Preference Reversals to Explain Ambiguity Aversion

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October, 2007

ABSTRACT. Preference reversals are found in measurements of ambiguity aversion even under constant psychological and informational circumstances. This finding complicates the study of what the "true" ambiguity aversion is. The reversals are not attributable to mistakes and concern reversals within one attribute (ambiguity perception). They are, thus, of a fundamentally different nature than known preference reversals in multiattribute or risky choice. The reversals can be explained by Sugden's random-reference theory: loss aversion generates an overestimation of ambiguity aversion for willingness to pay. Hence, ambiguity aversion may be less strong than commonly thought.

KEYWORDS: ambiguity aversion, choice vs. valuation, preference reversal, loss aversion
JEL CLASSIFICATION: D81, C91

1. Introduction

One of the greatest challenges for the classical paradigm of rational choice was generated by preference reversals, first found by Lichtenstein & Slovic (1971): strategically irrelevant details of framing can lead to a complete reversal of preference. Grether & Plott (1979) confirmed preference reversals while using real incentives and while removing many potential biases. Preference reversals raise the question what true preferences are, if they exist at all. This paper shows that preference reversals also occur in one of the most important domains of decision theory today: choice under uncertainty when probabilities are unknown (ambiguity).

The preference reversals that we find are of a fundamentally different nature than the preference reversals found in the literature on decision under risk and, in general, on choices between multiattribute objects. Those preference reversals have been found when the tradeoffs between different attributes (such as probability and gain in decision under risk) are different in different decision modes (Lichtenstein & Slovic 1971; Tversky et al. 1988; Tversky et al. 1990). Our preference reversals concern a complete reversal of ordering within one attribute, i.e. the (likelihood) weighting of ambiguous events. It can be contrasted with preference reversals found for risky choice. There a more favorable gain is to be traded against a better probability. This trading is done differently in different contexts. In our design there will be only one fixed gain, so that the reversal must entirely take place within the likelihood attribute.

We investigate two commonly used formats for measuring ambiguity attitudes. The first is to offer subjects a straight choice between an ambiguous and a risky prospect, and the second is to elicit subjects' willingness to pay (WTP) for each of the prospects. We compare the two approaches in simple Ellsberg two-color problems. In four experiments, WTP generates a very strong ambiguity aversion, with almost no subject expressing higher WTP for the ambiguous urn than for the risky urn. Remarkably, however, this finding also holds for the subjects who in straight choice prefer the ambiguous urn. Hence, in this group the majority assigns a higher WTP to the not-chosen risky urn, entailing a preference reversal. There are virtually no reversed preference reversals of subjects choosing the risky urn but assigning a higher WTP to the ambiguous urn. This asymmetry between choice and WTP shows that

either WTP finds too much ambiguity aversion, or straight choice finds too little (or both).

Using Sugden's (2003) and Schmidt, Starmer, & Sugden's (2005) generalization of prospect theory with a random reference point, we develop a quantitative model that explains the preference reversals found: a distorting loss aversion effect in willingness to pay leads to an overestimation of loss aversion there. In interviews conducted after one of the experiments, we made subjects aware of the preference reversals if occurring. No subject wanted to change behavior, suggesting that the preference reversals are not due to choice errors. The explanations that subjects gave suggested reference dependence and loss aversion in WTP, which led to our theoretical explanation. Differences between WTP measurements and another measurement, using certainty equivalents, further supports our theory that WTP overestimates ambiguity aversion. It does so not only for the subjects for whom it leads to a preference reversal but also for the other subjects.

It is well known that changes in psychological and informational circumstances can affect ambiguity attitudes. Examples of such circumstances are accountability (being evaluated by others or not; Curley, Yates, & Abrams 1986), relative competence (whether or not there are others knowing more; Tversky & Fox 1995; Heath & Tversky 1991; Fox & Weber 2002), gain-loss framings (Du & Budescu 2005), and order effects (Fox & Weber 2002). Closer to the preference reversals reported in our paper is a discovery by Fox & Tversky (1995), that ambiguity aversion is reduced if choice options are evaluated separately rather than jointly (Du & Budescu 2005, Table 5; Fox & Weber 2002). From this finding, preference reversals can be generated. The preference reversals reported in our paper are more fundamental. We compare two evaluation methods while keeping psychological and informational circumstances constant. For example, all evaluations will be joint and not separate. Thus, the preference reversals cannot be ascribed to changes in information or to extraneous framing effects. They must concern an intrinsic aspect of evaluation.

We present a theoretical model to explain the preference reversals found, based on loss aversion for willingness to pay. Recent studies demonstrating the importance of loss aversion are Fehr & Götte (2007) and Myagkov & Plott (1997). That loss aversion may not only be the strongest component of risk attitude, but also the most volatile, can be inferred from Plott & Zeiler (2005). That it plays an important role in willingness-to-pay questions was demonstrated by Morrison (1997).

There is much interest today in relations between risk/ambiguity attitudes and demographic variables. We find that females and older students are more risk averse and more ambiguity averse.

The organization of the paper is as follows. Section 2 presents our basic experiment, and our preference reversals. Section 3 presents a control experiment where no preference reversals are found, supporting our theoretical explanation. Whereas the WTP was not incentivized in our basic experiment so as to avoid income effects, it is incentivized in Section 4, showing that this aspect does not affect our findings. Section 5 considers a modification of the random lottery incentive system used and shows that this modification does not affect our basic finding either. Section 6 discusses the effect of gender and age for the pooled data of all three experiments. A theoretical explanation of our empirical findings is in Section 7. Section 8 discusses implications, and Section 9 concludes.

2. Experiment 1; Basic Experiment

Subjects. N = 59 econometrics students participated in this experiment, carried out in a classroom.

Stimuli. At the beginning of the experiment, two urns were presented to the subjects, so that when evaluating one urn they knew about the existence of the other. The known urn[1] contained 20 red and 20 black balls and the unknown urn contained 40 red and black balls in an unknown proportion. Subjects would select a color at their discretion (red or black), announce their choice, and then make a simple Ellsberg choice. This choice was between betting on the color selected for the (ball to be drawn from the) known urn, or betting on the color selected from the unknown urn. Next they themselves randomly drew a ball from the urn chosen. If the drawn color matched the announced color they won €50; otherwise they won nothing.

[1] This term is used in this paper. In the experiment, we did not use this term. We used bags instead of urns, and the unknown bag was designated through its darker color without using the term "unknown." We did not use balls but chips, and the colors used were red and green instead of red and black. For consistency of terminology in the field, we use the same terms and colors in our paper as the original Ellsberg (1961) paper did.

Subjects were also asked to specify their maximum WTP for both urns (Appendix A). In this basic experiment, the WTP questions were hypothetical to prevent possible house money effects arising from the significant endowment that would have been necessary to enable subjects to pay for prospects with a prize of €50. Subjects first made their choice and then answered the WTP questions.

All choices and questions were on the same sheet of paper and could be answered immediately after each other, or in the order that the subject preferred. We also asked for the age and the gender of the subjects.

Incentives. Two subjects were randomly selected and played for real. The subjects were paid according to their choices and could win up to €50 in cash.

Analysis. In this experiment as in the other experiments in this paper, usually a clear direction of effects can be expected, because of which we use one-sided tests unless stated otherwise throughout this paper. Further, tests are *t*-tests unless stated otherwise. The abbreviation ns designates nonsignificance. The *WTP-implied choice* is the choice for the prospect with the higher WTP value. The *WTP difference* is the WTP for the risky prospect minus the WTP for the ambiguous prospect. It is an index of ambiguity aversion, and it is positive if and only if the WTP-implied choice is for the risky prospect.

Results. In straight choice, 22 of 59 chose ambiguous, which entails ambiguity aversion ($p < 0.05$, binomial). The following table shows the average WTP separately for subjects who chose ambiguous and those who chose risky.

TABLE 1. Willingness to Pay in €

	WTP risky	WTP ambiguous	WTP difference	t-test
Ambiguous chosen	12.25	9.50	2.75	$t_{21}=2.72$, $p < 0.01$
Risky chosen	11.64	6.27	5.37	$t_{36}=6.7$, $p < 0.01$
Two-sided *t*-test	$t_{57} = 0.33$, ns	$t_{57} = 2.14$, $p < 0.05$	$t_{57} = 2.01$, $p < 0.05$	

The subjects who chose the ambiguous prospect, the *ambiguous choosers* for short, are in general more risk seeking, although their WTP for the risky prospect is not significantly higher than for the risky choosers. Their WTP for the ambiguous prospects is obviously much higher than for the risky choosers. Risky choosers value the risky prospect on average €5.37 higher than the ambiguous one ($p < 0.01$). Surprisingly, ambiguous choosers also value the risky prospect €2.75 *higher* than the ambiguous one ($p < 0.01$), which entails the preference reversal. The following table gives frequencies of WTP-implied choices and straight choices.

TABLE 2. Frequencies of WTP-Implied Choice versus Straight Choices

WTP-implied / straight	Ambiguous	Indifferent	Risky	Binomial test
Ambiguous	2	9	11	$p = 0.01$
Risky	0	6	31	$p < 0.01$

Almost no WTP-implied choice is for ambiguous, not only for the risky choosers but also for the ambiguous choosers. Thus, for 11 of 59 subjects the WTP-implied choice and the straight choice are inconsistent. For all these subjects, the WTP-implied choice is for risky and the straight choice is for ambiguous. No reversed inconsistency was found. The number of the reversals found is large enough to depress the positive correlation between straight and implied choices to 0.34 (Spearman's ρ, $p < 0.05$ two-sided), excluding indifferences. We find significant WTP-implied ambiguity aversion for the straight ambiguity choosers ($p=0.01$, binomial). For subjects with straight choice of risky this is clearly true as well ($p < 0.01$, binomial).

Discussion. We find ambiguity aversion in straight choice, but still 22 out of 59 subjects choose ambiguous. For WTP there is considerably more ambiguity aversion and virtually everyone prefers ambiguous, leading to preference reversals for 11 subjects. Only 2 ambiguous choosers also have an ambiguous WTP-implied choice. This result is particularly striking because straight choice and WTP had to be made just one after the other on the same sheet. No preference reversal occurs for the risky choosers. An explanation of the preference reversal found can be that during

their WTP task subjects take the risky prospect as a reference point for their valuation of the ambiguous prospect. Valuating the risky prospect is comparatively easy so that it is a natural starting point. Then, because of loss aversion, the cons of the ambiguous prospect relative to the risky prospect weigh more heavily than the pros, leading to a systematic dislike of the ambiguous prospect. Section 7 gives a more detailed explanation. Experiment 2 serves to test for this explanation because there no similar choice of reference point is plausible.

An alternative explanation instead of genuine preference reversal could be suggested to explain our data, an error-conjecture. The *error conjecture* entails that WTP best measures true preferences, which supposedly are almost unanimously ambiguity averse, and that straight choice is simply subject to more errors. The 11 risky WTP-implied preferences would then be errors (occurring less frequently for WTP but still occurring) and they would not entail genuine preference reversals. One argument against this hypothesis is that straight choices constitute the simplest value-elicitations conceivable, and that the literature gives no reason to suppose that straight choice is more prone to error than WTP. This holds the more so as straight choices were carried out with real incentives. Other arguments against the error hypothesis are provided in Experiments 2 and 4 that test and reject the hypothesis.

The preference reversal in Experiment 1 were observed without incentivized WTP and in a classroom setting. WTP with real incentives may differ from hypothetical WTP (Cummins, Harrison, & Rutström 1995; Hogarth & Einhorn 1990). To test the stability of our finding in the presence of monetary incentives and in controlled circumstances in a laboratory we conducted Experiments 3 and 4.

3. Experiment 2; Certainty Equivalents from Choices to Control for Loss Aversion

Experiment 2 tests a loss-aversion explanation (with details in Section 7) of the preference reversal found in the basic experiment. It also tests the error conjecture described in the preceding section. It further shows that the WTP bias detected by the preference reversal holds in general, that is, also for subjects for whom it does not lead to a preference reversal.

Subjects. N = 79 subjects participated as in Experiment 1.

Stimuli. All stimuli were the same as in Experiment 1, starting with a simple Ellsberg choice, with one modification. Subjects were not asked to give a WTP judgment. Instead, they were asked to make 9 choices between playing the risky prospect and receiving a sure amount, and 9 choices between playing the ambiguous prospect and receiving a sure amount (Appendix A). Thus, there was no direct comparison of the risky and ambiguous prospects' values. The choices served to elicit the subjects' certainty equivalents, as explained later.

Incentives. The prizes were as in Experiment 1. Subjects first made all 19 decisions. Then two subjects were selected randomly. For both, one of their choices was randomly selected to be played for real by them throwing a 20-sided die, where the straight choice had probability 2/20 and each of the 18 CE choices had probability 1/20.

Analysis. For each prospect, the CE was the midpoint of the two sure amounts for which the subject switched from preferring the prospect to preferring the sure money. All subjects were consistent in the sense of specifying a unique switching point. The *CE-implied choice* is the choice for the prospect with the higher CE value. The *CE difference* is the CE of the risky prospect minus the CE of the ambiguous prospect.

Results. In straight choice, 26 of 79 chose ambiguous, which entails ambiguity aversion ($p < 0.01$, binomial). The following table gives average CE values.

TABLE 3. CEs in €

	CE risky	CE ambiguous	CE difference	t-test
Ambiguous chosen	16.73	17.60	–0.86	t_{25}=1.61, p=0.06
Risky chosen	14.84	11.90	2.94	t_{52}=4.84, $p < 0.01$
Two-sided *t*-test	$t_{77} = 1.53$, ns	$t_{77} = 4.75$, $p < 0.01$	$t_{77} = 4.02$, $p =< 0.01$	

The ambiguous choosers are again more risk seeking with higher CE values. Their CE for the risky prospect is not significantly higher than for the risky choosers, but is very significantly higher for the ambiguous prospect. Now, however, the ambiguous choosers evaluate the ambiguous prospect higher, reaching marginal significance and entailing choice consistency. The following table compares the CE-implied choices with straight choices.

TABLE 4. Frequencies of CE-Implied Choice versus Straight Choices

CE-implied / straight	Ambiguous	Indifferent	Risky	Binomial test
Ambiguous	8	16	2	$p = 0.05$
Risky	4	18	31	$p < 0.01$

There is considerable consistency between CE-implied preferences and straight preferences, with only few and insignificant inconsistencies. Hence, we do not find preference reversals here. There is a strong positive correlation of 0.64 between straight and implied choices (Spearman's ρ, $p < 0.01$ two-sided), excluding indifferences. We reject the hypothesis of CE-implied ambiguous preference for the risky straight choosers ($p < 0.01$, binomial), and we reject the hypothesis of CE-implied risky preference for the ambiguous straight choosers ($p = 0.05$). Subjects who are indifferent in the CE task distribute evenly between risky and ambiguous straight choice.

Results Comparing Experiments 1 and 2. For both prospects, CE values in Experiment 2 are significantly higher than the WTP values in Experiment 1 ($p < 0.01$). The CE differences in Experiment 2 are smaller than the WTP differences in Experiment 1 ($p < 0.01$), suggesting smaller ambiguity aversion in Experiment 2.

Discussion. The results of Experiment 2 are in many respects similar to those in Experiment 1. Only, the CE values are generally higher than the WTP values whereas the differences between risky and ambiguous are smaller. They are so both for the ambiguous choosers, who exhibit preference reversals, but are so also for risky choosers. This suggests that there may be a general overestimation of ambiguity

aversion in WTP. Because the CE differences are negative for ambiguous choosers, no preference reversals are found here. The error-conjecture that ambiguous straight choice be due to error is rejected because there is significant CE-implied ambiguous choice among the ambiguous straight choosers.

4. Experiment 3; Real Incentives for WTP

N = 74 subjects participated similarly as in Experiment 1. Everything else was identical to Experiment 1, except the incentives.

Incentives. At the end of the experiment, four subjects were randomly selected for real play. They were endowed with €30. Then a die was thrown to determine whether a subject played his or her straight choice to win €50, or would play the Becker-DeGroot-Marschak (1964) (*BDM*) mechanism (both events had equal probability). In the latter case, the die was thrown again to determine which prospect was sold (both prospects had an equal chance to be sold). Then, following the BDM mechanism, we randomly chose a prize between €0 and €50. If the random prize was below the expressed WTP, the subject paid the random prize to receive the prospect considered and played this prospect for real. If the random prize exceeded the expressed WTP, no further transaction was carried out and the subject kept the endowment (Appendix B).

Results. In straight choice, 15 of 74 chose ambiguous, which entails ambiguity aversion ($p < 0.01$, binomial). The following table gives average WTP.

TABLE 5. Willingness to Pay (BDM) in €

	WTP risky	WTP ambiguous	WTP difference	*t*-test
Ambiguous chosen	13.44	11.21	2.23	t_{14}=2.58, p = 0.01
Risky chosen	13.46	7.14	6.31	t_{58}=6.21, p < 0.01
Two-sided *t*-test	t_{72} = 0.01, ns	t_{72} = 1.99, p = 0.05	t_{72} = 1.97, p = 0.05	

The WTPs for both groups and both prospects are slightly (but not significantly) higher than the WTPs in experiment 1 ($p>0.5$, two-sided). Also the WTP differences are not significantly different from Experiment 1 ($p>0.5$, two-sided). All patterns of Experiment 1 are confirmed. In particular, the ambiguous choosers have a higher WTP for the risky prospect. The following table compares choices implied by WTP with subjects' straight choices.

TABLE 6. Frequencies of WTP-Implied Choice (BDM) versus Straight Choices

WTP-implied / straight	Ambiguous	Indifferent	Risky	Binomial test
Ambiguous	0	9	6	$p < 0.05$
Risky	1	13	45	$p < 0.01$

Here 6 out of 15 ambiguous choosers were inconsistent in having a WTP-implied preference for risky. All other ambiguous choosers exhibited WTP-implied indifference, and not even one of them had a WTP-implied preference for ambiguous. Of 59 risky choosers 1 was inconsistent and had a WTP-implied preference for ambiguous. Clearly, there is no positive correlation between straight and implied choices (Spearman's $\rho = -0.051$, ns two-sided) excluding indifferences. We find significant WTP-implied ambiguity aversion for the straight ambiguity choosers ($p < 0.05$, binomial). The same holds for the risky choosers ($p < 0.01$, binomial).

The distribution of bids in experiment 3 is very similar to that in experiment 1. There is no systematic over- or underbidding (WTP > 25 or WTP = 0) that would suggest that subjects misunderstood the BDM mechanism. The subjects who reversed their preference did so over a large range of buying prices[2].

Discussion. With all parts of the experiment, including WTP, incentivized, this experiment confirms the findings of Experiment 1.

[2] The subjects who reversed their preference from ambiguous in choice to risky in valuation had the following pairs of WTPs (WTP risky/WTP ambiguous): (25/20), (20/15), (20/10), (12.5/5), (10/5), and (3/2).

5. Experiment 4; Real Incentives for Each Subject in the Laboratory

This experiment was identical to Experiment 1 except for the following aspects.

Subjects. N = 63 students participated in groups of 4 to 6 in the laboratory. Now about 25% were from other fields than economics.

Incentives. The experiment was part of a larger session with an unrelated task. Every subject would receive €10 from the other task and up to €15 from the Ellsberg task. Each subject played his or her choice for real. Subjects were paid in cash. Now the nonzero prize was €15 instead of €50.

Results. In straight choice, 17 of 63 chose ambiguous, which entails ambiguity aversion ($p < 0.01$). The following table gives average WTP values. Note that the prize of the prospects was €15 now.

TABLE 7. Willingness to Pay in € when the Nonzero Prize is €15

	WTP risky	WTP ambiguous	WTP difference	*t*-test
Ambiguous chosen	5.63	4.65	0.99	t_{16}=1.56,p = 0.07
Risky chosen	5.23	2.71	2.53	t_{45}=8.53,p < 0.01
Two-sided *t*-test	t_{61} = 0.53, ns	t_{61} = 2.90, p < 0.01	t_{61} = 2.49, p = 0.01	

The pattern is identical to previous results. The following table compares WTP-implied choices with straight choices.

TABLE 8. Frequencies of WTP-Implied Choice (Lab) versus Straight Choices

WTP-implied / straight	Ambiguous	Indifferent	Risky	Binomial test
Ambiguous	2	6	9	p < 0.05
Risky	0	6	40	p < 0.01

The positive correlation between straight and implied choices is 0.39 (Spearman's ρ, $p < 0.01$ two-sided), excluding indifferences. The hypothesis of WTP-implied ambiguous preference can be rejected for the ambiguous straight choosers ($p < 0.05$, binomial). The same holds for the risky straight choosers ($p < 0.01$, binomial). After the experiment we approached the 9 subjects who exhibited inconsistencies, pointing out the inconsistency and asking them if they wanted to change any experimental choice. None of them wanted to change a choice and they confirmed that they preferred to take the ambiguous prospect in a straight choice but nevertheless would not be willing to pay as much for this prospect as they did for the risky one.

Discussion. This experiment replicates the findings of experiment 1 in the laboratory and with real incentives for every subject. This shows that the preference reversal is not due to low motivation in the classroom. The interviews reject the error-conjecture that suggested that ambiguous straight choice be due to error.

6. Pooled Data: Gender and Age Effects

The four experiments conducted for this study provide comparable choice and valuation data and can therefore be pooled into a large data set with 275 subjects. This allows us to consider the effects of age and gender. There is much interest into the role of such personal characteristics (Barsky et al. 1997; Booij & van de Kuilen 2006; Cohen & Einav 2007; Donkers et al. 2001; Hartog, Ferrer, & Jonker 2002; Schubert et al. 1999).

Table 9 shows the valuations for risky and ambiguous prospects, valuation differences, and actual choices, separated by age and gender. Valuations are calculated here as the percentage of the monetary prize of the prospect. For example, a WTP of €15 for an ambiguous prospect with a prize of €50 gives a percentage valuation of 30.00.

The table shows that females hold significantly lower valuations for both the risky and the ambiguous prospect than do males. Their valuation differences are not significantly smaller though. Our finding is consistent with the evidence in the

literature that women are more risk averse than men (Cohen & Einav 2007). Booij & van de Kuilen (2006) argued that females' stronger risk aversion can be explained by stronger loss aversion in a prospect theory framework. The last column in the table shows that women are significantly more ambiguity averse than men in a straight choice between the prospects. This has also been found by Schubert et al. (2000) for the gain domain.

Although there is relatively little variation in age in our sample, we find that young students give lower valuations for both the risky and the ambiguous prospect, but are not more ambiguity averse than older students. This is confirmed by correlational analysis, where age has a positive correlation with risky evaluation (ρ = 0.15, $t(273) = 2.55$, p = 0.01) and with the ambiguous evaluation ($\rho = 0.11$, $t(273) = 1.86$, p= 0.06) but not with value difference ($\rho = 0.06$, $t(273) = 0.97$, ns) or with the percentage of straight risky choices ($\rho = -0.07$, $t(273) = 1.10$, ns).

TABLE 9. Age and Gender Effects in the Pooled Data

	Percentage Valuation of Risky Prospect	Percentage Valuation of Ambiguous Prospect	Valuation Difference	Choice of Risky prospect (%)
Females (N=79)	24.77	14.64	10.13	79.7
Males (N = 196)	31.23	22.64	8.59	63.3
Two-sided t-test	$p < 0.01$	$p < 0.01$	ns	$p < 0.05$
Age≤19 (N=153)	26.48	18.39	8.09	73.9
Age>19 (N=122)	33.00	22.79	10.21	67.2
Two-sided t-test	$p < 0.01$	p = 0.01	ns	ns

Age ranged from 17 to 31 with median age 19. There is no correlation between age and gender in the data.

7. Modeling Preference Reversals through Loss Aversion in Comparative WTP

Butler & Loomes (2007) wrote about preference reversals that they are " … easy to produce, but much harder to explain." This section presents a theoretical deterministic model that explains our data, building upon theories that have been employed to explain preference reversals under risk (Sugden 2003; Schmidt et al. 2005). Incorporating imprecision of preference is a topic for future research. That the preference reversals found here cannot be ascribed exclusively to error was demonstrated in Experiments 2 and 4.

Definitions. Let f and g be uncertain prospects over monetary *outcomes* x, and let a constant prospect be denoted by its outcome. We assume that preferences are reference dependent, and that reference points can depend on states of nature, following Schmidt et al. (2005). The latter paper extended Sugden (2003) to incorporate probability weighting. We extend this model to uncertainty with unknown probabilities.

Let $V(f|g)$ denote the value of prospect f with prospect g as reference point. This value will be based on: (a) an event-weighting function W; (b) a utility function $U(x|r)$ of outcome x if the reference outcome on the relevant event is r, where U satisfies $U(r|r) = 0$ for all r; and (c) a loss aversion parameter λ, with furter details provided below. Sugden (2003) derived the case where $U(x|r)$ is of the form $\varphi(U^*(x) - U^*(r))$. Our analysis can be seen to agree with the multiple priors model, with the weighting function W assigning minimal probabilities to events (Gilboa & Schmeidler 1989; Mukerji (1998).

Let ρ represent the *risky prospect* and α the *ambiguous prospect* of guessing a color drawn from an urn with a known and unknown proportion of black and red balls, respectively. We consider four atomic events ("states of nature") that combine results of (potential) drawings from urns—a black ball is/would be extracted from both the risky and the ambiguous urn (*Event 1;* E_1); a black ball from the risky urn and a red one from the ambiguous urn (*Event 2;* E_2); a red ball from the risky urn and a black ball from the ambiguous urn (*Event 3;* E_3); a red ball from both the risky and the ambiguous urn (*Event 4;* E_4). Let us assume that the announced color to be

gambled on is black; for red the problem is exactly equivalent. Let *x* be the prize to be won in case the announced color matches the color of the ball extracted from the chosen urn.

Straight Choice. We first consider straight choice. In later analyses we will consider subtracting a constant c from all paymnents, and for convenience we have written c already in Table 10. For the current analysis, c can be ignored, i.e., c=0. The following payoffs result under the four events.

TABLE 10. Payoffs for the Risky and the Ambiguous Prospect

	$\mathbf{E_1}$ $\mathbf{(B_RB_A)}$	$\mathbf{E_2}$ $\mathbf{(B_RR_A)}$	$\mathbf{E_3}$ $\mathbf{(R_RB_A)}$	$\mathbf{E_4}$ $\mathbf{(R_RR_A)}$
α	x−c	−c	x−c	−c
ρ	x−c	x−c	−c	−c

Because $P(E_1 \cup E_2) = 0.5$, the event $E_1 \cup E_2$ is unambiguous and ρ is risky. $P(E_1 \cup E_3)$ is unknown so that event $E_1 \cup E_3$, and α, are ambiguous. The reference point at the time of making the choice can be assumed to be zero (previous wealth). Then

$$V(\alpha|0) = W(E_1 \cup E_3)U(x|0) \tag{1}$$

and

$$V(\rho|0) = W(E_1 \cup E_2)U(x|0) \tag{2}$$

where we dropped terms with $U(0|0) = 0$.[3] In Ellsberg-type choice tasks a minority of individuals prefer the ambiguous prospect over the risky prospect, with $V(\alpha|0) > V(\rho|0)$. Then event $E_1 \cup E_3$, the receipt of the good outcome x under α, receives more weight than event $E_1 \cup E_2$, the receipt of the good outcome x under ρ:

$$\text{Ambiguity seeking in straight choice} \Leftrightarrow W(E_1 \cup E_3) > W(E_1 \cup E_2). \tag{3}$$

Most people exhibit the reversed inequality of ambiguity aversion with more weight for the known-probability event $E_1 \cup E_2$, but nevertheless several people exhibit

[3] Thus, we need not specify the (rank-dependent) weights of the corresponding events in our analysis.

ambiguity seeking as in Eq. 3. Note that each single event $E_1,\ldots,E_4$ will be weighted the same because each has the same perceived likelihood and the same perceived ambiguity, because of symmetry of colors. The unambiguity of $E_1 \cup E_2$ versus the ambiguity of $E_1 \cup E_3$, and the different weightings of these events depending on ambiguity attitudes, are generated through the unions with E_1, with different likelihood interactions between E_3 and E_1 than between E_2 and E_1.

Willingness to Pay and Loss Aversion. We next turn to the WTP evaluation task. Consider Table 10 with a value c that may be positive,. Such cases are relevant for WTP. We will take the WTP of ρ as given and equal to c without need to analyze how c has been determined. In particular, we need not specify the reference prospect relevant for the WTP of ρ. We now show that the value of the upper row regarding α is lower, which will imply that its WTP must be smaller than c. The following analysis is in fact valid for any value of c. In particular, it is conceivable that some subjects, when evaluating the ambiguous prospect α for WTP, do not incorporate the values of c as should be under rational choice theories, but ignore c ($c = 0$) in their mind, then come up with a lower preference value of α than of ρ along the lines analyzed hereafter, and then derive a smaller WTP value for α from that in intuitive manners.

Because subjects have to come up with a value for the two prospects, it is natural to start from the one for which probabilities are given and for which it is thus easier to produce a quantitative evaluation. This way of thinking for WTP is natural irrespective of the actual straight choice made between these prospects. It was also suggested by the interviews we conducted after Experiment 4 with subjects who committed preference reversals. For their WTP evaluation of α they would refer to the WTP of ρ and then would emphasize the drawbacks of α relative to ρ.

We will, therefore, assume that the risky prospect ρ in the lower row in Table 10 is the reference point for the determination of the WTP for α. Consider the prospect in the upper row of Table 10, α with the WTP of ρ, c, subtracted. According to the theory of Schmidt et al. (2005), events E_1 and E_4 are taken as neutral (utility 0) and they do not contribute to the evaluation, which is why they do not appear in the equation below. Thus, we need not specify their rank-dependent weights. E_2 is now a loss event and E_3 is a gain event. Although the nonadditive decision weights of loss

events can in principle be different than for gain events, many studies do not distinguish between such decision weights, and empirical studies have not found big differences so far (Tversky & Kahneman 1992). (Note that loss aversion will be captured through a different parameter, namely λ.) We will therefore simplify the analysis and use the same weighting function for losses as for gains. For ambiguity aversion we have to establish negativity of the following evaluation, where the utility function depends only on an obtained and a counterfactual outcome for each event considered according to Schmidt et al. (2005).

$$\text{Ambiguity aversion in WTP} \;\Leftrightarrow\; W(E_3)U(x{-}c|{-}c) + \lambda W(E_2)U(-c|x{-}c) \;<\; 0. \quad (4)$$

Here λ is the loss aversion parameter, which usually exceeds 1 indicating an overweighting of losses. We next discuss utility U in some detail, and show that

$$U(x{-}c|{-}c) = -U(-c|x{-}c) \quad (5)$$

may be assumed. All cases considered in the literature are special cases of Sugden's

$$U(x|r) = \varphi(U^*(x) - U^*(r)).$$

In general, for moderate amounts as considered here, it is plausible that these functions do not exhibit much curvature, so that

$$U(x{-}c|{-}c) \;\approx\; x{-}c-(-c) \;=\; x \;\text{ and }\; U(-c|x{-}c) \;\approx\; -c-(x{-}c) = -x.$$

Then Eq. 5 follows. In prospect theory, outcomes are changes with respect to the reference point as in

$$U(x|r) = \varphi(x - r), \text{ which implies } U(x{-}c|{-}c) = \varphi(x) \text{ and } U(-c|x{-}c) = \varphi(-x).$$

Tversky & Kahneman (1992) estimated $\varphi(x) = x^{0.88}$ and $\varphi(-x) = -x^{0.88}$. Then Eq. 5 holds exactly, also for large outcomes. A similar assumption was central in Fishburn & LaValle (1988). Thus, we assume Eq. 5. We divide Eq. 4 by $U(-c|x{-}c)$, and get:

$$\text{Ambiguity aversion in WTP} \;\Leftrightarrow\; W(E_3) - \lambda W(E_2) < 0. \quad (6)$$

In the above analysis, given symmetry of colors, events E_2 and E_3 will have similar perceived likelihood and ambiguity. In Eqs. 4 and 5, they are weighted in isolation and not when joint with another event. Hence it is plausible that they have the same weights, $W(E_2) = W(E_3)$. Then Eq. 6 reduces to:

511 Ambiguity aversion in WTP $\Leftrightarrow$ $1 < \lambda$. (7)

512 This inequality is exactly what defines loss aversion. Because only single events play
513 a role in Eq. 6 and no unions as in Eq. 3, ambiguity attitudes did not play a role in
514 establishing Eq. 7. By this equation we can expect a higher WTP of the risky
515 prospect as soon as loss aversion holds ($\lambda > 1$), irrespective of ambiguity attitude.
516 Empirical studies have suggested that loss aversion is very widespread and strong.
517 Hence virtually all subjects will evaluate the risky prospect higher than the ambiguous
518 prospect, in agreement with our data.
519 The conclusion just established, with WTP for the ambiguous prospect entirely
520 driven by loss aversion with no role for attitude towards ambiguity, has been derived
521 under the theory of Schmidt et al. (2005). This result should not be expected to apply
522 exactly to all subjects. There will be many subjects who entirely, or partly, are driven
523 by other considerations in which also ambiguity aversion affects a negative WTP of
524 α. We believe, however, that the phenomenon just established is prevailing and that
525 much of the ambiguity aversion ascribed to WTP observations is in fact due to loss
526 aversion.
527
528 *Discussion*. Summarizing, prospect theory predicts that our preference reversals
529 appear whenever a subject is ambiguity seeking and loss averse. Given that there is a
530 nonnegligible minority of subjects exhibiting ambiguity seeking and given that
531 virtually all of them will be loss averse, preference reversals as we found can be
532 expected to arise for a nonnegligible minority indeed. Reversed preference reversals
533 would arise among those subjects who are ambiguity averse and who are not loss
534 averse but rather the opposite, gain seeking ($\lambda < 1$). In view of the strength of loss
535 aversion this can be expected to be a rare phenomenon, as was confirmed by our data.
536 Systematic preference reversals as modeled above cannot be expected to occur
537 for CE valuations. Whereas for the WTP assessment of the ambiguous prospect the
538 subjects will resort for reference to the risky prospect that is easier to evaluate, for the
539 CE measurements the subjects are involved in comparing the ambiguous prospect to a
540 sure outcome for the purpose of choosing, which will not encourage them to search
541 for other anchors. The CE tasks are similar to the straight choices and can be
542 expected to generate similar weightings and perceptions of reference points. That the
543 differences between ambiguous and risky CE evaluations are smaller than the

corresponding WTP differences for both ambiguous and risky choosers further supports the theory of this section. It also underscores that the bias for WTP that we discovered at first through the observed preference reversals does not apply only to the subjects, a minority, for whom this preference reversal arises, but that it concerns all subjects.

An interesting question is what happens if the reference point is changed extraneously. Roca, Hogarth, & Maule (2006) found that when subjects are endowed with the ambiguous prospect they indeed become reluctant to switch to the risky prospect if offered such an opportunity. The authors explain such reluctance through loss aversion where the ambiguous prospect constitutes the reference prospect. This finding supports our theory.

Many studies have used willingness to accept (WTA) to measure ambiguity attitudes. Here subjects are first endowed with a prospect and are then asked for how much money they are willing to sell it. This procedure will encourage some subjects, as in the study of Roca, Hogarth, & Maule (2006), to take the ambiguous prospect as reference point when determining its WTA. Other subjects may, however, take the risky prospect as reference point, and then an analysis as in this section will apply. Therefore, it can be expected that for WTA there will be biases as in our WTP but possibly to a less pronounced degree. Eisenberger & Weber (1995) found similar ambiguity aversion for WTA as for WTP.

Fox & Weber (2002) considered evaluations of ambiguous prospect both if preceded by risky prospects and if not. In the former case, their evaluations were considerable lower than in the latter case. This finding is consistent with our analysis based on loss aversion.

8. General Discussion

It is common in individual choice experiments not to pay for every choice made because this would generate distorting income effects. Hence, random payment is used (Myagkov & Plott 1997; Holt & Laury 2002; Harrison et al. 2002). Its equivalence to a single and payoff relevant decision task has been empirically tested and confirmed (Starmer & Sugden 1991, Hey & Lee 2005). Some papers explicitly tested whether it matters if for each subject one choice is played for real as in our

experiment 4, or if this is done only for some randomly selected subjects as in our other experiments (Armantier 2006, Harrison et al. 2007). These studies found no difference, and our study confirms this finding.

We have found preference reversals in choice under ambiguity. The reversals are not due to errors, as appeared from Experiment 2 where straight choice and CE-implied choice were consistent, and from the interviews after Experiment 4. They are neither due to extraneous manipulations in framing. All evaluations and choices were joint in the sense that the subjects were first presented with all choice options and all choices to be made before they made their first choice. Further, the subjects could always carry out all choices in any order they liked and compare them all with each other; all choices were on one page. Thus, there was no psychological or informational difference between the different choice situations considered.

As preference reversals have had far-reaching implications for the domains where they have been discovered, their discovery in ambiguous choice sheds new light on previous findings. Many studies in the literature have measured ambiguity aversion through WTP, where ambiguity aversion will be strongest. Our empirical findings and theoretical model suggest that this ambiguity aversion may in fact be driven primarily by loss aversion with reference points following Sugden (2003) and Schmidt et al. (2005). That the WTP differences exceed the CE differences for all groups suggests that the WTP bias affects all subjects, also the straight-risky choosers for whom the bias could not lead to a preference reversal. Binary choice may give more unbiased assessments of ambiguity aversion. There ambiguity aversion still is a pronounced phenomenon.

The occurrence of preference reversals when two lotteries have to be evaluated jointly and the absence of such reversals when the lotteries are compared to different options, such as given certain amounts of money, support theories of comparative ignorance (Fox & Tversky 1995; Fox & Weber 2002). Fox & Tversky (1995) similarly found strong ambiguity aversion under joint evaluation, with ambiguity aversion even disappearing under separate evaluation. Du & Budescu (2005, Table 5) replicated this result in a finance setting and investigated a number of other factors influencing ambiguity attitudes. It will be useful to develop a taxonomy of situations that generate more or less ambiguity aversion, and our paper has contributed here.

9. Conclusion

Preference reversals have affected many domains in decision theory. We found that they also affect choice under ambiguity, even if psychological and informational circumstances are kept fixed. All results were obtained within subjects, with the willingness to pay task on the same sheet as the choice task. The results are stable under real incentives, different experimental conditions, and concern deliberate choices that were not made by mistake. Our results support recent theories explaining preference reversals through reference dependence and loss aversion for willingness to pay (Sugden 2003; Schmidt et al. 2005). Our study suggests that the often used willingness to pay measurements overestimate ambiguity aversion.

Appendix A. Instructions Experiment 1 and 2

Both experiments' instructions started with the following description of prospects:

> Consider the following two lottery options:
>
> **Option A** gives you a draw from a bag that contains exactly 20 red and 20 green poker chips. Before you draw, you choose a color and announce it. Then you draw. If the color you announced matches the color you draw you win €50. If the colors do not match, you get nothing. (white bag)
>
> **Option B** gives you a draw from a bag that contains exactly 40 poker chips. They are either red or green, in an unknown proportion. Before you draw, you choose a color and announce it. Then you draw. If the color you announced matches the color you draw you win €50. If the colors do not match, you get nothing. (beige bag)

In experiment 1 the subjects were then asked to make a straight choice and give their WTP for both options:

> You have to choose between the two prospect options. Which one do you choose?
>
> **O** Option A (bet on a color to win €50 from bag with 20 red and 20 green chips)

O Option B (bet on a color to win €50 from bag with unknown proportion of colors)

Additional hypothetical question:

Imagine you had to pay for the right to participate in the above described options with the possibility to win €50. How much would you maximally pay for the right to participate in the prospects? Please indicate your valuations:

I would pay €_____ to participate in Option A (bet on a color to win €50 from bag with 20 red and 20 green chips).

I would pay €_____ to participate in Option B (bet on a color to win €50 from bag with unknown proportion of colors).

In experiment 2 the subjects were asked to make a straight choice and 18 choices between sure amounts and the prospects:

Below you are asked to choose between the above two options and also to compare both options with sure amounts of money. Two people will be selected for real play in class. For each person one decision will be randomly selected for real payment as explained by the teacher.

[1, 2] You have to choose between the two prospect options. Which one do you choose?

O Option A (bet on a color to win €50 from bag with 20 red and 20 green chips)

O Option B (bet on a color to win €50 from bag with unknown proportion of colors)

Valuation of prospects.

Now determine your monetary valuation of the two prospect options. Please compare the prospect options to the sure amounts of money. Indicate for both options and each different sure amount of money whether you would rather choose the sure cash or try a bet on a color from the bag to win €50!

Option A (bet on color from bag with 20 red and 20 green chips to win €50) **or** sure amount of €:

[3] Play Option A **O** **or** **O** get €25 for sure
[4] Play Option A **O** **or** **O** get €20 for sure
[5] Play Option A **O** **or** **O** get €15 for sure
[6] Play Option A **O** **or** **O** get €10 for sure
[7] Play Option A **O** **or** **O** get €5 for sure
[8] Play Option A **O** **or** **O** get €4 for sure
[9] Play Option A **O** **or** **O** get €3 for sure
[10] Play Option A **O** **or** **O** get €2 for sure
[11] Play Option A **O** **or** **O** get €1 for sure

Option B (bet on color from bag with unknown proportion of colors to win €50) **or** sure amount of €:

[12] Play Option B **O** **or** **O** get €25 for sure
[13] Play Option B **O** **or** **O** get €20 for sure
[14] Play Option B **O** **or** **O** get €15 for sure
[15] Play Option B **O** **or** **O** get €10 for sure
[16] Play Option B **O** **or** **O** get €5 for sure
[17] Play Option B **O** **or** **O** get €4 for sure
[18] Play Option B **O** **or** **O** get €3 for sure
[19] Play Option B **O** **or** **O** get €2 for sure
[20] Play Option B **O** **or** **O** get €1 for sure

Make sure that you filled out all 18 choices on this page!

In both experiments we asked the following question at the end:

Please give your age and gender here:

Age:_____ Gender: male **O** female **O**

Appendix B. Instructions Experiment 3

In experiment 3 the hypothetical WTP questions have been replaced by the following real payoff WTP decision using the BDM mechanism:

You have to buy the right to make a draw from the above described bags with the possibility to win 50€. The procedure we use guarantees that a truthful

718 indication of your valuation is optimal for you, see details below at (*). How
719 much do you maximally want to pay for the right to participate in the prospect
720 options? Please indicate your offers:
721 I will pay €_____ to participate in Option A (bet on a color to win €50
722 from bag with 20 red and 20 green chips).
723 I will pay €_____ to participate in Option B (bet on a color to win €50
724 from bag with unknown proportion of colors).
725
726 *
727 The procedure is as follows: The experimenter throws a die to determine
728 which option he wants to sell. If a 1,2, or 3 shows up, Option A will be
729 offered; if a 4,5, or 6 shows up, Option B will be offered. After the option for
730 sale has been selected, the experimenter draws a lot from a bag that contains
731 50 lots, numbered 1, 2, 3, …, 48, 49, 50. The number indicates the
732 experimenter's reservation price (in Euro) for the selected option: if your offer
733 is larger than the reservation price, you pay the reservation price only and play
734 the option. If your offer is smaller than the reservation price, the experimenter
735 will not sell the option. You keep your money and the game ends.
736
737

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