Preference Reversals to Explain Ambiguity Aversion

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ABSTRACT. Preference reversals are found in measurements of ambiguity aversion even under constant psychological and informational circumstances. The reversals are of a fundamentally different nature than the reversals found before because they cannot be explained by context-dependent weightings of attributes. We offer an explanation based on Sugden's random-reference theory with different elicitation methods generating different reference points. Measurements using willingness to pay are confounded by loss aversion and overestimate ambiguity aversion.

KEYWORDS: ambiguity aversion, choice vs. valuation, preference reversal, loss aversion, asymmetric loss function

JEL CLASSIFICATION: D81, C91

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1. Introduction

One of the greatest challenges to the classical paradigm of rational choice was put forward by preference reversals, first found by Lichtenstein & Slovic (1971): strategically irrelevant details of framing can lead to a reversal of preference. Grether & Plott (1979) confirmed this phenomenon while using real incentives and controlling for several potential biases. The question then arises 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 those found before. They cannot be explained by different weightings of attributes in different evaluation modes, but entail a complete reversal of preference within one attribute. Details are given in the discussion in Section 2.

We investigate two commonly used formats for measuring ambiguity attitudes. The first is to offer participants a straight choice between an ambiguous and a risky prospect, and the second is to elicit participants' willingness to pay (WTP) for each of the prospects. We compare the two approaches in simple Ellsberg two-color problems. In three experiments, WTP for the risky option strongly exceeds that for the ambiguous option, with almost no participant expressing higher WTP for the ambiguous urn than for the risky urn. Remarkably, however, this finding also holds for the group of participants who in straight choice prefer the ambiguous urn. Hence, in the latter group the majority assigns a higher WTP to the not-chosen risky urn, entailing a preference reversal. There are virtually no reversed preference reversals, suggesting the reversals found are systematic and are not due to noise.

The contradictory findings of WTP versus choice raises the question which of these, if any, measures true ambiguity attitudes. To distinguish between the two findings, and allow for the possibility that at least one does not reflect true ambiguity attitude, we add qualifiers. The finding of higher WTP for the ambiguous than for the risky urn is called WTP-ambiguity aversion, and a direct choice of the risky urn rather than the ambiguous one is called choice-ambiguity aversion. A fourth experiment with certainty equivalent measurements instead of WTP will suggest that WTP-ambiguity aversion entails a uniform overestimation, also for participants who did not exhibit preference reversals.

Using Sugden's (2003) and Schmidt, Starmer, & Sugden's (2008) generalization of prospect theory with a random reference point, we develop a quantitative model that explains the pattern of ambiguity attitudes and preference reversals in our experiments. The different elicitation methods promote the perception of different reference points. Preferences under choice depend on the attitudes toward unknown probabilities, as is warranted for measurements of ambiguity attitudes. WTP evaluations are, however, determined primarily by loss aversion, which distorts WTP-ambiguity measurements. Recent studies supporting the importance of loss aversion in risky and in riskless choice include Fehr & Götte (2007) and Gaechter, Johnson, & Hermann (2007). This paper demonstrates its importance under ambiguity.

Birnbaum et al. (1992) and Weber (1994) developed a psychogical model for decision under risk that is very similar to our decision model. Their model assumes that a decision maker perceives the evaluation of a risky prospect as an estimation problem. An overestimation results if an outcome delivered by the prospect is below the estimation. Similarly, underestimations can result. Asymmetric perceptions of overestimations relative to underestimations can then have the same impact on decisions as loss aversion. This psychological model, when combined with Sugden's random reference model, can be applied to our case of decision under ambiguity. It then leads to the same conclusions as Schmidt, Starmer, & Sugden's (2008) model, which combines prospect theory with Sugden's random reference model.

In our experiments, WTP-ambiguity aversion is considerably stronger than choice-ambiguity aversion. Thus, loss aversion under WTP generates a much stronger aversion to ambiguous prospects than aversion to unknown probabilities does under choice. This finding has implications for the valuation of ambiguous prospects in applications. In choice situations, ambiguity aversion leads to a widespread but not uniform preference of unambiguous options and to moderate valuation differences. Consider for example the ambiguous risks surrounding genetically modified food. We would expect the majority of consumers to choose genetically unmodified alternatives of some product as long as the price difference with modified alternatives is not very large. In situations more similar to WTP, however, for instance when evaluating various financial investments simultaneously, our study predicts a strong preference for unambiguous options and a large discount in the valuation of ambiguous options (Easley & O'Hara, 2008; Zeckhauser, 2006). Our findings suggest, for instance, that in contingent valuation studies the willingness to pay for reductions in ambiguous security or health risks may be mismeasured due to loss aversion (Carlsson, Johansson-Stenman, & Martinsson, 2004; The Economist, 2008).

It is well known that changes in psychological and informational circumstances can affect behavior under ambiguity. 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). Closest to the preference reversals reported in our paper is a discovery originating from Fox & Tversky (1995): ambiguity aversion is reduced when measured through separate rather than joint evaluations (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 such 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.

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 incentive system used in Section 4 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. The final section discusses implications and concludes.

2. Experiment 1; Basic Experiment

Participants. N = 59 econometrics students from the Erasmus University Rotterdam in the Netherlands participated in this experiment, carried out in a classroom.

Stimuli. At the beginning of the experiment, two urns were presented to the participants, 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. Participants had to 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.

Participants 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 (Thaler & Johnson 1990) arising from the significant endowment that would have been necessary to enable participants to pay for prospects with a prize of €50. Participants first made their choice and subsequently answered the WTP questions.

All choices and questions were on the same sheet of paper and could be answered in the order that the participant preferred. We also recorded the participants' age and gender.

Incentives. Two participants were randomly selected and played for real. These participants 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. Therefore, unless stated otherwise, one-sided tests

[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 in the original Ellsberg (1961).

were employed. Further, tests are *t*-tests unless stated otherwise. The abbreviation ns designates nonsignificance. The *WTP difference* is the WTP for the risky prospect minus the WTP for the ambiguous prospect. It serves as an index of WTP-ambiguity aversion. WTP-ambiguity aversion holds if the index is positive.

Results. In straight choice, 22 of 59 chose ambiguous (37%; $p < 0.05$, binomial). Thus, we find a majority of choice-ambiguity aversion. The following table shows the average WTP separately for choice-ambiguity seekers and choice-ambiguity averters.

TABLE 1. Willingness to Pay in €

	WTP risky	WTP ambiguous	WTP difference	*t*-test
Choice-ambiguity seeking	12.25	9.50	2.75	t_{21}=2.72, $p < 0.01$
Choice-ambiguity averse	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 choice-ambiguity seekers are in general more risk seeking with higher WTP values, although their WTP for the risky prospect is not significantly higher than with the choice-ambiguity averters. Their WTP for the ambiguous prospects is, obviously, much higher than it is for the choice-ambiguity averters. The latter value the risky prospect on average €5.37 higher than the ambiguous one ($p < 0.01$). Surprisingly, choice-ambiguity seekers also value the risky prospect €2.75 *higher* than the ambiguous one ($p < 0.01$), which entails a preference reversal. They exhibit choice-ambiguity seeking but WTP-ambiguity aversion. The following table gives frequencies of WTP-ambiguity attitudes and choice-ambiguity attitudes.

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TABLE 2. Frequencies of WTP- versus Choice-Ambiguity Attitudes

	WTP-ambiguity seeking	WTP-indifferent	WTP-ambiguity averse	Binomial test
Choice-ambiguity seeking	2	9	11	p = 0.01
Choice-ambiguity averse	0	6	31	p < 0.01

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

Discussion. We find prevailing choice-ambiguity aversion, but still 22 out of 59 participants exhibit choice-ambiguity seeking. For WTP there is considerably more, almost universal, ambiguity aversion, leading to preference reversals for 11 participants. Only 2 choice-ambiguity seekers are WTP-ambiguity seeking. This result is particularly striking because straight choice and WTP had to be made together on the same sheet. No preference reversal occurs for the choice-ambiguity averters. As explained in the introduction, the reversals observed here are fundamentally different from preference reversals found before.

A classical example of a preference reversal concerns a "p-prospect" of a 97% chance at $4 versus a "$-prospect" of a 31% chance at $16. Here a pro in the probability ("p") dimension has to be weighed against a pro in the outcome ("$") dimension. The majority of subjects prefers the p-prospect in direct choice but, nevertheless, assigns a lower monetary value to it than to the $-prospect. Such preferences have been confirmed with real incentives (Grether & Plott 1979). Apparently, in monetary evaluations, people weigh the money attribute higher than in direct choice. Such different weightings of attributes in different decision tasks have been widely documented (Bleichrodt & Pinto 2002; Tversky, Sattath, & Slovic 1988).

Differential weightings of attributes as just described cannot explain the preference reversals that we find. In our choices, the prize to be gained is the same in all choices. Hence, our preference reversal must be explained by a complete switch of preference within the likelihood attribute, with one event weighted more heavily in direct choice but the other in WTP. Section 7 provides a detailed theoretical explanation of the phenomenon just mentioned. It is based on the assumption that during their WTP task the participants take the risky prospect as a reference point for their valuation of the ambiguous prospect. Experiment 2 will test this explanation by discouraging the choice of the risky prospect as a reference point.

An alternative explanation instead of genuine preference reversals that could be suggested to explain our data is an *error-conjecture*. It 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 WTP-ambiguity seeking that 11 choice-ambiguity averters exhibited would then concern simple errors and 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. Further arguments against the error hypothesis are provided in Experiments 2 and 4, which will test and reject the hypothesis.

The preference reversals 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 of the preference reversal found in the basic experiment. It also tests the error conjecture described in the preceding section. Further it shows that WTP increases the valuation difference between risky and ambiguous prospect for all participants, that is, also for those for whom no preference reversal is observed because they always prefer risky.

Participants. N = 79 participants participated as in Experiment 1.

Stimuli. All stimuli were the same as in Experiment 1, starting with a simple Ellsberg choice, with one modification. Instead of making a WTP judgment, participants 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 between the risky and ambiguous prospects' values. The choices served to elicit the participants' certainty equivalents, as explained later.

Incentives. The prizes were as in Experiment 1. Participants first made all 19 decisions. Then two participants 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 participant switched preference. All participants were consistent in the sense of specifying a unique switching point. The *CE difference* is the CE of the risky prospect minus the CE of the ambiguous prospect. CE-ambiguity aversion refers to a positive CE-difference.

Results. In straight choice, 26 of 79 chose ambiguous (33%; $p < 0.01$, binomial). Thus, we have a majority of choice-ambiguity averters. The following table gives average CE values.

TABLE 3. CEs in €

	CE risky	CE ambiguous	CE difference	t-test
Choice-ambiguity seeking	16.73	17.60	–0.86	t_{25}=1.61, p=0.06
Choice-ambiguity averse	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 choice-ambiguity seekers are again more risk seeking with higher CE values as in Experiment 1. Their CE for the risky prospect is not significantly higher than for the choice-ambiguity averters, but is very significantly higher for the ambiguous prospect. Now, however, the choice-ambiguity seekers evaluate the ambiguous prospect higher, reaching marginal significance and entailing choice consistency. The following table compares the CE-ambiguity attitudes with choice-ambiguity attitudes.

TABLE 4. Frequencies of CE- versus Choice-Ambiguity Attitudes

	CE-ambiguity seeking	CE-indifferent	CE-ambiguity averse	Binomial test
Choice-ambiguity seeking	8	16	2	p = 0.05
Choice-ambiguity averse	4	18	31	p < 0.01

There is considerable consistency between CE- and choice-ambiguity attitudes, with only few and insignificant inconsistencies. Hence, we do not find preference reversals here. There is a strong positive correlation of 0.64 between choice- and CE-ambiguity attitudes (Spearman's ρ, $p < 0.01$ two-sided), excluding indifferences. We reject the hypothesis of CE-ambiguity seeking for choice-ambiguity averters ($p < 0.01$, binomial), and we reject the hypothesis of CE-ambiguity aversion for the choice-ambiguity seekers ($p = 0.05$). Participants who are indifferent in the CE task distribute evenly between choice-ambiguity seeking and aversion.

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 for both choice-ambiguity seekers and choice-ambiguity averters ($p < 0.01$), suggesting smaller ambiguity aversion in Experiment 2.

Discussion. In Experiment 2 the CE differences are negative for choice-ambiguity seekers. Hence, no preference reversals are found here. The error-conjecture that choice-ambiguity seeking be due to error is rejected because there is significant CE-ambiguity seeking there. CE values are generally higher than the WTP values in Experiment 1 whereas the differences between risky and ambiguous are smaller. They are so both for the choice-ambiguity seekers, who exhibit preference reversals under WTP, and for choice-ambiguity averters, who exhibit no preference reversals. The consistency of CE-ambiguity aversion with choice-ambiguity aversion suggests that WTP-ambiguity aversion entails an overestimation.

4. Experiment 3; Real Incentives for WTP

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

Incentives. At the end of the experiment, four participants were randomly selected for real play. They were endowed with €30. Then a die was thrown to determine whether a participant 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 participant 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 participant kept the endowment (Appendix B). It is well known that under the BDM mechanism it is in the participants' best interest to report preferences truthfully.

Results. In straight choice, 15 of 74 chose ambiguous (20%; $p < 0.01$, binomial), implying a majority of choice-ambiguity aversion. The following table gives average WTP.

TABLE 5. Willingness to Pay (BDM) in €

	WTP risky	WTP ambiguous	WTP difference	*t*-test
Choice-ambiguity seeking	13.44	11.21	2.23	t_{14}=2.58, p=0.01
Choice-ambiguity averse	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 choice-ambiguity seekers exhibit WRT-ambiguity aversion. The following table compares WTP- with choice-ambiguity attitudes.

TABLE 6. Frequencies of WTP- (through BDM) versus Choice-Ambiguity Attitudes

	WTP-ambiguity seeking	WTP-indifferent	WTP-ambiguity averse	Binomial test
Choice-ambiguity seeking	0	9	6	p < 0.05
Choice-ambiguity averse	1	13	45	p < 0.01

Here 6 out of 15 choice-ambiguity seekers were inconsistent in exhibiting WTP-ambiguity seeking. All other choice-ambiguity seekers exhibited WTP-indifference, and not even one of them exhibited WTP-ambiguity seeking. Of 59 choice-ambiguity averters 1 was inconsistent and exhibited WTP-ambiguity seeking. Clearly, there is no positive correlation between choice-ambiguity aversion and WTP-ambiguity aversion (Spearman's $\rho = -0.051$, ns two-sided) excluding indifferences. We find significant WTP-ambiguity aversion for the choice-ambiguity seekers ($p < 0.05$, binomial). The same holds for the choice-ambiguity averters ($p < 0.01$, 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 participants misunderstood the BDM mechanism. The participants 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. The reversals are therefore not caused by incentive effects or low motivation for the WTP task.

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

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

Participants. N = 63 students participated 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 participant received €10 from the other task and up to €15 from the Ellsberg task. Each participant played his or her choice for real. Participants were paid in cash. Now the nonzero prize was €15 instead of €50.

Results. In straight choice, 17 of 63 chose ambiguous, implying a majority of choice-ambiguity aversion (27%; $p < 0.01$, binomial). The following table gives average WTP values. Note that the prize of the prospects was €15 now.

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[2] The participants 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).

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

	WTP risky	WTP ambiguous	WTP difference	t-test
Choice-ambiguity seeking	5.63	4.65	0.99	t_{16}=1.56, p=0.07
Choice-ambiguity averse	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-ambiguity aversion with choice-ambiguity aversion.

TABLE 8. Frequencies of WTP- (Lab) versus Choice-Ambiguity Attitudes

	WTP-ambiguity seeking	WTP-indifferent	WTP-ambiguity averse	Binomial test
Choice-ambiguity seeking	2	6	9	p < 0.05
Choice-ambiguity averse	0	6	40	p < 0.01

The positive correlation between choice- and WTP-ambiguity aversion is 0.39 (Spearman's ρ, p < 0.01 two-sided), excluding indifferences. The hypothesis of WTP-ambiguity seeking can be rejected for the choice-ambiguity seekers (p < 0.05, binomial). The same holds for the choice-ambiguity averters (p < 0.01, binomial).

Interviews. After the experiment we approached the 9 participants 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 explained that they were ready to take their chance and try the ambiguous prospect in a straight choice. In the WTP evaluation, they commonly started from the easier to assess risky prospect and then adjusted the WTP of the ambiguous prospect downward for the higher uncertainty. Although they chose ambiguous in straight choice (choice-ambiguity seeking), they were not willing to pay as much for this prospect as for the risky one (WTP ambiguity aversion).

Discussion. This experiment replicates the findings of experiment 1 in the laboratory and with real incentives for every participant. It shows that the preference reversal is not due to low motivation in the classroom. The interviews reject the conjecture that suggested that choice-ambiguity seeking be due to error. The interviews with the inconsistent participants suggested that in the WTP task the risky prospect serves as a reference point for the WTP of the ambiguous prospect.

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 participants. For the evaluations, we combine WTP- and CE-ambiguity aversion into one index of general revealed ambiguity aversion, leaving aside what the exact theoretical interpretation of this phenomenon is. In this way, we can 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 significantly larger choice-ambiguity aversion among women than among men. 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 choice-ambiguity aversion Thus, we have a majority of choice ($\rho = -0.07$, $t(273) = 1.10$, 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

This section presents a theoretical deterministic model that explains our data, building upon theories that have been employed to explain preference reversals under risk. That the preference reversals found here cannot be ascribed exclusively to error, so that they must have a basis in an underlying core theory, was demonstrated in Experiments 2 and 4. We use Sugden's (2003) idea of random reference points. He originally introduced it for expected utility theory. It was generalized to prospect theory for decision under risk by Schmidt et al. (2008). We extend it to decision under ambiguity, resulting in the random-reference dependent generalization of

Tversky & Kahneman's (1992) prospect theory for ambiguity, building on Gilboa's (1987) and Schmeidler's (1989) rank-dependent utility.

In what follows, we only consider prospects with at most one gain and one loss. For such prospects, the random-reference dependent generalization of rank-dependent utility and prospect theory agrees with those of most other theories used to analyze ambiguity, including multiple priors (Gilboa & Schmeidler 1989) and the α-maxmin model. Hence, our analysis is generic for most models of ambiguity in the literature today once Sugden's reference dependence has been accepted. We also sometimes consider Sugden's random reference point theory when combined with the asymmetric loss function theory of Birnbaum et al. (1992) and Weber (1994), extending the latter from risk to ambiguity.

Definitions. Let f and g be uncertain prospects over monetary *outcomes* x, and let a constant prospect be denoted by its outcome. Let V(f|g) denote the value of prospect f with prospect g as reference point. Sugden's (2003) random-reference generalization entails that g can be a prospect rather than a riskless outcome as it was in original prospect theory. The value V(f|g) 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 outcome-relevant event is r, where U is scaled such that U(r|r) = 0 for all r; and (c) a loss aversion parameter λ, with further details provided later. Sugden (2003) provided conditions implying that U(x|r) is of the form $\varphi(U^*(x) - U^*(r))$.

Let ρ represent the *risky prospect* and α the *ambiguous prospect* of gambling on a color drawn from an urn with a known and an 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; B_RB_A*); a black ball from the risky urn and a red one from the ambiguous urn (*Event 2; E_2; B_RR_A*); a red ball from the risky urn and a black ball from the ambiguous urn (*Event 3; E_3; R_RB_A*); a red ball from both the risky and the ambiguous urn (*Event 4; E_4; R_RR_A*). Let us assume that the announced color to be gambled on is black; for red the problem is equivalent. Let *x* be the prize to be won in case the color gambled on matches the color of the ball extracted from the chosen urn.

Straight Choice. We first consider straight choice. Table 10 displays the payoffs that result for each prospect under the four events.

TABLE 10. Payoffs for the Risky and the Ambiguous Prospect under Straight Choice

	E_1 (B_RB_A)	**E_2 (B_RR_A)**	**E_3 (R_RB_A)**	**E_4 (R_RR_A)**
α	x	0	x	0
ρ	x	x	0	0

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. We assume that the reference point at the time of making the choice is 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:

$$\text{Choice-ambiguity seeking} \Leftrightarrow W(E_1 \cup E_3) > W(E_1 \cup E_2). \tag{3}$$

Most people exhibit the reversed inequality, $W(E_1 \cup E_3) < W(E_1 \cup E_2)$, with ambiguity aversion and with more weight for the known-probability event $E_1 \cup E_2$. Nevertheless, several people exhibit choice-ambiguity seeking. We 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 different likelihood interactions between E_3 and E_1 than between E_2 and E_1. Note that choice-ambiguity

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

aversion and -seeking are driven by the W-weighing of uncertain events; i.e., by the attitude of the decision maker towards ambiguity.

Willingness to Pay and Loss Aversion. We next turn to the WTP evaluation task. We assume that the decision maker has determined a WTP value c for ρ, making the value of ρ–c neutral. The following analysis holds true for any value of c. That is, it holds true for any way in which the decision maker determined the WTP of ρ and, in particular, for any way in which the reference point was chosen there. Hence, we need not commit to any way in which this was done.

As suggested by the interviews with our participants, we assume that the risky prospect serves as a reference point for the ambiguous prospect. It is easier to produce a quantitative evaluation for risky because of the known probabilities and, hence, this way of thinking for WTP is natural irrespective of the actual straight choice made between the prospects. More precisely, we will assume in what follows that the decision maker takes ρ–c as neutral and as reference point, so that WTP(α) makes α – WTP(α) equivalent to the neutral ρ–c. That iss, V(α–WTP(α)|ρ–c) = 0. We analyze, for the sake of comparison, α–c. Table 11 displays outcomes for various events.

TABLE 11. Payoffs for the Risky and the Ambiguous Prospect under Straight Choice

	E_1 (B_RB_A)	**E_2 (B_RR_A)**	**E_3 (R_RB_A)**	**E_4 (R_RR_A)**
α–c	x–c	–c	x–c	–c
ρ–c	x–c	x–c	–c	–c

For the evaluation of α–c, the events E_1 and E_4 are now taken as neutral (utility 0) according to the theory of Schmidt et al. (2008). These events do not contribute to the evaluation, which is why they do not appear in the following Eq. 4. In particular, we need not specify their rank-dependent weights. E_2 is now a loss event and E_3 is a gain event for α–c. 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 (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.

WTP-ambiguity aversion (WTP(α) < c) results if α–c is evaluated lower than ρ–c. Given that ρ–c is the reference point with $V(\rho-c|\rho-c)$ scaled to be 0, this is equivalent to negativity of the following evaluation through Schmidt et al.'s (2008) theory.

$$\text{WTP-ambiguity aversion} \iff$$

$$V(\alpha-c|\rho-c) = W(E_3)U(x-c|-c) + \lambda W(E_2)U(-c|x-c) < 0. \quad (4)$$

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

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

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

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

Tversky & Kahneman (1992) estimated $\varphi(x) = x^{0.88}$ and $\varphi(-x) = -x^{0.88}$. Then Eq. 5 holds exactly, also for large outcomes. This assumption, called skew-symmetry, was central in Fishburn & LaValle's (1988) theory. Thus, we assume Eq. 5. We divide Eq. 4 by U(0|x), and obtain:

$$\text{WTP-ambiguity aversion} \iff W(E_3) - \lambda W(E_2) < 0. \quad (6)$$

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 in a union with another event. Hence it is plausible that they have the same weights, $W(E_2) = W(E_3)$. Then Eq. 6 reduces to:

$$\text{WTP-ambiguity aversion} \quad \Leftrightarrow \quad 1 < \lambda. \qquad (7)$$

This inequality is exactly what defines loss aversion.

The asymmetric loss function theory of Birnbaum et al. (1992) and Weber (1994) similarly suggests a negative evaluation in Eq. 4. Here the decision maker, when taking ρ as a point of comparison, will take the "overestimation" that the target ρ delivers at event E_2 more seriously than the "underestimation" at event E_3. This theory was developed for decision under risk where it can explain risk aversion. Under the plausible assumption of $W(E_2) = W(E_3)$ it similarly implies WTP-ambiguity aversion for our case of decision under ambiguity.

Ambiguity played a role in the above evaluation process through its effect on the reference point. Because only single events play a role in Eq. 6 and no unions as in Eq. 3, ambiguity *attitudes* did not play a role in establishing Eq. 7. By this equation we can expect a higher WTP of the risky prospect as soon as loss aversion holds ($\lambda > 1$), irrespective of ambiguity attitude if the decision maker takes the risky process as the reference point. A decision maker who is ambiguity neutral or seeking but loss averse will reveal WTP-ambiguity aversion. Empirical studies have suggested that loss aversion is very widespread and strong. Hence virtually all participants will exhibit WTP-ambiguity aversion, in agreement with our data.

The scenario analyzed above is, of course, only one of several possible ones. In general, many choices of reference points are conceivable in reference-dependent theories. Although subjects may resort to many heuristics for their evaluation, the phenomena in our theoretical analysis will play a significant role, implying that WTP(α) is lowered because of loss aversion leading to an overestimation of ambiguity aversion. It is psychologically plausible that the reference point is related to ρ. Loss aversion, which has the tendency of favoring the reference point relative to its alternatives by overweighting the cons of the alternatives relative to their pros, then decreases the value of α. This is what the theoretical analysis of this section has demonstrated.

8. General Discussion

It is common in individual choice experiments not to pay for every choice made so as to avoid distorting income effects. Hence, the random incentive system is generally used (Myagkov & Plott 1997; Holt & Laury 2002; Harrison et al. 2002), where one task is randomly selected to be played for real. The validity of the random incentive system was demonstrated by Starmer & Sugden (1991), Hey & Lee (2005), and others. Some papers explicitly tested whether it matters if for each participant one choice is played for real as in Experiment 4, or if only for some randomly selected participants one choice is played for real, as in our other experiments (Armantier 2006, Harrison et al. 2007). They found no difference. The consistency of our results between experiments 1, 3, and 4 confirms this finding. Baltussen et al. (2008) did find differences, but their stimuli were complex and concerned dynamic choices. Our experiment only concerned simple static choices.

Systematic preference reversals as modeled in the preceding section cannot be expected to occur for CE valuations. There the participants are involved in comparing the ambiguous prospect to a sure outcome for the purpose of choosing, which will not encourage them to search for other anchors. The CE tasks are similar to the straight choices and can be expected to generate similar weightings and perceptions of reference points. That the differences between ambiguous and risky CE evaluations are smaller than the corresponding WTP differences for both choice-ambiguity averters and choice-ambiguity seekers. This finding further supports the theory of the preceding 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 minority of participants for whom this preference reversal arises. Rather, it is a general phenomenon that concerns all participants.

Many studies have used willingness to accept (WTA) to measure ambiguity attitudes. Here participants are first endowed with a prospect and are then asked for how much money they are willing to sell it. As in the study of Roca, Hogarth, & Maule (2006) this procedure will encourage some participants, especially after having chosen ambiguous in the straight choice, to take the ambiguous prospect as reference point when determining its WTA. Our model therefore predicts a reduction in the observed preference reversals compared to WTP. To test this prediction we conducted an experiment that was identical to Experiment 1, except that we asked participants for their WTA instead of WTP. The results are shown in Table 12.

TABLE 12. Frequencies of WTA- versus Choice-Ambiguity Attitudes

	WTA-ambiguity seeking	WTA-indifferent	WTA-ambiguity averse	Binomial test
Choice-ambiguity seeking	8	14	5	$p = 0.87$
Choice-ambiguity averse	1	26	35	$p < 0.001$

As predicted, we observe that only a minority of the choice-ambiguity seekers commits a preference reversal under WTA. Still, reversals occur more often for choice-ambiguity seekers than for choice-ambiguity averters. This is consistent with the assumption that, similar to WTP, the WTA of the risky prospect is easier to determine, and therefore more likely to serve as a reference point in the WTA task.

An interesting question is what happens if the reference point is changed extraneously. Roca, Hogarth, & Maule (2006) found that when participants 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. Our theory is also consistent with the reduced aversion to ambiguous prospects if evaluated separately from risky options (Du & Budescu 2005; Fox & Tversky 1995), or if preceding the risky prospects (Fox & Weber 2002). If the risky prospect is not (yet) present when the ambiguous prospect is evaluated, it obviously will not serve as a reference point. Then the increase in aversion to the ambiguous prospect derived in the preceding section cannot arise.

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. The preference reversals found in our study are of a different nature than preference reversals found before, requiring a reversal of preference within one attribute. The results are stable under real incentives and different experimental conditions. They concern deliberate choices that were not made by mistake. Our results support recent theories on reference dependence by Sugden (2003) and Schmidt et al. (2008). These theories suggest that it is primarily loss aversion (or an asymmetric loss function as in Birnbaum et al., 1992, and Weber, 1994) that generates a strong aversion to ambiguous options under willingness to pay. This implies that the often used willingness to pay measurements overestimate ambiguity aversion.

Our finding that WTP-ambiguity phenomena and choice-ambiguity phenomena are driven by different factors and exhibit different characteristics, has many empirical implications. Examples include the evaluation of new treatments in the health domain, the evaluation of public programs, and investment decisions in a firm. Extrapolation of ambiguity attitudes elicited from choices without concern for other factors that play a role will not correctly predict preferences in situations more similar to WTP, and vice versa. For applications it will be valuable to develop a taxonomy of factors that affect choices under ambiguity in different situations.

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

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