to think of ambiguity in terms of missing information (see also Fox & Tversky, 1995; Frisch & Baron, 1988). In the case of ambiguity over probability, it is the probability information that is missing.

Expanding the concept of ambiguity into the domain of intertemporal choice introduces a third source of ambiguity, ambiguity over time. In ambiguity over time, the time until an outcome is received is unknown. Like ambiguity over probability, ambiguity over time can be conceptualized either in terms of second-order probabilities (a probability distribution of possible time delays) or in terms of missing information, where the missing information is the length of the delay. Ambiguity over time differs from ambiguity over probability in that ambiguity over time does not also imply ambiguity over outcome. In ambiguity over time, the eventual outcome is known, but the length of time before the outcome will occur is uncertain.

The original Ellsberg paradox is non-normative in part because it violates the sure-thing principle, with an increase in probability common to both options producing a preference reversal. Violations of the sure-thing principle have been widely demonstrated in the domain of risky choice (one of the best-known being the Allais paradox: Allais, 1953). The immediacy effect in intertemporal choice is a similar phenomenon, with an increase in time delay common to both outcomes leading to a preference reversal. Common consequence effects (a category of paradoxes that includes the Allais and Ellsberg paradoxes) have also been demonstrated in intertemporal choice. For example, Loewenstein (1987) found that adding a fancy lobster dinner to be eaten two weekends from now changed decision makers' preferred time for fancy French dinner from the following weekend to the current weekend. Rao & Li (2011) also demonstrated that in some situations, adding the same outcome to two delayed options can lead to a preference reversal. (For example, subjects preferred ¥1,000,000 immediately to ¥5,000,000 in 10 years, but were indifferent between the two when a common ¥6,000,000 in 1 year was added to both options.)

Thus, there is some reason to think there might be an equivalent to the Ellsberg paradox in the domain of delay. If so, it would suggest that ambiguity aversion is not specific to the domain of risk, but is a more general phenomenon. It would also demonstrate that ambiguity aversion occurs even when there is no outcome ambiguity—that is, when the final outcome is known for certain. The purpose of the present experiment was to see whether decision makers will display ambiguity aversion when the Ellsberg paradox is translated into intertemporal choice

2 Method

2.1 Subjects

179 Iowa State University undergraduates participated in the experiment as part of a class requirement for an introductory psychology class.

2.2 Design

Each subject was presented both with two versions of the Ellsberg paradox in the domain of risk, and three versions of the analogue of the Ellsberg paradox in the domain of delay. These are described in more detail below. For each version, the subject saw both levels of the Ellsberg paradox, for a total of 10 choices. For each choice, subjects were asked to choose which gamble they would prefer to play, and also asked on a scale of 1 to 10 how strongly they preferred the chosen gamble.

2.2.1 Ambiguity aversion: Risk

Subjects saw two versions of the Ellsberg paradox. The first was the classic paradox first presented by (Ellsberg, 1961), the second an expanded version of the paradox

Table 2: Ellsberg Paradox gambles: Delay.

	Delivery time when in Town B (Level 1)		Delivery time when in Town C (Level 2)
	A-B Transit	B-C Transit	Total A-C Transit
Service One	*AB* days	(9–*AB*) days	9 days
Service Two (three versions)	3 days	(9-*AB*) days	(12-*AB*) days
	5 days	(9–*AB*) days	(14–*AB*) days
	7 days	(9–*AB*) days	(16–*AB*) days

using a hypothetical urn with 120 balls, 30 red and 90 yellow, black, or green. (See Table 1.) This resulted in a 2 (classic vs. expanded) by 2 (level of paradox) within-subjects design.

2.2.2 Ambiguity aversion: Delay

Subjects were asked to imagine three towns: Town A, Town B, and Town C. They were to imagine they were being sent a package from Town A, which they wanted to receive as soon as possible. Subjects were given no information about the geographic arrangement of towns A, B, and C.

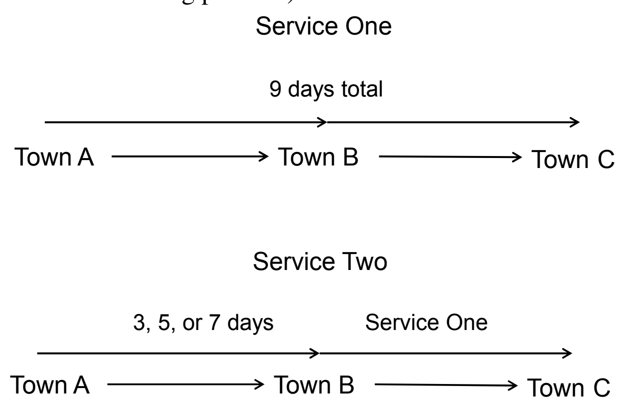
Subjects were told that two shipping options were available. Both options ship a package from Town A to Town C, via Town B. Service One takes 9 days total to move the package from Town A to Town C. How long it takes to get the package from Town A to Town B, or Town B to Town C, is not known: the subjects are only told it takes 9 days total to travel from A to B and then from B to C. Service Two takes a fixed amount of time to travel from Town A to Town B (either 3, 5, or 7 days). Upon reaching Town B, the package is transferred to Service One to travel from Town B to Town C. How long it takes to get from Town B to Town C is not known, only that it takes the same (unknown) amount of time as going from B to C via Service One. Therefore the total transit time from A to C using Service Two is unknown. (See Figure 1 and Table 2.)

Subjects were presented with 3, 5, and 7 day transit times from A to B with Service Two. Subjects were also asked to imagine that they were in either B or C for each transit time. This resulted in a 2 (subject in B or C) x 3 (3, 5, or 7 days) within-subjects design.

This scenario is structurally equivalent to the Ellsberg paradox. Service One is analogous to the black and yellow balls—the total number of days is known, but the way the days are distributed between the A-B and B-C legs are not. The A-B leg of Service One in analogous to the black balls, and the B-C leg is analogous to the yellow balls. The Town A-Town B leg of Service Two is analogous to the red balls—the total number of days is known. When the subject is in Town B, the decision is equivalent to the first level of the Ellsberg paradox: the subject is choosing between Service Two's known A-B transit time (red balls) and Service One's unknown A-B transit time (black balls). When the subject is moved to Town C, the same unknown B-C transit time (yellow balls) is added to each option, resulting in an unknown A-C transit time for Service Two but a known A-C transit time for Service One. This is equivalent to the second level of the Ellsberg paradox.

Just as in the Ellsberg paradox, a preference for Service Two over Service One when in Town B implies the subject thinks Service One takes more than 3, 5, or 7 days (depending on condition) to get from Town A to Town B. This implies that Service Two is still the faster option when in Town C, and therefore should be preferred. A subject who prefers Service Two when in Town B, but

Figure 1: Ellsberg paradox gambles: delay. Subjects were told the package originated in Town A and would travel through Town B to Town C. Subjects were sometimes told to imagine they were in Town B (equivalent to level 1 of the standard Ellsberg paradox) and sometimes that they were in Town C (equivalent to level 2 of the standard Ellsberg paradox).



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Service One when in Town C, is demonstrating the same ambiguity-averse pattern of choices that is seen in the Ellsberg paradox.

2.3 Materials

Questions were presented to the subjects using ePrime (Psychology Software Tools). Gambles were arranged in two blocks: four risk choices and six delay choices. All subjects saw the risk block first, followed by the delay block. Choices were presented in random order within each block.

3 Results

3.1 Ambiguity aversion: Risk

The percentage of subjects choosing to gamble on the red ball is shown in Figure 2. In both the classic and expanded Ellsberg paradox, subjects were more likely to choose to bet on the red ball when it was the unambiguous option than when it was the ambiguous option, showing the standard Ellsberg paradox pattern of ambiguity aversion. A 2x2 (classic vs. expanded Ellsberg paradox x level of Ellsberg paradox) logistic regression analysis on only the risk questions found that the Ellsberg paradox was statistically significant (χ^2(1, N=179)= 52.53, p<.0001). The main effect of version (classic vs. extended) was not significant, (χ^2(1, N=179)= 0.34, p=.56), and neither was the interaction between version and level of the Ellsberg paradox was not significant, (χ^2(1, N=179)= 2.13, p=.14) indicating that subjects were not more likely to show the Ellsberg paradox in one version than the other. The simple main effect of level of the Ellsberg paradox was significant for both the classic and expanded versions ((χ^2(1, N=179)= 32.67, p<.0001), classic Ellsberg paradox; (χ^2(1, N=179)= 48.94, p<.0001), extended Ellsberg paradox) indicating that subjects showed the Ellsberg paradox for both versions.

3.2 Ambiguity aversion: Delay

The percentage of subjects choosing to ship their package with Service Two is shown in Figure 3. In all three versions of the problem, subjects were more likely to choose Service Two when it was the unambiguous option than when it was the ambiguous option, indicating that subjects will show the Ellsberg pattern of ambiguity aversion in the domain of delay as well as in the domain of risk. A 3x2 (A-B transit time in Service Two x level of Ellsberg paradox) logistic regression analysis on only the delay questions found that the Ellsberg paradox was statistically significant (χ^2(1, N=179)= 29.83, p<.0001). The main effect of version (3, 7, or 9 days) was significant, (χ^2(1, N=179)= 100.82, p<.0001), indicating that subjects were more likely to choose Service Two (known transit time from A to B) when the A-B transit time was shorter. The interaction between A-B transit time and level of the Ellsberg paradox was not significant, (χ^2(1, N=179)= 1.96, p=.37) indicating that probability of showing the Ellsberg paradox in the three delay conditions did not significantly differ from one another. The simple main effect of level of the Ellsberg paradox was significant for all three versions of the problem, (χ^2(1, N=179)= 15.08, p=.0001), (χ^2(1, N=179)= 21.28, p<.0001), (χ^2(1, N=179)= 8.70, p=.003), for A to B transit time of 3, 5, and 7 days respectively, showing that subjects showed the Ellsberg paradox for all thee A-B transit times.

Figure 2: Percentage of subjects choosing the "Red" option: risk. Differences marked with an ** were significant at the p<.0001 level in a within-subjects logistic regression.

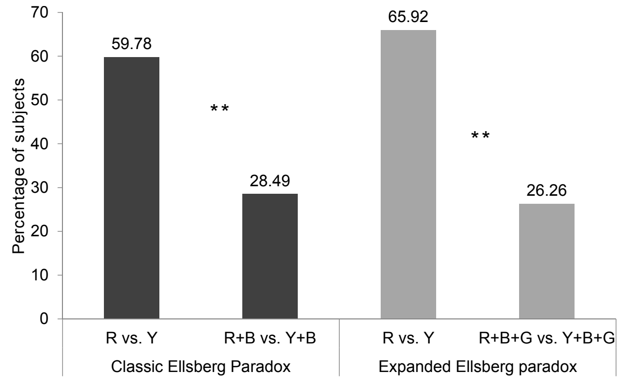

Figure 3: Percentage of subjects choosing Service Two: delay. Differences marked with an ** were significant at the $p\leq$0.0001 level in a within-subjects logistic regression. Differences marked with an * were significant at the p<.01 level.

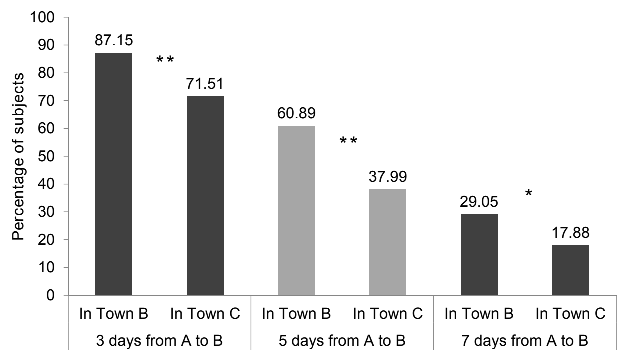

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Table 3: Mean preference for the chosen option.

	Chose ambiguous option		Chose non-ambiguous option	
	Mean (SD)	N	Mean (SD)	N
Risk	6.21 (2.66)	231	6.79 (2.48)	485
Delay	6.19 (2.09)	448	6.52 (2.15)	626

3.3 Ambiguity aversion: Risk vs. delay comparison.

A 2x2 (risk vs. delay x level of the Ellsberg paradox) logistic regression analysis found that the interaction between level of the Ellsberg paradox and domain was significant, (χ^2(1, N=179)= 14.52, p<.0001), indicating that subjects were more likely to show the Ellsberg paradox in the domain of risk than in the domain of delay. Because subjects saw two versions of the Ellsberg paradox for risk, and three versions for delay, it was possible to compare the number of times subjects showed the Ellsberg paradox for each domain. A gamma test of association showed no relationship between the number of times a subject showed the Ellsberg paradox for risk and the number of times they showed it for delay (γ=−.082, z=−0.81, p=0.42).[1]

3.4 Ambiguity aversion: Preference for the chosen option

For both risk and delay, subjects indicated a stronger preference for the chosen option when they chose the non-ambiguous option than when they chose the ambiguous option (Table 3). This effect was statistically significant for both risk (F(1,119) = 9.27, p=.0029) and delay (F(1,168) = 6.72, p=.01).

4 Discussion

The present experiment demonstrates ambiguity aversion in intertemporal choice. This shows that ambiguity aversion is not confined to risky choice, but is a more general phenomenon that can occur in other domains as well. It also shows that ambiguity aversion is not confined to problems where the final outcome is unknown at the time the decision is made, but can occur in the absence of outcome ambiguity. More generally, the present results demonstrate a novel violation of the sure-thing principle in the domain of intertemporal choice.

As mentioned above, Camerer and Weber (1992) suggested two ways of conceptualizing ambiguity: in terms of second order probabilities, or in terms of lack of relevant information. Either conceptualization is consistent with the results of the present study.

The decision maker may have in mind a probability distribution of various possible arrival dates in the delay version of the Ellsberg paradox, comparable to the probability distribution of possible ball distributions in the risk version of the Ellsberg paradox. Risk aversion may then lead decision makers to favor both certain arrival dates and certain numbers of balls. However, if this were the case, we would expect risk attitudes and ambiguity attitudes to be correlated, and multiple studies have found no correlation between risk attitudes and ambiguity attitudes (Cohen, Jaffray, & Said, 1985; Curley, Yates, & Abrams, 1986; Hogarth & Einhorn, 1990). (However, Lauriola and Levin, 2001, found a correlation between risk attitudes and ambiguity attitudes in some situations.)

Conceptualizing ambiguity in terms of lack of relevant information is also consistent with the present results. Under this understanding of ambiguity, ambiguity aversion is explained by hypothesizing that decision makers show a preference for the option about which they are more knowledgeable (Fox & Tversky, 1995; Frisch & Baron, 1988; Heath & Tversky, 1991). In the risk version of the paradox, they prefer the option with the known number of balls, in the delay version, the service for which they are sure of the delivery date. Because the comparative ignorance hypothesis does not consider ambiguity aversion a form of risk aversion, it does not predict that risk and ambiguity aversion should be correlated.

One finding in the present study is puzzling under any conception of ambiguity: the fact that subjects who showed the Ellsberg paradox in risky choice were not more likely to show it in intertemporal choice, and vice versa. This is not what we would expect if a common mechanism causes the Ellsberg paradox in both domains. At the same time, given the similarity in behavior between the risk and delay versions of the Ellsberg paradox, it would be surprising if there was no commonality in the underlying processes. It may be that some subjects felt more knowledgeable about possible distributions of balls in urns, while other subjects felt more knowledge-

[1] The Pearson correlation between number of times subjects showed the Ellsberg paradox for risk and delay was −.093. The Cronbach alpha reliability coefficients for the number of times subjects showed the Ellsberg paradox were .53 for risk and .47 for delay.

https://doi.org/10.1017/S1930297500002734 Published online by Cambridge University Press

able about possible shipping times. More research is required to determine how to best integrate the present findings with existing theories of ambiguity aversion.

The presence of ambiguity aversion in intertemporal choice demonstrates that ambiguity aversion is a psychological phenomenon that is not limited to risky choice, but can occur in multiple domains. This suggests possibilities for future research into the role ambiguity aversion may play in situations outside the realm of risky choice. In the real world, information about outcomes is rarely certain, and thus a greater understanding of ambiguity is essential to a greater understanding of decision making.

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