

A Note on Selection in Experimental Auction Markets for Uncertain Prospects

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March, 2009

Abstract: We study experimentally the selection into first-price auctions for a risky prospect or an ambiguous prospect. Most subjects chose to submit a bid for the risky prospect, leading to thinner markets for the ambiguous prospect. Transaction prices (maximum bids) for both prospects were equal although subjects expected the markets for the ambiguous prospects to be smaller. Evidence of a positive correlation between risk and ambiguity attitudes suggests that the markets for the ambiguous prospect were populated by relatively risk tolerant bidders. A control experiment with selection in a simple choice task shows that subjects correctly anticipate the effects of selection.

Keywords: decision under uncertainty, risk aversion, ambiguity aversion, market prices

JEL classification: C91, D44, D81

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^{*} We thank Theo Offerman, Jan Potters, Peter P. Wakker, Richard Zeckhauser and seminar participants at the *Decision and Uncertainty Workshop 2007*, the *ESA world meeting 2007*, *FUR 2008*, *IMEBE 2008*, the Dutch Central Bank, the University of Innsbruck and the *ENABLE* symposium 2008 in Amsterdam for helpful suggestions. We gratefully acknowledge financial support from the *ENABLE* Project under the European Union 6th Framework Program. The paper reflects the views of the authors, and the European Union is not liable for any use that may be made of the information contained herein.

1. Introduction

In decisions under uncertainty people have been found to prefer prospects involving known probabilities (*risky prospects*) to prospects with unknown probabilities (*ambiguous prospects*), even if expected utility theory (Savage 1954) prescribes indifference. This phenomenon is called *ambiguity aversion* (Ellsberg 1961). The idea that agents treat decisions under risk differently from decisions under ambiguity dates back to Keynes (1921) and Knight (1921), and numerous studies have demonstrated the empirical relevance of ambiguity aversion. People are often willing to spend significant amounts of money to avoid ambiguous prospects in favor of risky prospects that are equivalent under expected utility (Becker and Brownson 1964; Charness and Gneezy 2003, Gilboa 2004, Halevy 2007, Schmidt and Maffioletti 2008).

In the real world, decisions under uncertainty often involve only vague probabilities, making ambiguity aversion a possible cause for observed market phenomena which are anomalies from the point of view of expected utility theory. Ambiguity aversion has been incorporated in theoretical models to explain such anomalies. Examples include the home bias in investment and consumption (Uppal and Wang 2003; Huang 2007), the equity premium puzzle (Maenhout 2004), or the underdiversification of incomes risks (Mukerji and Tallon 2001).

There is, however, little direct evidence of the effect of individual ambiguity attitudes on market outcomes and, vice versa, of the effect of market interaction and market institutions on ambiguity attitudes. In this paper, we study the effect of selection into markets for risky and ambiguous prospects on market prices and market sizes in two experiments. Consider two markets, one of them providing a risky asset and one of them providing an ambiguous asset. We investigate a situation in which you can participate in only one of the two markets because of capacity constraints, sunk costs of information acquisition, (legal) participation restrictions or similar reasons. In such a context, we particularly analyze (i) the self-selection into markets depending on risk attitudes, ambiguity attitudes and expectations, (ii) the effect of the market institution on prices, and (iii) the correlation of risk and ambiguity attitudes and its effects on the market outcome.

Recent applications of ambiguity to financial regulation and investment behavior emphasize the effect of ambiguity aversion on self-selection and market size (Easley and O'Hara 2009; Zeckhauser 2006). Ambiguity averse agents shy away from markets for

ambiguous investments, leading to reduced competition and lower prices. Often capacity constraints and participation restrictions exist in markets, for instance in simultaneous procurement bidding for multiple projects (Iyer and Pazgal 2007), allowing agents to operate only in one market. In such settings we expect strong selection effects if the agents have to choose between markets of different levels of ambiguity. With selection, additional strategic considerations become relevant. If market participants expect competitors to stay out of ambiguous markets, then there is an incentive for them to enter these markets even if they preferred less ambiguous markets otherwise. Our results support these predictions. We find that selection affects market outcomes through risk and ambiguity attitudes and through subjects' expectations of other participants' risk and ambiguity attitudes. The results also show that heterogeneity in risk and ambiguity attitudes becomes important because of a positive correlation between these attitudes that makes the effect of ambiguity on prices dependent on the market institution.¹

Markets for risky and ambiguous prospects have also been studied by Sarin and Weber (1993) and more recently by Bossaerts et al. (2007). Bossaerts et al. let their experimental subjects trade securities with state-dependent payoffs where state probabilities were either risky or ambiguous. They find that equilibrium prices and security holdings are affected by ambiguity and suggest a positive correlation between ambiguity aversion and risk aversion, consistent with our result. Sarin and Weber report higher prices for risky prospects in first-price sealed-bid auctions and oral double auction markets. In their experiment there was no selection and all subjects bid in all markets. Considering their institutional setup, we will be able to add to the understanding of their results with the findings from our paper.

Camerer and Kunreuther (1989) study ambiguity aversion in insurance markets, i.e. the loss domain, and operationalize ambiguity through compound lotteries (second-order probabilities). Consistent with individual choice evidence on ambiguity attitude for losses (Hogarth and Kunreuther 1985, Smith et al. 2002), this insurance market study does not find effects of ambiguity. In contrast, we use Ellsberg-type uncertainty in the gain domain in our experiments.

¹ Easley and O'Hara (2009) show that heterogeneity of ambiguity attitudes can affect asset markets also when all agents have identical risk attitudes. In their model, ambiguity aversion leads to smaller markets and suboptimal risk sharing.

In section 2 we review theoretical results in the literature on first price auctions with uncertain payoffs and ambiguity and derive hypotheses for the market setting with selection that is examined in our paper.

Sections 3 and 4 present our main experiment in which we offer a large group of subjects the choice to bid from their own money for either a risky or an ambiguous prospect, using first-price sealed-bid auctions. As a real world analog consider the simultaneous auctioning of multiple oil tract leases in different regions. Some tracts might carry more ambiguous risks than others and each company can only bid for one lease because of capacity constraints to exploit tracts.² In the housing market, a similar situation arises when potential buyers have to decide for which of several houses they want to make a bid. A house located in an established neighborhood could exhibit less ambiguous risks (such as the level of criminal activity in the neighborhood, for which statistics are readily available) than a house in a newly developed suburb for which there is little data yet.

In our experiment we observe strong ambiguity aversion leading to thinner markets for the ambiguous prospect, but equal transaction prices (maximum bids) for risky and ambiguous prospects. Using a measure of risk attitude from an unrelated decision task, we find that bidders in the market for the ambiguous prospect are less risk averse than those in the market for the risky prospect.

With such sorting in terms of risk attitudes, subjects' expectations about market sizes and about the other bidders' risk attitudes in the two markets affect choices. To isolate the effect of expectations about market size from expectations about sorting, we conduct a control experiment, which we discuss in Section 5. In a simple choice task one person from the group choosing the risky prospect and one person from the group choosing the ambiguous prospect is randomly selected for real play. This setting is similar to lotteries for affordable housing. Eligible families can enter a lottery for the right to rent or buy a house at a price below the market rate, but may be constrained to submit only a limited number of applications. Houses may differ in the ambiguity of the risks they carry. While the family in the earlier described auction situation should clearly consider both the number and the aggressiveness of their competitors, the family in the housing lottery need only consider their expectations about how many people enter the lotteries for different houses.

² These risks are assumed to be independent of possible uncertainty about the yield of the tract and the signals thereof. Examples would be political or environmental risk as modeled in Esö and White (2004).

We find that with such pure size incentives the markets for the ambiguous prospect are no longer thinner than those for the risky prospect, consistent with the strategic incentives for subjects who expect a majority choice of the risky market.

Section 6 discusses our results and relates them to the literature. In this section we also review the evidence about the correlation between risk and ambiguity attitude. The last section offers conclusions for ambiguity-based explanations of market anomalies.

2. Theory and Hypotheses

Theoretical accounts of first price auctions mostly assume sure payoffs from winning the auction and common knowledge of the distribution of valuations over market participants. Risk attitudes and market size, then, affect market outcomes through their effect on the optimal shading of bids (Cox et al. 1982, 1985). However, there are extensions of the basic paradigm to either account for potentially risky payoffs from the auction, or to account for ambiguity.

Esö and White (2004) extend the basic model to allow for risky payoffs from the auction that are independent of possible common value components. That is, they study pure ex-post risk that is known to all agents and is considered by the agents in their bids. Esö and White show that under decreasing absolute risk aversion the ex-post risk affects bids through three factors: First, a risk premium discounts the value of the risky payoffs compared to the situation with sure payoffs. Second, there is a precautionary premium that additionally reduces the bid, because marginal utility of income is higher in case an agent wins the auction.³ And third, stronger risk aversion increases bids by reducing the amount of bid shading. Their results show that the first two effects dominate the third effect, leading to a decrease in the bids by more than the risk premium.

Chen et al. (2007) and Salo and Weber (1995) study auctions in which the distribution of payoffs is ambiguous but the payoffs themselves are certain. The intuition of these models is that the distribution of private values will not be known precisely by bidders in real world situations and, hence, they have to form ambiguous beliefs about this distribution. These studies show that ambiguity aversion reduces bid shading and can, therefore, explain

³ The effect is similar to the precautionary saving motive where agents are less willing to accept risks in states of the world where wealth is lower (Eeckhoudt and Schlesinger 2006).

overbidding in first price auctions. There are no results, yet, regarding the extension of these findings to situations in which payoffs are also ambiguous.

While the size of the effect of the additional uncertainty component will depend on the assumed model for decisions under ambiguity, the above discussed results by Esö and White also that bids should be reduced by the risk and also by the ambiguity premium. Salo and Weber find that the reduction of bid shading as the number of bidders increases carries over to situations under ambiguity. Moreover, ambiguity about the number of bidders reduces bid shading under ambiguity aversion.

Our setting with auction markets for prospects that differ in their degree of ambiguity and with agents selecting into these markets according to their ambiguity attitudes combines features of both streams of research. Because private values depend on the unknown risk and ambiguity premiums of other bidders, the distribution of private values is also ambiguous. Market sizes are not fixed, making the number of bidders ambiguous.

Equilibria in such settings will be complex, especially because of the asymmetry of bidders.⁴ If preferences and beliefs are correlated, e.g. if ambiguity averse agents believe that other bidders have a similar dislike for ambiguity, theoretical models will have a hard time to predict market behavior. In this paper we do not aim to introduce a theoretical account of selection into auctions with ambiguous payoffs. We rather study empirically whether results from basic settings hold if agents self-select into risky and ambiguous markets.

In particular, we test two hypotheses regarding price and size effects of ambiguity on markets. Our hypotheses extrapolate results from individual decision settings and markets without selection. We are particularly interested in behavior in one-shot situations, because with repeated interaction ambiguity diminishes over time.

Assume two first-price sealed-bid auction markets for a risky and an ambiguous prospect that are equivalent under expected utility. Subjects can only submit one bid, that is, they have to decide in which of the two auctions they want to participate. Subject can only submit a bid once. We state the following two hypotheses:

Hypothesis 1: The transfer price of an ambiguous prospect will be lower than the transfer price of a risky prospect that is equivalent under expected utility.

⁴ Esö and White derive their results for bidders who have identical utility functions.

Numerous studies have shown that subjects' willingness to pay for ambiguous prospects is much lower than for prospects with well-defined probabilities. This has been found to be true also for market prices. Hypothesis 1 tests whether this effect also prevails in a market setting with selection.

Hypothesis 2: The number of bidders for the ambiguous prospect will be lower than the number of bidders for the risky prospect.

In equilibrium, agents should be indifferent between submitting a bid for either market. Depending on subjects' preferences and beliefs, various distributions of bidders over the two markets are conceivable in our one-shot setting. Under the widely observed pessimistic attitude towards the prize in the ambiguous market, we expect that convergence to an equilibrium would be attained from a situation with too few bids for the ambiguous prospect. In a one-shot selection situation this suggest fewer bids for ambiguous than for risky.

3. Experiment 1 (Main Experiment): Design

Subjects. One hundred and seventy-six undergraduate students participated in eight laboratory sessions. In each session there were between 20 and 24 subjects. Students were recruited electronically from a pool of approximately 1200 potential participants and came from different fields of study. Each subject participated only once.

Payoffs. Each subject received a show-up payment of €5. In each session, two subjects could participate in a prospect that paid €30 in case of success and €0 otherwise. These two persons were determined by an auction. Each subject could bid from his or her own money for the right to play one of the two prospects. The two winners in each session had to pay their own bid immediately before playing. Subjects could also earn between zero and €200 from a risky decision task that preceded the auction. At the time of the auction subjects did not know how much they would win from the risky decision task. The auction experiment took approximately 30 minutes.

Procedure. Upon arriving at the laboratory subjects were randomly assigned to computers that are placed in individual cubicles. All parts of the experiment were computerized using the

experimental software z-tree (Fischbacher 2007). All randomizations of prospects were conducted by throwing dice or drawing chips from a bag, at the subjects' desks. Subjects first made decisions in the risky choice task. One decision would be selected for real payment, and the payoffs depended on subjects' choices and chance. All subjects faced exactly the same decision tasks but the payoff-relevant task was chosen independently for each subject. Before the payoff-relevant decision was selected for each subject and the payoffs determined according to the subjects' choices, we offered subjects the possibility to participate in a first-price sealed-bid auction for one of two prospects. At this point subjects had no information about their earnings from the risky decision task but each subject had received €5 for showing up on time. We offered to each group of 20 to 24 subjects the following two lottery options that represented the risky and the ambiguous urn in the Ellsberg (1961) two-color choice task:⁵

“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 to the experimenter. Then you draw. If the color you announced matches the color you draw, you win €30. If the colors do not match, you get nothing.”

“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 to the experimenter. Then you draw. If the color you announced matches the color you draw, you win €30. If the colors do not match, you get nothing.”

Option A offers a risky prospect with a probability of 50% for each color to be drawn. Option B offers an ambiguous prospect because the probabilities for each color to be drawn are unknown. Subjects had to choose the winning color, and it was clear that the experimenter had no possibility to influence the outcome of either option. If subjects are indifferent between betting on either color in option B, the two options are equivalent under expected utility. If subjects believe that there are more than 20 red chips in option B, this option is preferred to option A because it offers a higher expected utility by betting on red. A similar

⁵ The description of the two options is taken from the instructions that were used in the laboratory. Complete instructions can be found in the Appendix.

argument holds if subjects believe that there are more than 20 green chips in option B. The order and the letter for the two options in the instructions and on the computer screens were counterbalanced in half of the sessions.

It was explained to the subjects that only one option A and one option B was offered to the whole group and that two persons were determined by an auction to play the prospects, one for each prospect. Each subject could place a bid for *either* the risky option A *or* the ambiguous option B. This was done at the computer by first choosing one option and then placing a bid for that option. Subjects could only submit one bid. After the auction winners were determined they would immediately pay their bid from their own cash and play the prospects at their desks. It was made clear to subjects that they could not use any advances from possible earnings from the experiment to pay their bid. Any bid between €0 and €30 could be submitted and change was available.⁶

The one-shot auction design is applied because of the inherent uniqueness of ambiguous situations and because it avoids possible biases in learning with repeated auctions. Neugebauer and Selten (2006) have shown that feedback on other participants' bids affects bidding in repeated auctions when resale values of the prize are certain.⁷ In particular, information about winning bids leads to overbidding. With risky and ambiguous prospects as prizes such effects may be even stronger, and they may potentially be different for the two prospects. Learning through repeated bidding with an immediate resolution of the prospects, on the other hand, is impossible with ambiguous prospects because subjects would learn about the probabilities of the ambiguous option, therefore eliminating the ambiguity.

After submitting their bid, but before learning the maximum bid in the auction in which they participated and whether they were the winner of this auction, subjects answered questions regarding their expectation of how many people would choose the auction for option A, and the expectation about their chances to win the €30 if they were *simply playing* option B. The latter question was included to elicit a matching probability and measure ambiguity aversion outside the auction setting (Kahn and Sarin 1988). Both questions offered

⁶ Participants might have been subjected to budget constraints in our setup. It is unlikely that budget constraints in the range relevant here correlate with risk and ambiguity attitudes. Providing the endowment necessary to avoid any budget constraints in bidding seemed more likely to affect uncertainty attitudes.

⁷ Duwfenberg and Gneezy (2002) and Ockenfels and Selten (2005) find similar effects of feedback. Filiz-Ozbay and Ozbay (2007) show that regret from intermediate auction outcomes (i.e. winning or losing the item) can influence bidding behavior in repeated settings.

five brackets of 20% as answers: "less than 20%", "between 20% and 40%", "between 40% and 60%", "between 60% and 80%", "more than 80%". These wide brackets were chosen to make the task relatively easy for students and avoid any prominence of the 50% probability. The choices were scored on a five-point scale with 1 referring to the bracket with the smallest expected probability ("less than 20%").

Subjects knew the size of the whole group. Experimental instructions were distributed individually and read aloud to the subjects. Remaining questions were answered privately. After playing the prospects, the experimental earnings from the other decision task were determined. Subjects filled out a demographic questionnaire, were paid for the other task and dismissed from the laboratory.

Risk attitudes. In the first part of the experiment subjects made choices between risky prospects. To compare subjects' risk attitudes we constructed a measure of risk aversion from six choices between sure payoffs and risky prospects. Three of the decision problems offer a choice between a risky prospect and its expected value (problems 1 to 3). The other three decision problems are adapted from prospect choices for which a preference of roughly 50% for each option has been found in previous studies (problems 4 to 6), and these choices are therefore likely to distinguish well between subjects (Wakker et al. 2007). Our measure of individual risk aversion is the number of safe choices in the six decisions made by a subject. The six prospects are displayed in Table 1, with x denoting a sure payoff and $(x, p; y)$ denoting a prospect that pays x with probability p and pays y with probability $1-p$.

The prospects were played by the subjects for real payoffs using the random incentive lottery system (Filiz-Ozbay and Ozbay 2007; Holt and Laury 2002; Starmer and Sugden 1991). Note that the €30 prize of the prospects sold in the auction lies within the range of payoffs of the prospects we use to measure individual differences in risk attitude.

Table 1: Decisions Problems for Risk Attitude Measurement

	Risky decision problem					
	1	2	3	4	5	6
Sure option	€10	€3	€12	€4	€3	€11
Risky option	€20, 0.5; €0	€52, 0.25; €0	€15, 0.8; €0	€18, 0.95; €0	€32, 0.5; €0	€200, 0.05; €0

4. Experiment 1: Results and Discussion

4.1. Results

Market Outcomes. We find strong ambiguity aversion in our auction markets. Only 65 of 176 subjects (37%) chose to bid for the ambiguous prospect ($p=0.001$, binomial test). The details of the eight individual sessions are summarized in Table 2a and Figure 1.

Table 2: Market Outcomes per Session

	Session number								Mean
	1	2	3	4	5	6	7	8	
a)									
Number of participants	21	21	21	20	24	24	24	24	22.38
Bidders in market for ambiguous prospect	5	3	10	9	7	12	11	8	8.13
Bidders in market for risky prospect	16	18	11	11	17	12	13	16	14.25
Transaction price ambiguous prospect in €	10.02	6.00	8.50	10.00	9.02	10.52	12.06	5.05	8.90
Transaction price risky prospect in €	7.80	10.05	11.00	7.20	14.00	6.35	8	10.01	9.30
b)									
Average risk aversion ambiguous market*	2.2	2.3	2.9	3.2	3.7	2.6	3.7	3.8	3.05
Average risk aversion risky market*	3.5	3.7	3.6	3.7	4	4.5	3.7	4.3	3.88

*Number of safe choices in six risky choice problems shown in Table 1.

The number of bidders in the market for the ambiguous prospect is smaller than the number of bidders in the market for the risky prospect in seven out of eight sessions and once it is equal. The percentage of bids for the ambiguous prospect ranges from 14% to 50%, making markets for the ambiguous prospect significantly thinner than markets for the risky prospect ($p=0.003$, Mann-Whitney test).

Larger markets for the risky prospect should, everything else equal, lead to higher transaction prices (maximum bids): it is more likely that a high-value bidder is in the market, and if participants correctly anticipate strong competition they will shade their bids less. Although competition is much lower for the ambiguous prospect, transaction prices are equal

for both prospects. The transaction price of the ambiguous prospect is higher than the price for the risky prospect in four out of eight sessions, and average transaction prices for the two options do not differ ($p=0.834$, Mann-Whitney test). This result is based on the observation of eight markets, but strong support comes from the analysis of the individual bids. The average and median bids are slightly higher for the ambiguous prospect with a mean of €4.30 (median €4.00), compared to a mean of €3.43 (median €3.05) for the risky prospect ($p=0.039$, Mann-Whitney test).

Figure 1: Market Outcomes per Session

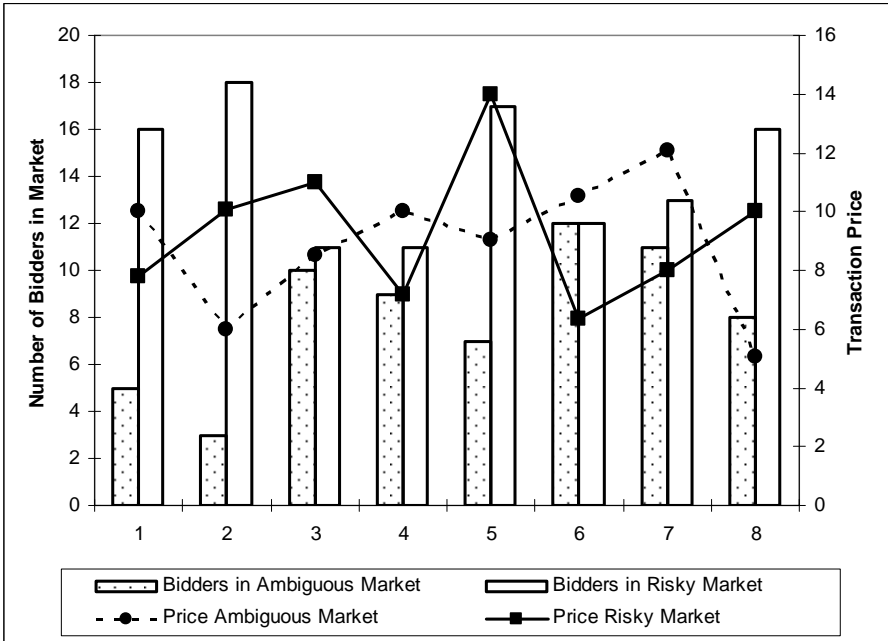


Figure 2 shows the distribution of bids for both options. Small bids ($\leq €$) are much more frequent in the market for the risky prospect and large bids ($> €$) are more frequent in the market for the ambiguous prospect. This observation suggests that there is a segmentation of subjects with different risk attitudes into the two markets, with less risk averse subjects choosing to bid for the ambiguous prospect.

The data from the independent risk attitude measurement confirm that subjects in the risky markets were more risk averse on average than subjects in the ambiguous markets ($p=0.001$, Mann-Whitney test). Table 2b shows that the average risk aversion in the ambiguous markets was smaller in seven of the eight sessions.

Figure 2: Distribution of Bids

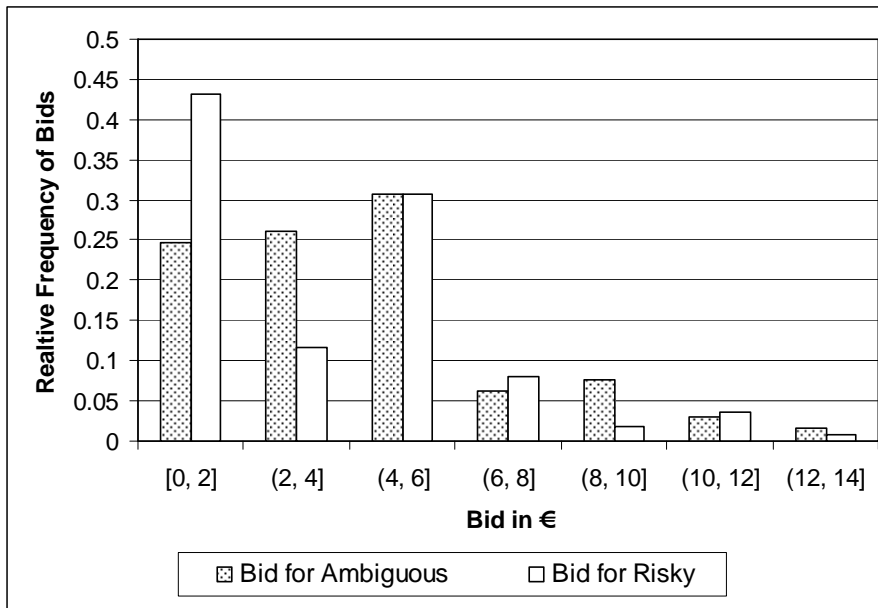


Figure 3: Distribution of Risk Attitudes

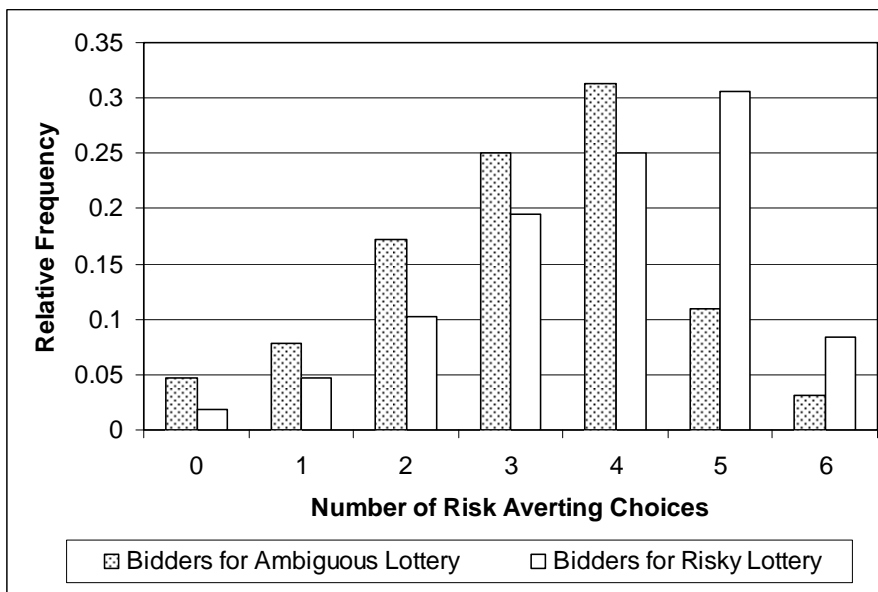


Figure 3 gives the distribution of the number of safe choices for both options. Extreme levels of risk aversion with five or six risk averse choices are much more common for subjects in the market for the risky prospect, and risk seeking behavior with zero or one risk averse choice only is more common for subjects bidding for the ambiguous prospect. The probit regression in Model I of Table 3 shows that each risk averting choice increases the

probability that a subject bids for the risky option by 7 percentage points, controlling for gender. The effect of risk attitudes is robust if we control for expectations about competition and for attitudes toward the ambiguous prospect (Table 3, Model II).

If selection of relatively risk tolerant subjects into the ambiguous prospect's market contributes to the equality of prices in the two markets, we would expect lower bids from more risk averse subjects. Linear regression results in Model III of Table 3 show that more risk averse subjects indeed submit lower bids in their market. Each risk averting choice decreases a subject's bid by €0.37.

Table 3: Regression Analyses of Market Choices, Bids, and Transaction Prices

	Model I	Model II	Model III	Model IV
	Probit ^b : Choice of market for the risky prospect	Probit ^b : Choice of market for the risky prospect	OLS: Bid for prospect	OLS: Transaction price
Risk aversion	0.0733** (0.0269)	0.0654* (0.0274)	-0.3748* (0.1498)	
Expected market size risky prospect		0.0608 (0.0428)		
Expected chance to win with ambiguous prospect		-0.1419** (0.053)		
Expected market size own market ^a			0.2447 (0.2418)	
Market size				0.4253* (0.1739)
Choice of market for the risky prospect			-0.821 (0.5737)	-2.2003 (1.4414)
Female	0.1116 (0.0788)	0.0664 (0.0855)	-1.1793* (0.4564)	
# of observations ^c	172	172	172	16

Robust standard errors in parenthesis; *significant at the 5%-level, **significant at the 1%-level.

a: Equal to expected market size of the risky prospect for subjects bidding for the risky prospect and equal to one minus this expectation for subjects bidding for the ambiguous prospect.

b: Marginal effects reported.

c: Four subjects did not make a choice in at least one of the independent risky decision tasks and were excluded from the regression analyses.

Further evidence that the countervailing effects of risk attitude and expected market size lead to equal transaction prices in the two markets comes from the analysis of the 16 auction winners. The winners of the auction for the risky prospect on average make 3.38 safe choices in the risky decision task, while winners of the ambiguous prospect make only 1.75 safe choices ($p=0.062$, Mann-Whitney test). However, the winners of the risky prospect expected

strong competition in their market (score 4.38 or approximately 75% of all participants), while the winners of the ambiguous prospect expected relatively low competition (score 2.5 or approximately 40% of all participants) in their market ($p=0.001$, Mann-Whitney test). We conclude that the positive correlation between risk and ambiguity attitude leads to thinner markets with more risk prone subjects in the market for the ambiguous prospect than for the risky prospect. This market segmentation contributes to the equality of transaction prices for the two prospects in our experiment.

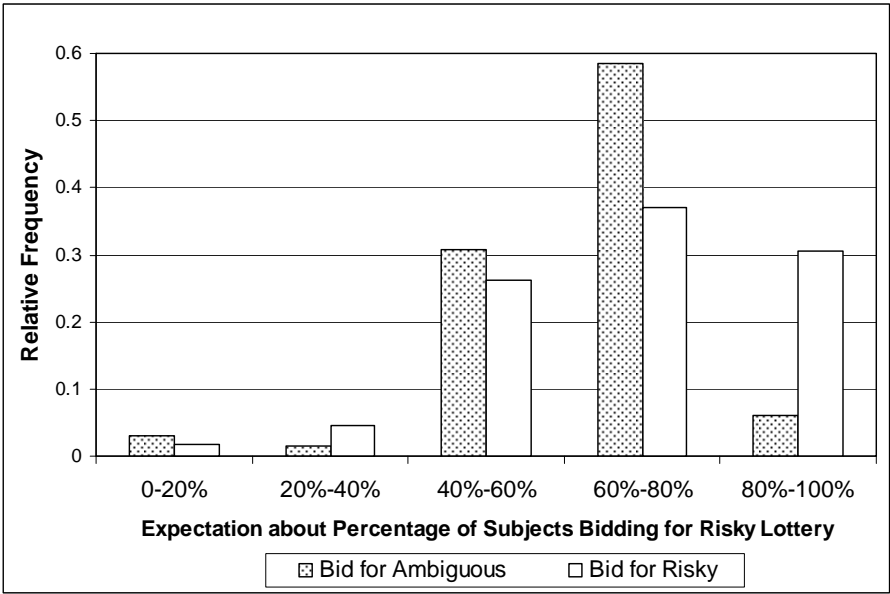
Gender differences. Females are more likely to bid for the risky option ($p=0.047$, Fisher test). Controlling for risk attitudes in the probit regression (Model I in Table 3), the effect of gender becomes insignificant, however. We observe significantly lower bids by females after controlling for risk attitude (Model III in Table 3). Females do not differ from males in their expectations about the competitiveness of the two markets ($p=0.628$, Mann-Whitney test). This suggests that they differ from their male counterparts in some dimension that we do not observe and that has an effect on bidding, such as competitive behavior (Gneezy et al. 2003; Gneezy and Rustichini 2004) or emotional reactions like regret or social loss aversion (Filiz-Ozbay and Ozbay 2007; Delgado et al. 2008).

Effects of Expectations. After submitting their bids, but before learning the result of the auction, we asked subjects to indicate their expectations about the competition in the market for the risky prospect and about the winning chances with the ambiguous prospect. The latter question is used to approximate in how far subjects perceive the ambiguous prospect as an unattractive option. We would expect that the anticipation of strong competition for the risky prospect makes a bid for the ambiguous prospect more likely. Expecting strong competition in their own market should have a positive effect on subjects' bids in each market. Perceiving the ambiguous prospect as an unattractive option (having low expectations of success when simply playing this option) should make a bid for the risky option more likely.

On average subjects are well-calibrated in their expectations about the competition for the risky prospect. Very few subjects expect more competition for ambiguous. On the five-point scale with brackets of 20%, the average score is 3.8, and the median is 4. This indicates an expectation of about 65% choices for the market with the risky prospect (compared to a true average value of 63%). The probit regression in Table 3, Model II shows, however, that the effect of beliefs about the competition for the risky prospect is insignificant and points in

the wrong direction. If anything, more expected competition for the risky option seems to increase the probability to bid this option. Figure 4 shows that this effect is driven by subjects in the market with the risky prospect holding beliefs of strong competition for this prospect. About 70% of bidders in the risky market expect a majority of participants in their own market, and about 30% of bidders in the risky market expect more than 80% of the participants in their market. That is, these latter subjects prefer competing with 16 people in the risky market over competing with 4 people in the ambiguous market.

Figure 4: Market Choice and Expectations about Competition

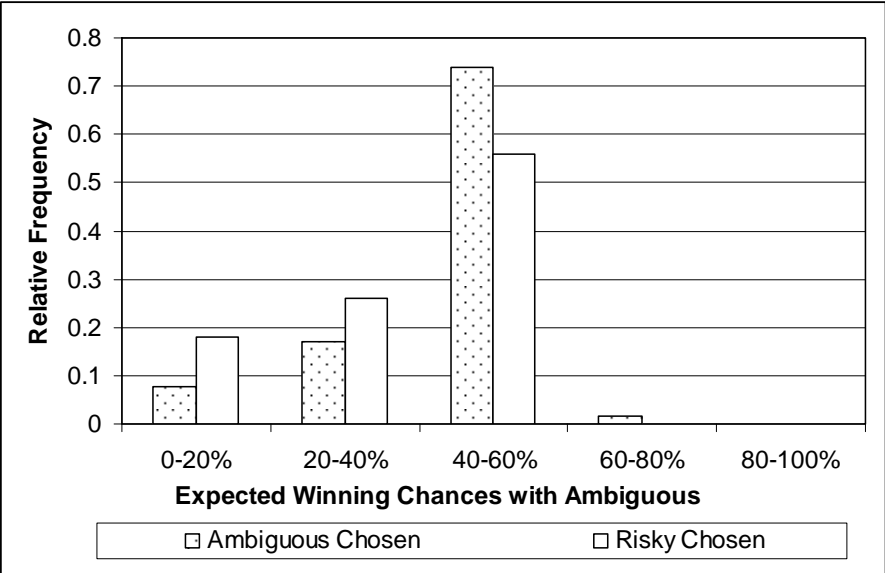


In contrast to the expectations about competition, the attractiveness of the ambiguous option has the expected effect on market choices. Subjects who perceived the ambiguous prospect as less attractive were more likely to submit a bid for the risky prospect. Figure 5 shows, however, that while few people have a distinctly positive attitude towards ambiguity according to the question about winning chances, extremely negative attitudes are also rare for bidders in both markets.

Effects of Market Size. Market segmentation in terms of risk attitudes implies that, while transaction prices should be higher in larger markets for either urn, they should be lower for the risky markets when controlling for market size. Model IV of Table 3 reports linear regression results showing that an additional bidder in a market increases the transaction price

by approximately €0.40. The transaction price is €2.20 higher in the ambiguous prospect's markets, but this effect is only marginally significant one-sided.

Figure 5: Expected Winning Chances with Ambiguous



4.2. Discussion

We study the effect of selection in first-price auctions and find strong ambiguity aversion leading to smaller markets for ambiguous prospects than for risky prospects, supporting our second hypothesis. There is no support for our first hypothesis regarding the price effects of ambiguity, however: Equal transaction prices are observed in both markets. These results can be explained by assuming a positive correlation between risk and ambiguity attitudes, and we find indeed that the markets for the risky prospect are populated by relatively more risk averse bidders than markets for the ambiguous prospect. Participants correctly anticipate the stronger competition in our risky markets. Therefore, the countervailing effects of bidders' risk attitudes and the expected market sizes seem to have led to equal prices for both prospects. An ambiguity-neutral bidder who perceives both prospects as equally good would be indifferent between bidding for the risky and bidding for the ambiguous option in our experiment. There is no ambiguity premium to be earned from the ambiguous prospect over and above the risk premium for the equivalent risky prospect.

We also observe many bidders for the risky prospect expecting strong competition in their market. These subjects may be extremely ambiguity averse, making the risky prospect

more attractive despite the fierce competition and the strategic incentives to bid for ambiguous. Alternatively, they may correctly anticipate the presence of more risk tolerant bidders in the market for the ambiguous prospect, perceiving low chances to win this auction at a cheap price even with little competition. If a company expects few but very aggressive competitors for an ambiguous project in procurement bidding, it may well decide to bid for a less ambiguous project with many, but more cautious competitors. A third explanation may be that subjects simply did not understand the strategic incentives provided by possible differences in market size for the two prospects. Huberman and Rubinstein (2002) find evidence for such strategic mistakes in games where there is no rational explanation for subjects' actions given their beliefs.

In order to be able to distinguish between these explanations, we conducted a control experiment (experiment 2) with selection in a simple choice task that isolates the effects of market size.

5. Experiment 2: Isolating the Effect of Market Size

5.1. Design

Subjects. Another one hundred undergraduate students participated in five laboratory sessions. In each session there were 20 subjects. Students were recruited electronically from the same pool as in experiment 1. Each subject participated only once and had not participated in experiment 1.

Payoffs. Each subject received a show-up payment of €5 and could earn approximately €15 from an unrelated experiment. In each session, two subjects could earn up to €30 from the choice task described below. The whole experiment took approximately 15 minutes.

Procedure. The stimuli in this experiment were identical to those used in experiment 1, and we used the same descriptions of the risky and ambiguous prospects as in experiment 1. In each group of 20 participants subjects had to decide whether they wanted to play the risky option A or the ambiguous option B, under the condition that for each option exactly one subject was randomly selected to play his or her choice for real. That is, subjects' chances to be chosen for play depend only on the group sizes for options A and B. Subjects knew the size of the whole group.

Subjects made their decision between option A and option B by choosing one of two decision sheets. On this decision sheet they then made 30 choices in a choice list between sure payoffs and the prospect they had chosen (see Appendix). With this list we elicit the subjects' *certainty equivalents* (CE) for their chosen option, that is, the sure amount of money that makes subjects indifferent between receiving the sure amount or playing the prospect they have chosen. The certainty equivalent was calculated as the midpoint between the two sure amounts for which a subject switched from preferring the sure money to preferring the prospect.

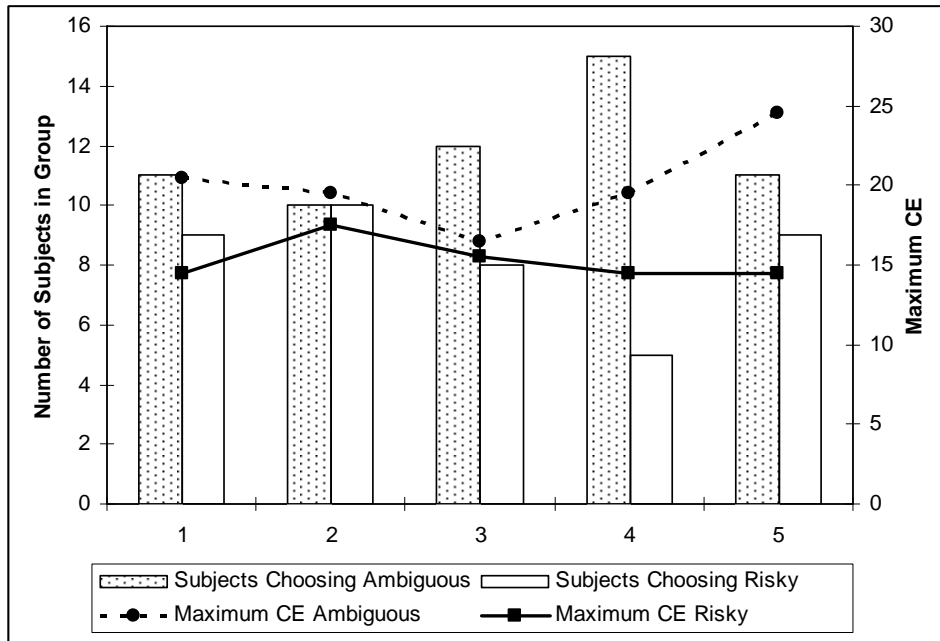
Subjects handed in their decision sheet in an envelope. One envelope was publicly drawn from the group of subjects choosing option A and one envelope from the group of subjects choosing option B. For these two subjects one of their decisions between a sure amount and their prospect was individually selected by drawing a numbered lot. According to the subject's decision in this choice problem the subject either received the sure amount or played the prospect.

5.2 Results

We find that 59 of 100 subjects choose the ambiguous option and we can therefore reject the null hypothesis of thinner markets for ambiguous ($p=0.044$, binomial test). The details of the five individual sessions are summarized in Figure 6.

The groups choosing the ambiguous option are significantly larger than the groups choosing the risky option ($p=0.011$, Mann-Whitney test). In each session, the maximum CE and the mean CE for the ambiguous option are larger than for the risky option. Pooling all sessions the mean CE equals €12.47 for the ambiguous prospect and €10.82 for the risky prospect ($p=0.07$, Mann-Whitney test).

Figure 6: Group Sizes and Maximum Certainty Equivalents in the Choice Task



5.3. Discussion

Experiment 2 isolates the effect of expectations about market size from the effect of expectations about other bidders' risk attitudes on market choice. In our choice task ambiguity averse subjects have an incentive to choose the ambiguous option if they expect that few people will do so. Low competition increases the chance to be randomly selected to play the ambiguous prospect, making this option more attractive than a low chance to be randomly selected to play the otherwise preferred risky option. In contrast to the market situation in experiment 1 the other participants' risk attitudes do not matter for the choice. In the auction in experiment 1 ambiguity averse subjects might choose to bid in the more competitive risky market if they expect the few bidders in the ambiguous market to be more risk tolerant. Our results from the simple choice task with selection in experiment 2 support this explanation. If other subjects' risk attitudes do not matter because of the random selection for real play, the majority of subjects choose the ambiguous prospect in most sessions.

Consistent with this explanation is the fact that maximum certainty equivalents are indeed larger for the ambiguous prospect in all sessions. The subjects with the maximum CE hold the highest valuation of the uncertain prize in the game, and in an auction these subjects would be among the highest bidders. This explains our observation of equal transaction prices

for risky and ambiguous prospects, although markets were much thinner for the ambiguous prospect.

The observation of larger groups for the ambiguous option in experiment 2 rejects an explanation of market choices in experiment 1 that is based on strategic mistakes as in Huberman and Rubinstein (2002). Subjects react to strategic incentives, but they seem to apply a rather low level of strategic rationality⁸. As shown in experiment 1, most subjects expect the majority of other bidders to be ambiguity averse. In the simple choice task, a majority of subjects chooses ambiguous, invalidating these expectations. The results also confirm that ambiguity aversion is widespread, but not overly extreme at the individual level (see Figure 5). If ambiguity aversion were extreme, the higher probability of being selected for play would not make up for the low expectation of winning the prize from ambiguous for most subjects.⁹

Note that subject's decisions in the simple random selection in experiment 2 are not equivalent to decisions in second-price auctions along the lines of experiment 1. Similar to our incentive compatible CE elicitation of the subjects' valuations of the uncertain prospects, the second price auction elicits true valuations in the bidding stage.¹⁰ When deciding whether to enter the second-price auction for the risky or the ambiguous prospect, however, both expected market sizes and expected risk attitudes of the other participants matter. Market sizes and others' risk attitudes influence the subject's chances to win the auction and the price the subject has to pay for the prospect if she wins.

The fact that the influence of market size and risk attitudes on winning chances and price must be considered by the subjects in the decision between the prospects, but not in their bid, requires complex reasoning and makes the second-price auction with selection susceptible to errors. The first-price auction in experiment 1 more naturally involves consideration of market size and risk attitudes at both stages.

⁸ Similar levels of rationality have been found for one-shot play or first rounds in other games, e.g. Stahl and Wilson (1994) and Nagel (1995).

⁹ Theoretical work by Ghirardato et al. (2004) extends the classic multiple prior model by Gilboa and Schmeidler (1989) to allow for more modest ambiguity aversion and heterogeneity.

¹⁰ Grimm and Schmidt (2000) show that the second price auction may not elicit true CEs if subjects violate the independence axiom.

6. General Discussion

We use a one-shot first-price auction to study market choices in the presence of ambiguity. This design provides a natural setting for ambiguity with strong strategic incentives. Our experimental data show that ambiguity aversion can persist in competitive markets and can affect market outcomes. This makes ambiguity aversion a potential explanation of market anomalies from the point of view of expected utility theory. Our main experiment provides support for the hypothesized market size effect, but not for the effect on transfer prices. Based on bidders' independently measured risk attitudes, we suggest that heterogeneity in ambiguity attitude and a positive correlation between attitudes toward ambiguity and risk can explain the observed equality in prices.

The existing evidence on the relation between individual risk and ambiguity aversion is mixed. Cohen et al. (1985) and Curley et al. (1986) find no relation between the two dimensions, whereas Potamites and Zhang (2007) report a weak positive correlation. These studies do not use independent tasks to measure risk and ambiguity attitudes, and they use only a single valuation exercise to measure each attitude. Presenting risky and ambiguous options jointly in one task will elicit evaluations that are mutually influenced by each other, leading to possibly biased estimates of the correlation. To illustrate the effect, consider a highly risk and ambiguity averse person. Joint evaluation will make the risky option look more attractive because of the presence of the highly unattractive ambiguous option, inducing an artificially high valuation for the risky prospect. The observed degree of risk aversion for this person will be too low, reducing the observed correlation between risk aversion and ambiguity aversion. Such an effect has been reported by Fox and Tversky (1995, p. 590) and by Halevy (2007, p. 532).

Using independent measures of risk and ambiguity attitude and multiple risky choices to measure risk attitude, Lauriola and Levin (2001) and Lauriola et al. (2007) find a significant positive relation between ambiguity and risk attitudes. They show that the correlation is largely due to subjects with extreme risk and ambiguity attitudes. Figure 3 shows that this can also be observed in our data. Koch and Schunk (2008) study the effect of liability on the correlation between risk and ambiguity attitudes. In particular, they implement treatments in which experimental subjects might incur real losses and compare them with treatments where subjects can only lose money from an initial endowment. Only in the case of real losses (full liability) do they observe a strong correlation between risk and ambiguity attitude.

Further evidence for a positive correlation comes from investment experiments by Charness and Gneezy (2003) and by Bossaerts et al. (2007). In Charness and Gneezy's study, the subjects could invest any fraction of a \$10 endowment in either a risky prospect or an ambiguous prospect – similar to our options A and B – and keep the rest for sure. If they correctly guessed the color in their chosen prospect, the investment was multiplied by 2.5. Otherwise the investment was lost. Each subject made an individual decision; hence, there was no strategic interaction. Charness and Gneezy find that the subjects who choose the ambiguous prospect invest significantly more than subjects who choose the risky prospect.

Bossaerts et al. let their subjects trade in markets for risky and ambiguous state-dependent assets and find that those subjects who hold more ambiguous assets also tend to hold more volatile portfolios. They argue that market segmentation in terms of risk and ambiguity attitudes can explain the value premium effect: value stocks tend to have higher returns than growth stocks (Fama and French 1998). If growth stocks are associated with high ambiguity they attract only ambiguity tolerant investors who are also risk tolerant and, therefore, require a smaller risk premium than the investors in value stocks.

In our institutional setting, ambiguity leads to market segmentation in terms of risk attitude and to equal prices for the risky and the ambiguous prospects, although the latter is perceived as less attractive by the majority of subjects. The importance of the market institution for market outcomes in the presence of ambiguity can be illustrated by a comparison of our results with those of Sarin and Weber (1993). Sarin and Weber conducted double-auction markets and first-price sealed bid auctions for risky and ambiguous Ellsberg urn prospects and consistently found lower prices for ambiguous prospects. This price difference can be explained by the fact that a selection of subjects with different ambiguity attitudes into the markets for the two prospects was precluded by their market design. All subjects would always participate in both markets, holding competition and average risk attitude constant in both markets. The relatively risk tolerant subjects who chose ambiguous in our experiment would bid for the risky prospect in Sarin and Weber's experiment, driving up prices in this market. The relatively risk averse subjects who chose risky in our experiment would have to bid for the ambiguous prospect in Sarin and Weber's experiment. These subjects are also ambiguity averse and, therefore, unlikely to submit high bids, leaving market prices unaffected. Positively correlated ambiguity and risk attitudes can explain both results when taking the different market institutions into account. The comparison of Sarin and

Weber's and our results illustrates the importance of the markets size effect of ambiguity aversion that was emphasized by Easley and O'Hara (2009) and Zeckhauser (2006).

The selection effects found in our experiment may be important in license auction markets (Binmore and Klemperer 2002; Goeree 2003; Janssen 2006; Offerman and Potters 2006). Firms competing in these auctions bid for a prize with an uncertain outcome. Assuming that firms are risk averse, it has been shown that auctions have an effect on prices in the aftermarket by selecting the most risk seeking firms (Janssen and Karamychev 2007). The selection of relatively risk and ambiguity prone firms into auctions for aftermarkets that have more ambiguous payoff distributions implies that this effect is reinforced for ambiguity.

7. Conclusion

Ambiguity aversion has been used in the explanation of market anomalies, regulatory recommendations and investment advice. Self-selection into different market segments has been suggested as an important factor affecting the mechanism by which ambiguity influences market outcomes. Our results show that ambiguity attitudes are important for market outcomes. Because of the heterogeneity of risk and ambiguity attitudes and the correlation of these attitudes, the effects on market outcomes depend on the institutional setting and selection effects. Extrapolating ambiguity effects from one market institution to another may yield wrong predictions.

In markets, the agents' revealed ambiguity attitudes depend on their expectations of other participants' attitudes toward risk and ambiguity. Studying the interaction between agents' expectations and their attitudes toward uncertainty in more complex markets seems a promising route to improve ambiguity-based explanations of market behavior and the resulting policy recommendations.

Appendix: Experimental Instructions

Extra Gamble Options!

We offer you the following extra gamble options before the payoffs of the experiment are determined and you receive your payoffs. Please read the descriptions carefully!

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 to the experimenter. Then you draw. If the color you announced matches the color you draw, you win €30. If the colors do not match, you get nothing.

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 to the experimenter. Then you draw. If the color you announced matches the color you draw, you win €30. If the colors do not match, you get nothing.

In experiment 1 the instructions proceeded as follows:

We offer only one option A and one option B to the whole group. We will determine the persons who play the options by an auction for each of the options. If you would like to play either of these options, you have to buy the right to play it from your own cash by making the largest bid for this option. If your bid wins the auction you have to pay your bid immediately and cannot use advance payments from possible earnings from the experiment. If there is more than one highest bid, the computer randomly determines one person as the winner of the auction.

You can place a bid for one option only! Thus you must decide for which option to bid and how much to bid for that option! You bid only once and privately, there are no repeated bids.

Procedure:

On the following screen you will first choose whether you want to bid for Option A or Option B.

Then you will submit a bid in Euro and Cent for that option. You can bid every amount between 0.00€ and 30.00€

If you do not want to bid from your own money for the option to play one of the gambles, choose one option and make a bid of zero Euros. If there is no positive bid in this auction, you may still win and play with a zero bid.

The auction winners for Options A and Option B are determined. An experimenter will come to each auction winner, collect the bid (we can change money if needed) and play the gamble. If the color matches, the person immediately receives 30€. If the colors do not match, the person does not receive any payoff.

In experiment 2 the instructions proceeded as follows:

We offer only one option A and one option B to the whole group. We will determine the persons who play the options as follows:

Each participant chooses which option he or she prefers to play. We will randomly draw one person from the participants who chose option A and give him or her the opportunity to play option A. We also randomly draw one person from the group of participants who chose option B and give him or her the opportunity to play option B.

Please read the instructions carefully and then make a choice whether you want to play option A or option B.

- If you want to play option A (bet on a color to win €30 from bag with 20 red and 20 green chips), open the envelope with the letter 'A' on it and fill out the sheet in there.
- If you want to play option B (bet on a color to win €30 from bag with unknown proportion of colors), open the envelope with the letter 'B' on it and fill out the sheet in there.

Please leave the envelope of the option you do not choose closed.

Decision Sheet Option A.

You want to play option A (bet on a color to win €30 from bag with 20 red and 20 green chips)

We offer you the following: for each of the choices on the back of this sheet you decide whether you want to play option A or receive a sure amount instead. If you are randomly selected for real play from the people who chose option A, the experimenter will come to your desk and you will draw a lottery number to determine which of the choices on the back will be played [indicated by the number in brackets left to the choice option].

Depending on your decision in this choice you will either play option A as described before, or immediately receive the sure amount.

Example 1. You were selected for real play. You draw number '30'. For this number you made the following decision:

[30] Play Option A or get €30 for sure

You chose the sure amount here. Therefore you immediately receive €30. You will not play the gamble.

Example 2. You were selected for real play. You draw number '1'. For this number you made the following decision:

[1] Play Option A or get €1 for sure

You chose to play the gamble here. Therefore you play the gamble as described and if you match the colors you get €30, otherwise you get nothing.

Only one number will be drawn, that is, only one of the thirty choices will be played. Make sure that for each choice you make a decision that is in your best interest because this choice might be the payoff relevant choice that determines your payoff!

Please give your desk number here: _____

Please also indicate your gender: female male

Fill out **all 30 choices** on the back now. Then the decision sheets will be collected. One person will be drawn from each group (option A choosers and option B choosers) and we play one randomly selected choice with them.

When we come to collect the sheets, please hand in your decision sheet in the envelope. Leave all other sheets on your desk.

Option A (bet on color from bag with 20 red and 20 green chips to win €30) **or** sure amount of €

[1]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €1 for sure
[2]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €2 for sure
[3]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €3 for sure
[4]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €4 for sure
[5]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €5 for sure
[6]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €6 for sure
[7]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €7 for sure
[8]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €8 for sure
[9]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €9 for sure
[10]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €10 for sure
[11]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €11 for sure
[12]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €12 for sure
[13]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €13 for sure
[14]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €14 for sure
[15]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €15 for sure
[16]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €16 for sure
[17]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €17 for sure
[18]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €18 for sure
[19]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €19 for sure
[20]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €20 for sure
[21]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €21 for sure
[22]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €22 for sure
[23]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €23 for sure
[24]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €24 for sure
[25]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €25 for sure
[26]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €26 for sure
[27]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €27 for sure
[28]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €28 for sure
[29]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €29 for sure
[30]	Play Option A	<input type="radio"/>	or	<input type="radio"/>	get €30 for sure

[Analogously for option B]

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