IS AMBIGUITY AVERSION A PREFERENCE? AMBIGUITY AVERSION WITHOUT ASYMMETRIC INFORMATION

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Abstract   Ambiguity aversion is the interpretation of the experimental finding (Ellsberg paradox) that most subjects prefer betting on events whose probabilities are known (objective) to betting on events whose probabilities are unknown (subjective). However in typical experiments these unknown probabilities are known by others. Thus the typical Ellsberg experiment is a situation of asymmetric information. People may try to avoid situations where they are the less informed party, which is normatively appropriate. We find that eliminating asymmetric information in the Ellsberg experiment while leaving ambiguity in place, makes subjects prefer the ambiguous bet over the objective one, reversing the prior results.

JEL Codes: D81, G11, C91

Keywords: uncertainty aversion, probabilistic sophistication, sources of ambiguity, Ellsberg paradox

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1 Introduction

Ambiguity aversion is frequently used to explain puzzles and promote policies. In this paper we propose an alternative explanation for the empirical evidence on which findings for ambiguity aversion rest. Ambiguity aversion is the interpretation of the experimental finding (Ellsberg paradox) that most subjects violate probabilistic sophistication: They prefer betting on events whose probabilities are known (objective) to betting on events whose probabilities are unknown to them (subjective). The observation that people exhibit the Ellsberg paradox is generally interpreted as a preference of the people. However in typical experiments these unknown probabilities are known and often determined by the experimenter. Thus the typical Ellsberg experiment is a situation of asymmetric information. People may try to avoid situations where they are the less informed party in an asymmetric situation setting. Indeed doing so is often normatively appropriate. Al-Najjar and Weinstein (2009) advanced the theoretical argument that Ellsberg-style choices reflect misplaced heuristics, a mental shortcut where "a difficult question is answered by substituting an answer to an easier one" (Kahneman and Frederick 2002). Our argument and empirical test focuses on asymmetric information present in typical Ellsberg experiments. If the Ellsberg paradox is an unusual, cognitively demanding situation for decision-makers, the situation might be substituted for a more familiar one, that of disadvantageous asymmetric information (the misapplication of a heuristic). In cases of disadvantageous asymmetric information—think of Akerlof's famous market for lemons—it is usually a good idea to avoid trade or to prefer trade in situations without such asymmetric information. This heuristic rule to avoid trade in situations of disadvantageous asymmetric information may be ecologically rational in many real world situations, but it is not in the specific situation of the Ellsberg paradox. Our innovation is to create an experiment that takes away the informational disadvantage subjects have vis-à-vis the experimenter but leaves ambiguity in place.

In the traditional Ellsberg thought experiments, the source of ambiguity is generated by the experimenter: For example, she presents the decision-maker with an urn of 100 balls which are red or black, but the exact composition is unknown to the subjects. But the experimenter knows, or participants may at least suspect the experimenter knows, the true proportion of red and black balls. Thus participants perceive this as a situation of asymmetric information. In the real world it is often a good idea to be careful in situations where you have an informational disadvantage vis-a-vis a potential counterparty, and indeed to avoid binding commitments in such situations altogether. In many situations such avoidance behavior makes strategic sense even for probabilistically sophisticated subjects, as Morris (1997) showed.[1] Thus an experimental finding like the Ellsberg paradox could be due to subjects misunderstanding the situation or misapplying (or correctly applying) the heuristic of avoiding situations of disadvantageous informational asymmetry rather than ambiguity aversion.

One way to attenuate the problem of informational asymmetry is to use a source of ambiguity that, unlike Ellsberg's ambiguous urn, is not generated by the experimenter. Fox and Tversky (1995, study 4) pioneer the experimental use of natural sources of ambiguity using bets on the future temperature in a familiar and an unfamiliar city of similar climate.[2] This cures one problem of the Ellsberg urn, which puts the source of ambiguity outside the control of the experimenter. But this at most slightly reduces the informational advantage of the experimenter: after all, the experimenter had the opportunity to look up historical temperature records prior to the study, and presumably did so to calibrate the questions and payments. This of course is a problem with presumably any natural source of ambiguity: subjects may always believe that the experimenter had the opportunity to invest more time in researching records or estimates of the event to be predicted.

Other experiments also reduce the asymmetry between the experimenter and subject. Hey et al. (2010) use a bingo blower to eliminate suspicion: the bingo blower is a physical

[1]"It is argued that proponents of subjective expected utility have always understood that a 'bid–ask spread' in rational individuals' willingness to bet is consistent with SEU maximization in the presence of private information."

[2]Abdellaoui et al. (2011) is another paper on natural ambiguity.

and transparent device which clearly cannot be manipulated by the experimenter to pick a particular ball. However, the informational asymmetry between the experimenter and the subjects remains. Strategic ambiguity remains since someone (usually the experimenter) must have filled the blower with differently colored balls and knows the true distribution. While subjects can see all the balls in the bingo blower, due to the rapid movement it is impossible to count them (if it were possible, there would be no ambiguity, and only risk). Trautmann and Zeckhauser (2013) give subjects a choice between an objective and ambiguous urn. Subjects fill both urns themselves, once wearing a blindfold, drawing from a box with 50 red and 50 black chips. Technically, this is risk, since there is an objective probability as the chips are countable. Kocher et al. (2015) has a student assistant blindly draw from an opaque bag, and from the instructions, subjects only learn that a student assistant drew the bag. Our design makes it clear that the other subjects are filling the urn, rather than affiliates of the experimenter. Oechssler and Roomets (2015) addressed the concern that subjects believe that they play a game against the experimenter by filling the urn through an irregular Galton box (balls would bounce left and right as they fall down a slope). The box is created by volunteer students hammering nails in it not knowing for what purpose. The total number of balls in the different bags collecting balls below the box would then determine the content of the urn. They find that the majority of subjects were ambiguity averse, and at a similar rate as with strategic ambiguity. One concern is that subjects were explicitly told the objective was to make the content of the bag unpredictable, which may result in subjects avoiding the unpredictable bag, and subtle forms of experimenter demand can affect behavior (Cilliers et al. 2015).

We think that some of the experimental findings could often be interpreted as experimenter demand: A subject is given two options which only differ in their amount of subjective uncertainty but which are equally valuable for anyone satisfying subjective expected utility, so a subject might feel he is expected to choose the option exhibiting less subjective uncertainty. Trautmann et al. (2008) employ a design where the preference of the subject over a pair of DVDs is private information, unknown to the experimenter, so that the experimenter cannot know more about the probability of getting the preferred prize. The instructions emphasized to subjects not to tell their preference to the experimenter, which may heighten the sense of adversarial asymmetric information. Our study removes the asymmetric information and stays within the framework of the classical Ellsberg game.

Taken together our analysis complements the prior research designs. For law and policy, it matters whether ambiguity aversion is a mistake or a consistent preference. Population preferences should be taken into account by policy-makers[3], while mistakes should not. This paper asks the question if economically substantial ambiguity aversion really exists as a preference or is rather due to misapplication of a heuristic. The remainder of the paper is organized as follows. Section 2 presents the Ellsberg Paradox and briefly reviews the literature. Section 3 presents a vignette experiment. Section 4 presents an incentivized experiment. Section 5 concludes.

2 Background

Ambiguity aversion has a long history in the study of individual decision making in psychology and in economics, and has also been the subject of much theoretical modeling in economics (Machina 2014). We briefly reproduce the classic Ellsberg Paradox. An urn is filled with 15 balls. As in Ellsberg (1961) the color of a third of the balls is known to be red. The remaining balls are black or white[4] in unknown combination. We follow Halevy (2007) in setting the number of subjective balls at 10.[5]

Urns

Ellsberg experiment		
5 balls	10 balls	
Red	Black	White
$n_R = 5$	n_B^t	n_W^t

[3] Though arguably not all preferences, see Harsanyi (1982, p.56) arguing that "sadism, ill will, or malice" should not count.

[4] We use white instead of yellow following Machina.

[5] In Ellsberg the number of balls was 90.

- Bet on Red: If a red ball is drawn you get $\$x$, else you get \$0.
- Bet on White: If a white ball is drawn you get $\$x + \varepsilon$ ($\varepsilon > 0$). Else you get \$0.
- Bet on Black: If a black ball is drawn you get $\$x + \varepsilon$. Else you get \$0.

PROPOSITION 1 *A probabilistically sophisticated decision-maker who satisfies first-order stochastic dominance and strict monotonicity in money and satisfies reduction of compound lotteries, strictly prefers "Bet on White" to "Bet on Red" or strictly prefers "Bet on Black" to "Bet on Red".*

PROOF: A probabilistically sophisticated decision maker (DM) has some subjective probability distribution for experiment t, such that $p_R^t = \frac{1}{3}$, $p_W^t + p_B^t = \frac{2}{3}$ (if in addition to probabilistic sophistication she accepts informational symmetry between W and B, then in particular $p_W^t = p_B^t = \frac{1}{3}$). Thus the bets can be written as the following lotteries $\left(\frac{1}{3}; x, \frac{2}{3}; 0\right)$ for red, $\left(p_W^t; x+\varepsilon, \frac{2}{3} - p_W^t; 0\right)$ for white, $\left(p_B^t; x+\varepsilon, \frac{2}{3} - p_B^t; 0\right)$ for black. It is sufficient to show that at least one of "Bet on Black" or "Bet on White" stochastically dominates "Bet on Red". Suppose "Bet on White" does not stochastically dominate "Bet on Red": Then as $\varepsilon > 0$ we must have $p_W^t < \frac{1}{3}$, which in turn implies that $p_B^t > \frac{1}{3}$ meaning that "Bet on Black" stochastically dominates "Bet on Red". *Q.E.D.*

In vignette studies, even after being advised about the Ellsberg paradox, 80% of subjects still exhibit ambiguity aversion (Slovic and Tversky 1974).

Ambiguity aversion has been used to explain many economic puzzles. For example, Erbas and Mirakhor (2007) and Maenhout (2004) attribute part of the equity premium to aversion to ambiguity. Erbas and Mirakhor (2007) write a "large part of equity premium may reflect investor aversion to ambiguities resulting from institutional weaknesses." Epstein and Schneider (2008) explain volatility in stock markets with ambiguity-averse investors who process news of uncertain quality and act as if they take a worst-case assessment of quality. As a result, they react more strongly to bad news than to good news. DeLong and Magin (2009) caution: "A bias-based psychological explanation must account not just for the bias, but for the failure of investors to deal with their biases the way that Ulysses dealt with the Sirens–by building institutions that tie themselves to the mast. That issue remains largely unanswered."

In legal applications, Talley (2009) finds that contract provisions in corporate acquisitions are consistent with ambiguity aversion. For incomplete contracts, Mukerji (1998) model an ambiguity-averse decision maker who adjusts his choice on the side of caution in response to his imprecise knowledge of the odds, and evaluates an act by the minimum expected value that may be associated with contract clauses. Ghirardato et al. (2000) explain selective abstention in elections, where ambiguity aversion about the candidates' policy positions can make abstention look to the voter a smaller "mistake" than voting for one of the candidates. Baliga et al. (2013) uses ambiguity aversion to explain polarization of beliefs even when individuals are interpreting identical information.

Ambiguity aversion has also been used to promote policies. Segal and Stein (2005) contend that defendants are more ambiguity averse than prosecutors, so the criminal process systematically results in defendants forced into harsh plea bargains. Viscusi and Zeckhauser (2006) argue that policymakers should collect data on ambiguity aversion to address risks surrounding environmental protection and medical malpractice. Lawsky (2013) proposes tax reforms that account for an ambiguity averse decision-maker who does not know the probability of audits. Farnsworth et al. (2010) discuss ambiguity of legal text, which can potentially be modeled with ambiguity aversion.

Besides Al-Najjar and Weinstein (2009)'s theoretical critique of findings of ambiguity aversion as possibly the result of mental heuristics, another recent theoretical and empirical contribution is Halevy (2007), which argues that aversion to compound lotteries goes a long way towards explaining aversion towards genuine ambiguity. He finds that a substantial fraction of subjects are ambiguity neutral and reduce compound lotteries, but that those who are not ambiguity neutral almost always fail to reduce compound lotteries; ambiguity reduces the willingness to pay by about the same amount as just introducing a compound lottery with the same resulting probabilities as the original objective urn.

Other evidence in Fox and Tversky (1995) indicate that ambiguity aversion basically disappears in noncomparative contexts, where ambiguous prospects are evaluated in isolation, and not in comparison to prospects with known probabilities. Chow and Sarin (2002) conduct a non-incentivized study using three types of urns, a standard objective one, an Ellsberg type one, and one where the there is an objective probability in a second order type. Whenever they elicit just the valuation of one urn they find no difference in willingness to pay across these types of urns. Their finding is in line with differences emerging only when subjects are presented with objective and subjective problems at the same time. This study also have subjects draw candy from a bag of M&M's, but the comparison was still across subjects rather than within subjects. Fox and Tversky (1995) argue that "comparative ignorance" seems to account for ambiguity aversion to a large extent. Their hypothesis is that ambiguity aversion results from comparisons with either other agents who have more information, or with acts that have less subjective uncertainty. Since developments in economic theory appear to ignore the challenge that ambiguity aversion disappears in noncomparative contexts, we keep close to the original experiment to more directly confront the evidence on which the theory is built.

3 Vignette Experiment

We propose a new thought experiment to contrast with the original Ellsberg thought experiment and the compound lottery analog, and then proceed to employ it in the laboratory in different variations. The central innovation is that fellow participants, rather than the experimenter, choose the contents of the ambiguous urn, and do so while remaining in a situation of ambiguity rather than risk. In our experiment, each subject gets an individual ambiguous urn. Each subject gets to co-determine the contents of the ambiguous urns of all the other participants.

3.1 Majority determines outcome An even number N of participants is invited to a laboratory session. There are two sources of uncertainty, an objective one and an ambiguous one. The objective source is a standard fair coin whose draw is determined by a computer. Then for each participant there is an ambiguous coin. Each participant chooses to send one of two symbols to the ambiguous source of the other participants. That choice has no consequence for the payoff of the sender herself. The ambiguous coin of participant i is defined to fall on symbol A if the majority of the other participants (of which there are an odd number) choose A than B, else it is defined to fall on B. In other words, the symbol is "drawn" from the ambiguous urn based on majority rule. Since A and B have a natural order, and participants might always send A, we use different symbol pairs for which no such natural order exists.

In addition to sending a symbol to the ambiguous coin of the other participants, which is a non-incentivized task, each participant also chooses one of four bets. The participant can bet on heads or tails (i.e., bet on something objective) or bet on symbol A or symbol B (i.e., bet on something ambiguous). If the participant wins the bet, she receives EUR4. The way participants choose the bet is by stating their valuation for each of the four possible bets. They then receive the bet with the highest stated valuation for free. The original instructions in German are in Appendix A and the English translation in Appendix B. On a single screen, people see the instructions, and make a choice about the symbol to send and the bet to choose. E.g., send a symbol (for you personally irrelevant, order randomized). Then, subjects were asked how much is each bet worth and told that they would receive the one they value most.

Each of an even number N of participants, chooses one of two options, either "heart" or "smiley." This generates a metaphorical and subjective coin for each participant: For participant i, the metaphorical coin is defined to fall on "heart" if more than half of the other participants choose "heart" than "smiley," else it is defined to fall on "smiley."

It is important to note that in the design, we randomly vary the order in which the bets are mentioned and presented (participants are made aware of this), such that using what is mentioned first as a focal point is prevented. People are explicitly told that symbol order is randomized.

Probabilistically sophisticated subjects have a single belief about the probabilities. If that belief happens to be 50%, then a subject is indifferent between all four bets offered. Otherwise, there exists a symbol such that the subject strictly prefers betting on that symbol to betting on heads or tails. In the experimental design, moreover, we allow participants to express indifference, and also ask them for their (non-incentivized) valuation of each lottery, as shown in Appendix Figure A.1.

3.2 Results We ran experiments in Zurich using oTree (Chen et al. 2016). We conducted a total of 16 experimental sessions with 418 participants. In the 16 sessions, 11 distinct symbols pairs were used, of these 11 pairs, 3 pairs (heart vs. smiley, down-left vs. down-right angle) were used in two sessions and 1 pair (large vs. small circle) was used in three sessions. We discuss the results using the first session of the pair that was used in three sessions. The symbols used here were a large empty circle, and a small full circle, and are shown in the appendix. Thus focal features of what one "should" use conflict here, choosing the larger object vs. choosing something that is full rather than empty. Recall that in any case, participants have no monetary incentive whatsoever in their own choice of symbol (to send to others), as it is payoff irrelevant for them. Figure 1 consists of four sub-panels, and we will explain it in detail here. Analogous figures for each of the other 15 sessions are in Appendix C. First, as shown in the legend of the figure, the blue colors always correspond to objective uncertainty (dark blue to heads; light blue to tails), while the red colors correspond to the subjective uncertainty.

The subpanel on the top left gives the symbol choices of the participants. The symbol choice has no effect for a participant herself, just for those of the other participants who chose to bet on the subjective source of uncertainty. In this session of the 28 subjects, 13 chose the large empty circle, and 15 chose the small full circle. The subpanel on the bottom left represents an attempt to gauge what probabilities of a symbol winning a rational actor would estimate. For the objective source of uncertainty, the probability of head and tail is

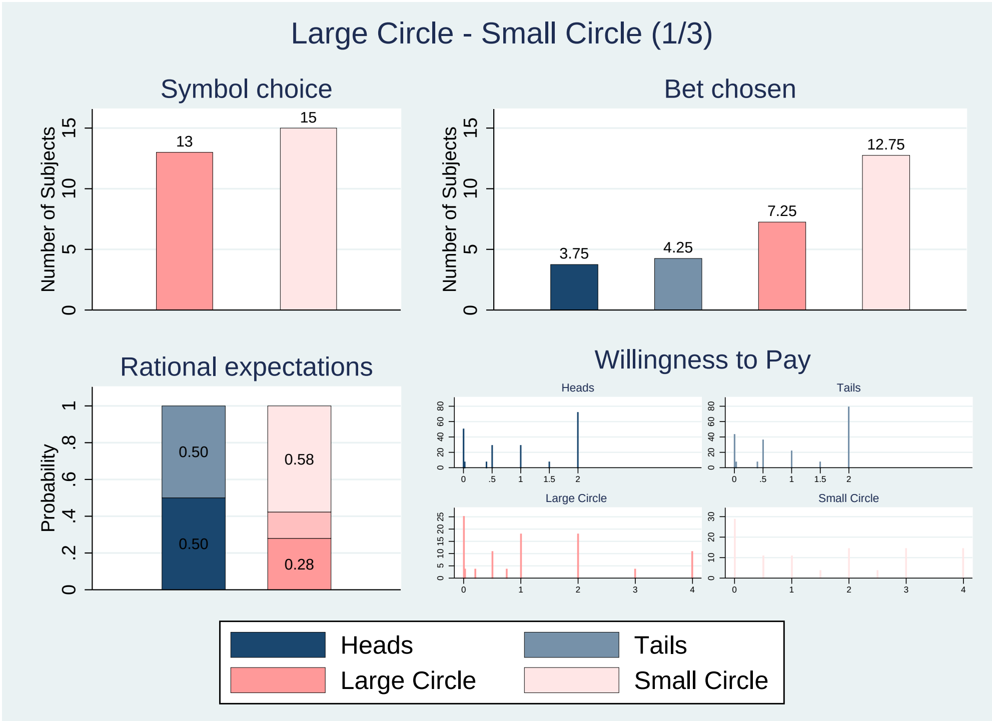
50% each and shown in the left bar. This of course is constant across all sessions.

For the subjective source of uncertainty, the question of what probability to estimate is somewhat trickier. We chose all symbol pairs such that we thought the symbols are interchangeable, and our prior of any symbol in a pair being chosen by a majority of the participants was 50%. Thus, when interpreting the data this should be kept in mind. The second bar in the subpanel of the bottom left imagines a participant who almost clairvoyantly knows what fraction of people chose each symbol. So in this session, for example, consider one of the 15 participants who thinks that the probability that another participant chooses large circle is $\frac{13}{27}$.[6] From her perspective, the probability that the majority of participants chose small circle can be calculated using the cumulative binomial distribution where $n = 27$ and $p = \frac{13}{27}$ evaluated at 13, which is rounded in the figure to 58% (the 28% is what a participant, who chose a large empty circle, would estimate).

The top right subpanel shows which bets participants chose. In our design, this choice was done by indicating a willingness to pay for each of the four possible bets. A participant got the bet for which she indicated the top willingness to pay. Thus, participants were permitted to indicate indifference between choices, and in the figure, if a participant had multiple top choices, the corresponding fractions are assigned to each option. In this figure, both subjective acts are more popular than both objective acts. In the bottom right panel, the histograms of the willingness to pay data are given. Note that other than that, a player would get the option for which she indicated the highest willingness to pay, this was not incentivized. Still, in vignette studies, even after being advised about the Ellsberg paradox, 80% of subjects still exhibit ambiguity aversion (Slovic and Tversky 1974).

[6] The other 13 participants would think the probability another participant chooses large circle is $\frac{12}{27}$.

Figure 1: Results from 1 of 16 Sessions



Overall, across all the sessions, the subjective acts were more popular than the objective ones, contrary to what one would expect under ambiguity aversion. For each of the 16 sessions, individuals were more likely to bet on a symbol with subjective uncertainty, and in all but 2 of the 16 sessions, both bets with subjective uncertainty were more popular than the bets with objective uncertainty, as illustrated in Figure 1.

3.3 Regression analyses The following table presents analyses of the bet choice. The regression variables are: (i) Choosing A, which is a dummy indicator for whether that player put symbol A in other participants' urns (we arbitrarily labeled a particular symbol as "A"); (ii) Risk aversion, a measure of risk aversion; (iii) P(A wins), a binomial probability that symbol A wins (i.e., the probability that symbol A was chosen by the majority of other players); (iv) P(A)>.5, a dummy indicator for whether P(A wins) is larger than 0.5; (v) an interaction of the last two variables.

Several results emerge. First, risk aversion is not significantly correlated with the choice

TABLE I

WITH PROB_A (BINOMIAL)

	Tails	Symbol A	Symbol B
Choosing A (d)	-0.00597	0.484***	-0.462***
	(0.0310)	(0.0440)	(0.0448)
Risk aversion	0.00184	-0.00910	-0.00480
	(0.00607)	(0.00961)	(0.00959)
P(A wins)	0.320	-0.0676	-0.255
	(0.187)	(0.305)	(0.270)
P(A wins) x P(A)>.5	-0.512*	0.308	-0.172
	(0.250)	(0.420)	(0.406)
P(A)>.5 (d)	0.238	-0.139	0.186
	(0.174)	(0.252)	(0.250)
Observations	416	416	416
Xmfx_y	0.122	0.371	0.364

Marginal effects; Standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

of the objective bet. Second, subjects often bet on the symbol that they put in others' urn. Third, the true probability of the symbol winning was not significantly correlated with subjects preferring to bet on that symbol.

4 Revealed Preference Experiment

4.1 Participant-generated Ellsberg urn Section 3 presented a design where a metaphorical coin fell on "heart" or "smiley" depending on which symbol the majority of the participants chose. This section has the ball drawn from an opaque urn with the exact composition of balls unknown, only the total number known. The latter design is as close as possible to the original Ellsberg-urn—with the composition determined not by the experimenter, but by subjects who fill the virtual urn of symbols for the other subjects in the experiment. In addition, in the previous section, subjects reported which bet was most valuable to them, but this choice was not incentivized. Still, to the extent subjects would just pick randomly when indifferent, we should have observed an even distribution of preferred choices, but we observed the subjective bets were preferred over the objective bets. This section incentivizes the bet.

Each subject again choose one of four acts: two objective acts and two subjective acts. The two purely objective acts are ones where a subject gets EUR4, if and only if, she correctly predicts the outcome of a fair coin. The outcome of the coin flip is publicly announced and subjects can choose which side of the coin to bet on, so the experimenter cannot ex-post somehow let the coin land on the opposite side of what the subject chose. The two subjective acts are bets on drawings from a participant-generated urn. The contents of this virtual urn is determined by what symbol the other subjects chose. For participant i, her subjective Ellsberg urn has $N-1$ balls in it, one for each participant, labeled smiley or heart according to the choices made by the other participants. One ball is drawn from that urn. The participant learns of the result of the ball drawn and the composition of her Ellsberg urn at the same time. Instructions and Nash equilibria in pure strategies are in Appendix D.

It is worth noting a subtle difference with the participant-generated urn rather than the majority determines outcome design, which is that instead of counting the majority of symbols sent (as the outcome of a virtual coin flip), one draws from a virtual urn *containing* these symbols.

4.2 Results The results of this experiment are also presented in visual and regression form. In the main text, we present the figure for one session. Analogous figures for each of the other 4 sessions are in Appendix E. First, as shown in the legend of the figure, the blue colors always correspond to objective uncertainty (dark blue to heads; light blue to tails), while the red colors correspond to the subjective uncertainty.

The subpanel on the top left gives the symbol choices of the participants. The symbol choice has no effect for a participant herself, just for those of the other participants who chose to bet on the subjective source of uncertainty. In this session of the 30 subjects, 40% chose the down-left arrow, and 60% chose the down-right arrow. The subpanel on the bottom left represents an attempt to gauge what probabilities of a symbol winning a rational actor would estimate. For the objective source of uncertainty, the probability of head and tail is 50% each and shown in the left bar. This of course is constant across all sessions.

For the subjective source of uncertainty, we chose all symbol pairs that in Section 3 were indicated by subjects as close to interchangeable. The second bar in the subpanel of the bottom left imagines a participant who almost clairvoyantly knows what fraction of people chose each symbol. The top right subpanel shows which bets participants chose. In our design, this choice was done by indicating one of four possible bets. In the bottom right panel, the histograms of the beliefs about the content of the ambiguous urn are given. Note that this was not incentivized. Overall, in this design, subjective acts were again more popular than the objective ones, contrary to what one would expect under ambiguity aversion.

Figure 2: Down-Left vs. Down-Right Arrow

4.3 Regression analyses This table presents analyses of choosing to bet on the ambiguous urn. The regression variables are: (i) Beliefs about the content of the ambiguous urn. This is the perceived % of participants who sent the symbol bet on, i.e., for participants who bet on A, the belief is the % of participants believed to have chosen A, and for participants who bet on B, the % of people believed to have chosen B. For participants who bet on the objective urn, the belief is the larger % of the two; (ii) Sending A, dummy indicator for whether that player put symbol A in other participants' urns; (iii) Betting on A, also a dummy indicator; (iv) objective urn displayed first, a dummy indicator; (v) choice A displayed first, another dummy indicator.

Not surprisingly, people bet on the symbol in the ambiguous urn that they believed to be more prevalent.[7] In addition, there is no significant impact of displaying the objective urn first

[7]However, this belief elicitation was not incentivized and was asked after making the bet, so cognitive

TABLE II

CHOOSING OBJECTIVE (0) VS SUBJECTIVE URN (1) - PROBIT MODEL

Belief [%]	0.0365***	0.0356***	0.0394***	0.0385***
	(0.00827)	(0.00811)	(0.00843)	(0.00828)
Sending A	0.00911	0.0363	0.0460	0.0730
	(0.253)	(0.249)	(0.259)	(0.255)
Betting on A	0.225	0.218	0.410	0.409
	(0.262)	(0.259)	(0.280)	(0.278)
Objective urn displayed first			0.151	0.130
			(0.227)	(0.225)
Choice A displayed first			-0.546*	-0.542*
			(0.244)	(0.243)
Symbol pairs FE	Yes	No	Yes	No

Marginal effects; Standard errors in parentheses

(d) for discrete change of dummy variable from 0 to 1

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

(and the coefficient has opposite sign than one would expect under an anchoring hypothesis). For some reason, displaying A first lowers the probability of choosing the ambiguous urn. But, choosing or sending A has no significant impact on choosing the ambiguous urn. Finally, the results are robust to controlling for fixed effects for symbol pairs.

5 Conclusion

Ambiguity aversion is an active area of research. It has been applied to explain puzzles and suggest policies. A key question is whether ambiguity aversion is a preference or a misapplication of a heuristic. This paper asks if economically substantial ambiguity aversion really exists as a preference. In our laboratory experiment, fundamental uncertainty is generated by participants rather than the experimenter. Asymmetric information is eliminated. The experimenter does not know and no single other subject knows the true probabilities. Our results indicate that very few people, if any, are ambiguity averse to an economically meaningful extent. Future research may explore if unlearning the wrong heuristic predicts changing behavior, for example, by becoming more likely to choose the ambiguous urn over

dissonance may drive subjects to increase their perceived prevalence of the symbol they bet on.

time.

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Web Appendix For Online Publication

A Original Instructions in German

Spiel mit zwei Münzen

In diesem Experiment können Sie auf den Ausgang von zwei Münzwürfen wetten. Diese unterscheiden sich in ihrer Art der Durchführung wie folgt:

Die 1. Münze ist eine **Geldmünze** und hat die Seiten **Kopf** und **Zahl**. Auf welche der beiden Seiten sie fällt wird per Zufall vom Computer entschieden, wobei Kopf und Zahl gleichwahrscheinlich sind.

Die 2. Münze ist eine **Symbolmünze** und fällt entweder auf ⓫ oder ⑪. Auf welche der beiden Seiten sie fällt wird wie folgt bestimmt: Zunächst wählt jeder Teilnehmer des Experimentes entweder ⓫ oder ⑪. Anschliessend fällt die Münze bei diesem virtuellen Münzwurf auf die Seite, die von den meisten Teilnehmern gewählt wurde, Sie ausgeschlossen. Somit fällt die Symbolmünze entweder auf ⓫, falls von den anderen Teilnehmern, also allen außer Ihnen, **mehr** ⓫ **als** ⑪ gewählt haben, oder auf ⑪, falls von den anderen Teilnehmern **mehr** ⑪ **als** ⓫ wählen. Die Teilnehmerzahl bei diesem Experiment ist eine gerade Zahl. Da Ihre Wahl bei der Entscheidung des zweiten Münzwurfs ausgenommen wird, entscheidet eine ungerade Anzahl von Teilnehmern über den Ausgang des Wurfs.

Auch fallen beide Münzen immer auf eine ihrer beiden Seiten und können **nicht** auf dem Rand liegen bleiben.

Wählen Sie nun zunächst ⓫ oder ⑪. Diese Wahl ist für Sie persönlich irrelevant, beeinflusst aber ob die Symbolmünzen der anderen Teilnehmer auf ⓫ oder ⑪ fallen.

Bitte wählen Sie eines der beiden Symbole

○ ⓫
○ ⑪

Bitte betrachten Sie als nächstes die folgenden vier **unterschiedlichen** Lotterien. Diese, und damit Ihre möglichen Auszahlungen, hängen vom **Ergebnis des Wurfs der Geldmünze sowie der Symbolmünze, d.h. den Entscheidungen der anderen Teilnehmer**, ab. Geben Sie für jede Lotterie an, wie viel diese Ihrer Meinung nach wert ist. Mit anderen Worten, wenn Sie die Lotterie kaufen könnten, wie viel würden Sie für die jeweilige Lotterie maximal bezahlen? Bitte geben Sie einen Betrag zwischen 0 und 400 Cents ein und verwenden Sie dabei keine Währungssymbole. Sie müssen diese Lotterie aber nicht kaufen, da Sie im nächsten Schritt die Lotterie, welche Ihnen am meisten wert ist, gratis erhalten (falls Ihnen zwei oder mehr Lotterien am meisten wert sind entscheidet die Reihenfolge in der diese unten aufgelistet sind).

Sobald alle Teilnehmer des Experiments wie Sie ihre Entscheidung für ⓫ und ⑪ getätigt sowie ihre Bewertungen für die verschiedenen Lotterien abgegeben haben, geht es wie folgt weiter: Der Computer ermittelt die Ergebnisse der zwei Münzwürfe, den für die **Geldmünze** für alle Teilnehmer gemeinsam, den für die **Symbolmünze** für jeden individuell. Abhängig von der Kombination der beiden Würfe gewinnen Sie persönlich dann entsprechend entweder 400 Cents oder eben nicht.

Während alles in diesem Experiment anonym durchgeführt wird gibts es folgende Ausnahme: auf dem nächsten Bildschirm wird Ihnen und allen anderen Teilnehmern die Entscheidungen aller Teilnehmer bezüglich ⓫ oder ⑪ anzeigen. Die Teilnehmer werden hierbei durch Ihre Sitzplatznummer identifiziert werden.

Option 1	**Kopf**	**Zahl**
⓫	**EUR 0**	**EUR 4**
⑪	**EUR 0**	**EUR 4**

Wie viel ist Ihnen Lotterie 1 wert? (In Cent)

Option 2	**Kopf**	**Zahl**
⓫	**EUR 4**	**EUR 0**
⑪	**EUR 4**	**EUR 0**

Wie viel ist Ihnen Lotterie 2 wert? (In Cent)

Option 3	**Kopf**	**Zahl**
⓫	**EUR 0**	**EUR 0**
⑪	**EUR 4**	**EUR 4**

Wie viel ist Ihnen Lotterie 3 wert? (In Cent)

Option 4	**Kopf**	**Zahl**
⓫	**EUR 4**	**EUR 4**
⑪	**EUR 0**	**EUR 0**

Wie viel ist Ihnen Lotterie 4 wert? (In Cent)

Weiter

Appendix Figure A.1: Instructions, Send Symbol, Choose Act

B English Translation of Instructions

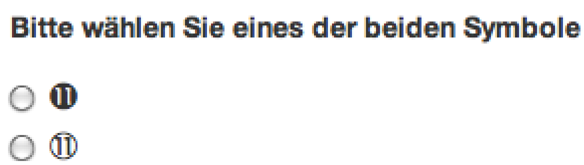
In this experiment you can bet on the result of two coin throws. The two coin throws differ as follows:

Coin 1 is a standard coin with Heads and Tails. It is thrown randomly by the computer, Heads and Tails are equally likely. Coin 2 is a symbol coin, and falls either on side A or side B. On which side it falls is decided as follows: First, each participant in this session chooses either A or B. Then the coin in this metaphorical coin throw falls on the side chosen by the majority of participants, excluding you. Thus the symbol coin falls on A, if among the other participants, that is all participants except you, more chose A than B; otherwise it falls on B, if among the other participants more participants choose B than A. In this session, there is an even number of participants. As your choice is excluded for the coin throw, an odd number of participants decides the result of the throw. Both coins fall on one side, it is impossible that a coin lands on its edge.

Now please first choose A or B. This choice is irrelevant for you personally, but influences whether the symbol coins of the other participants land on A or B. Please choose one of the following symbols

[radio buttons for choice of A or B].

Appendix Figure A.2: Please choose one of the two symbols



Now please consider the following four different bets. These, and thus your possible earnings, depend on the throw of the standard coin and the symbol coin, that is the choices of the other participants. Please specify for each bet what you think its value is. In other words, if you could buy the bet, how much would you maximally pay for it? Please enter a value between 0 and 400 Cents without entering a currency symbol. You are not buying these bet, instead you will receive the bet for which you indicated the highest value, for free (if you assign the same highest value to two or more bets, the bet which is listed first below is what you will get). As soon as all participants have made their choice for A or B, and have given her valuation for the different bets, the session continues as follows: The computer generates the coin throws, a single coin throw for all participants for the standard coin, and for the symbol coin for each participant individually. Depending on the combination of the two throws then you personally either win 400 Cents or nothing. While everything in the experiment is anonymous, there is one exception. On the next screen, we will show you and all other participants the choices regarding the symbols. The participants will be identified by their seat number.

[4 bets displayed in tables].

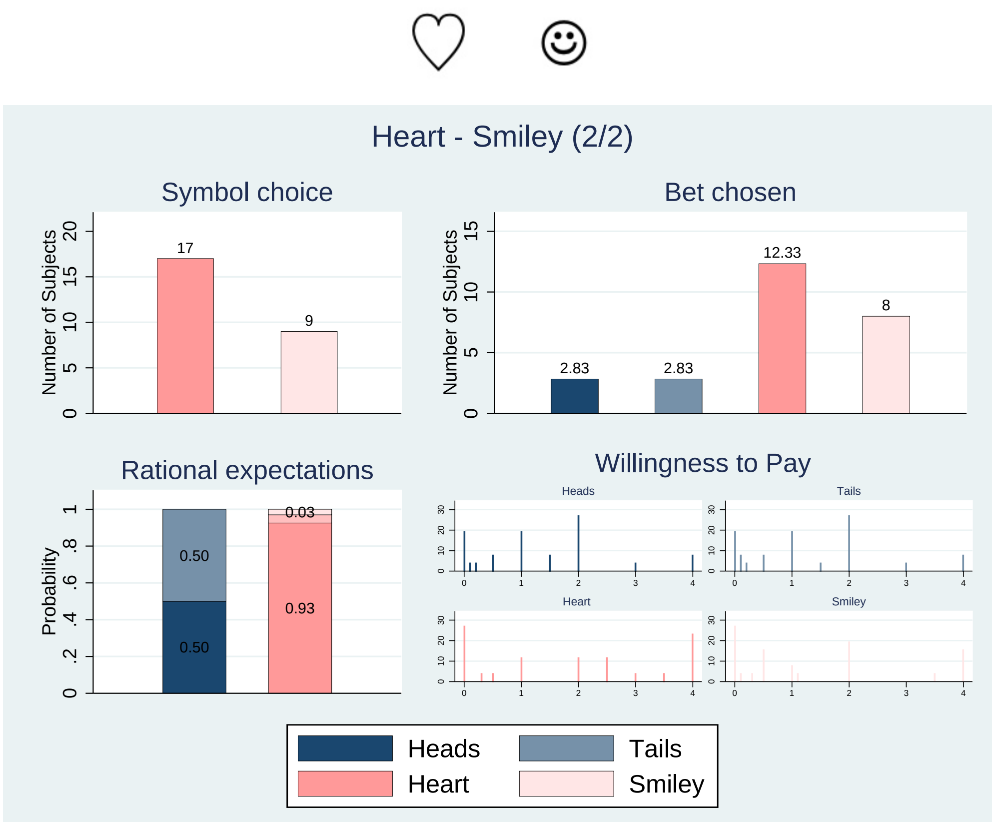
Appendix Figure A.3: How much is this lottery worth?

Option 1	**Kopf**	**Zahl**
⓫	**EUR 0**	**EUR 4**
⑪	**EUR 0**	**EUR 4**

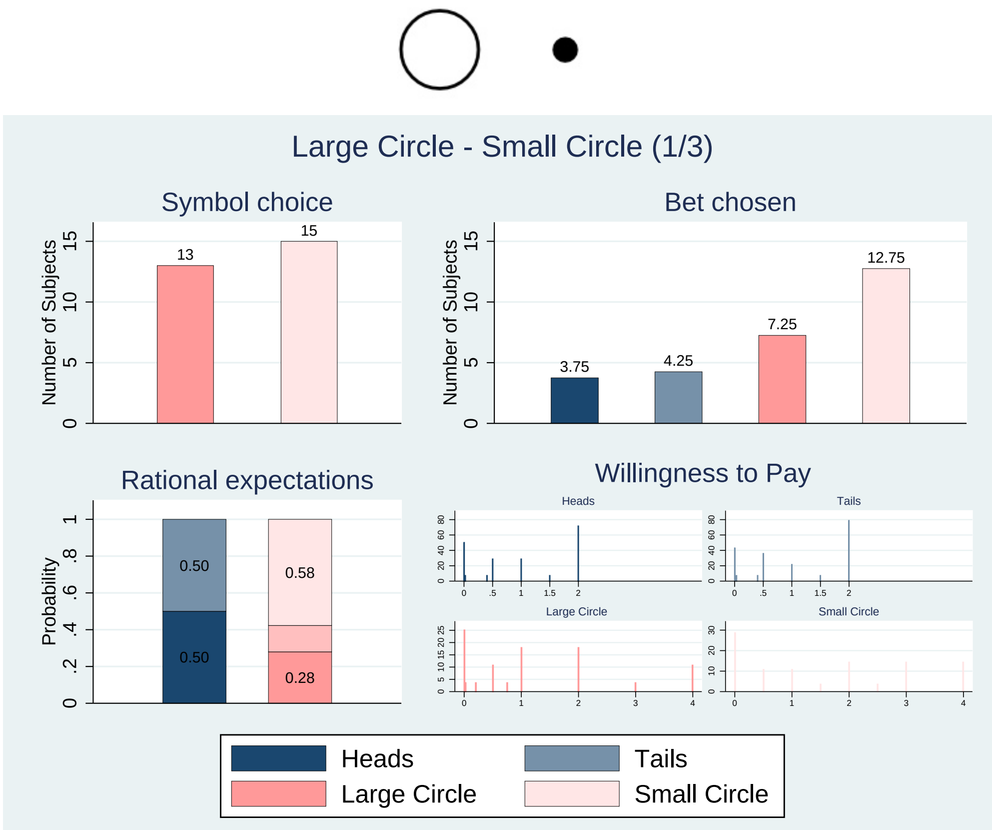
Wie viel ist Ihnen Lotterie 1 wert? (In Cent)

C Results from Majority Determines Outcome Design

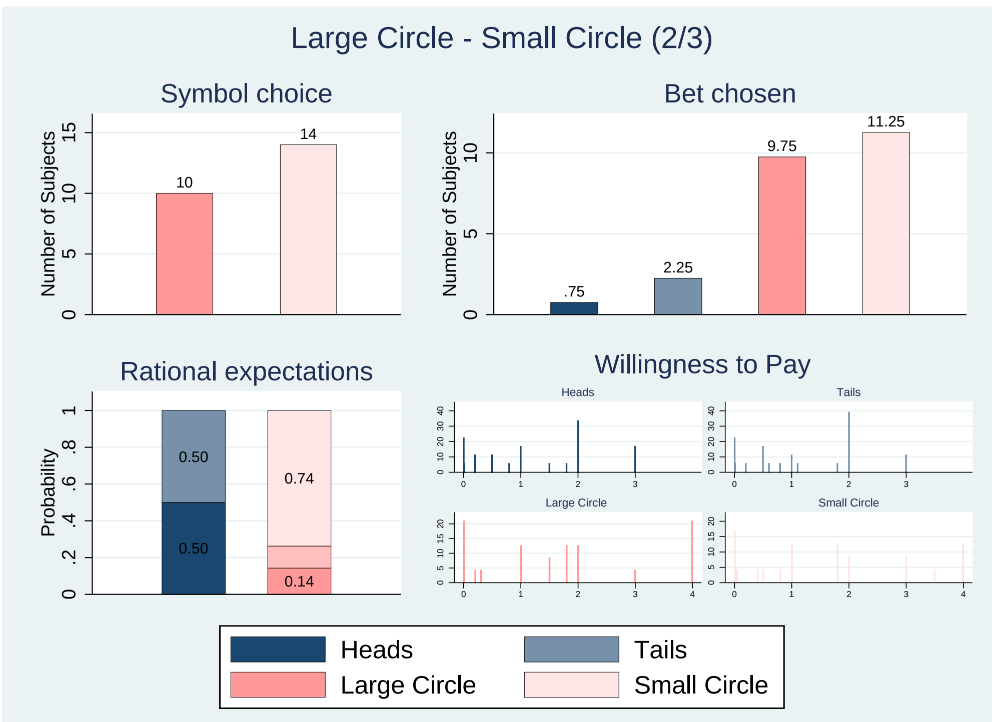
Appendix Figure C.1: Heart vs. Smiley (1/2)



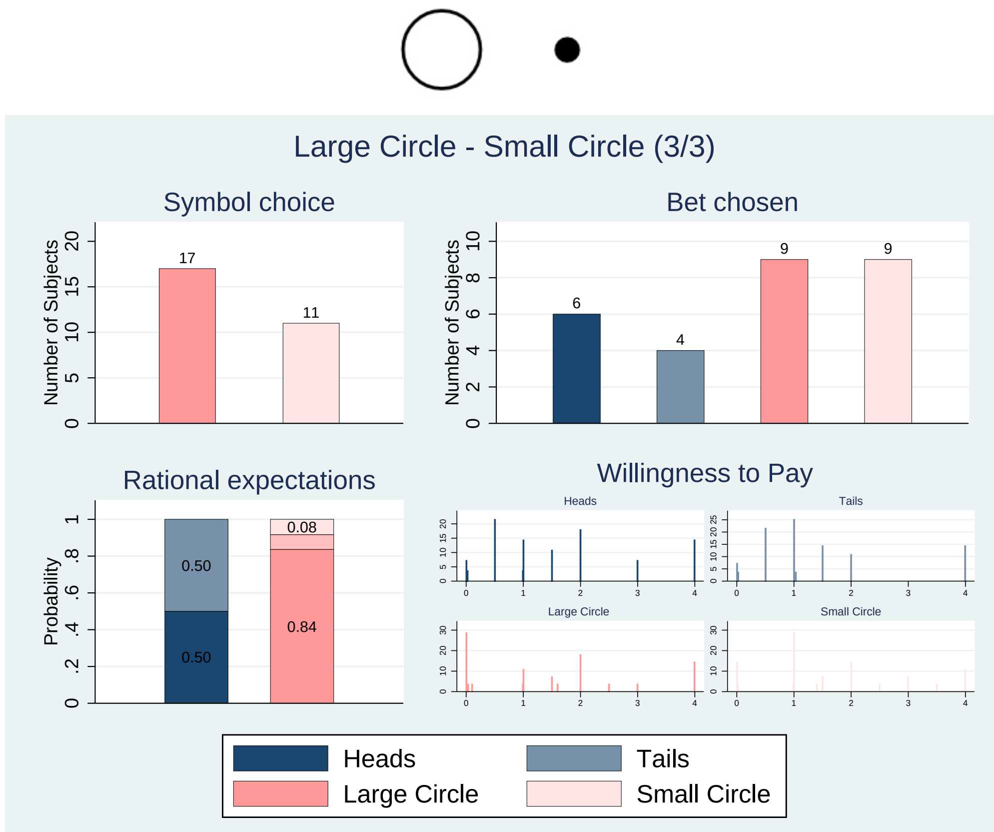
Appendix Figure C.2: Heart vs. Smiley (2/2)



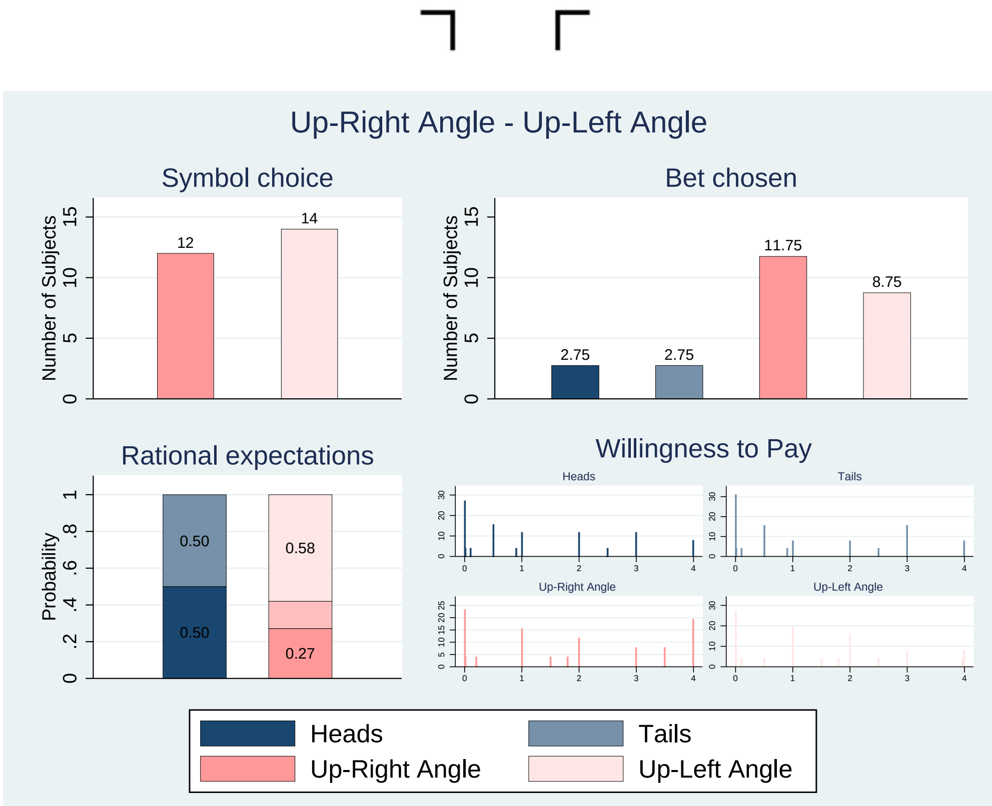
Appendix Figure C.3: Large vs. Small Circle (1/3)



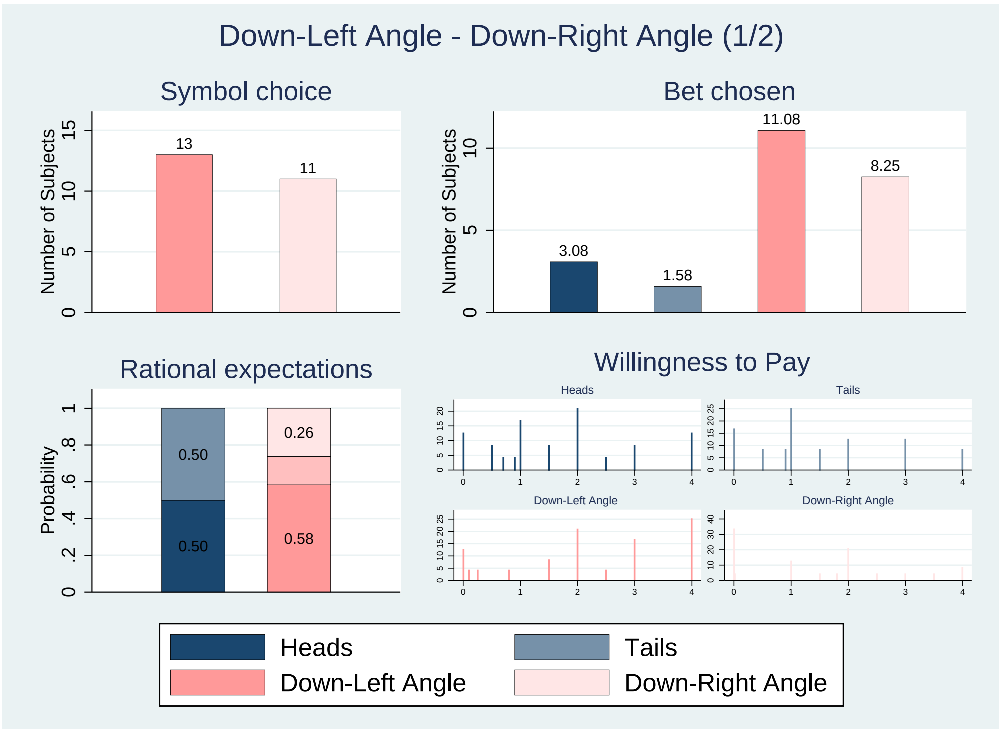
Appendix Figure C.4: Large vs. Small Circle (2/3)



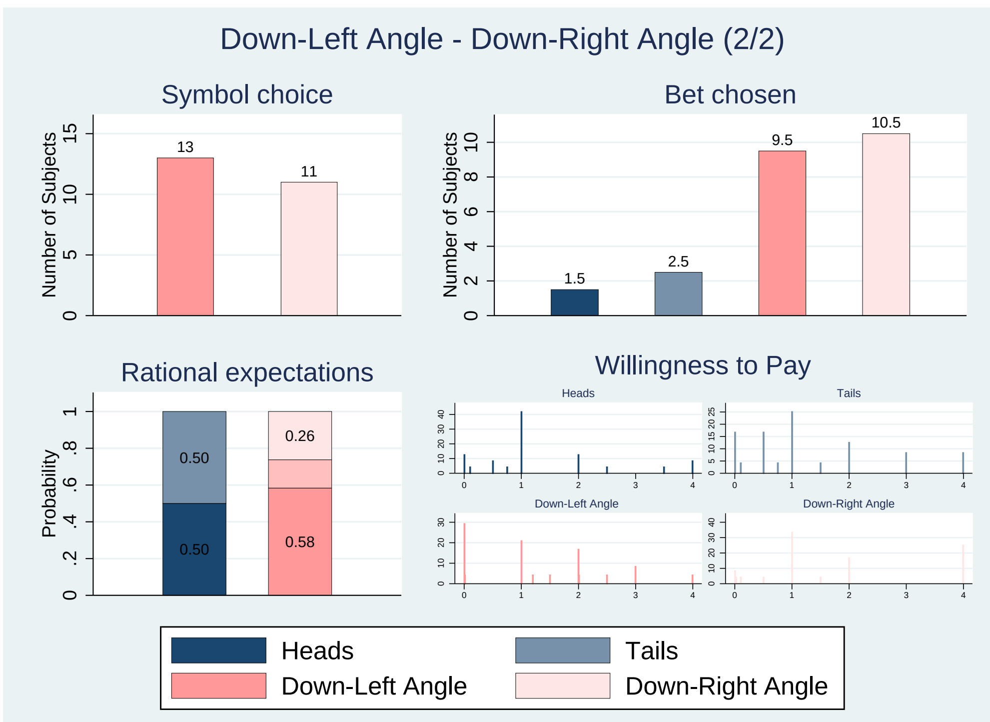
Appendix Figure C.5: Large vs. Small Circle (3/3)



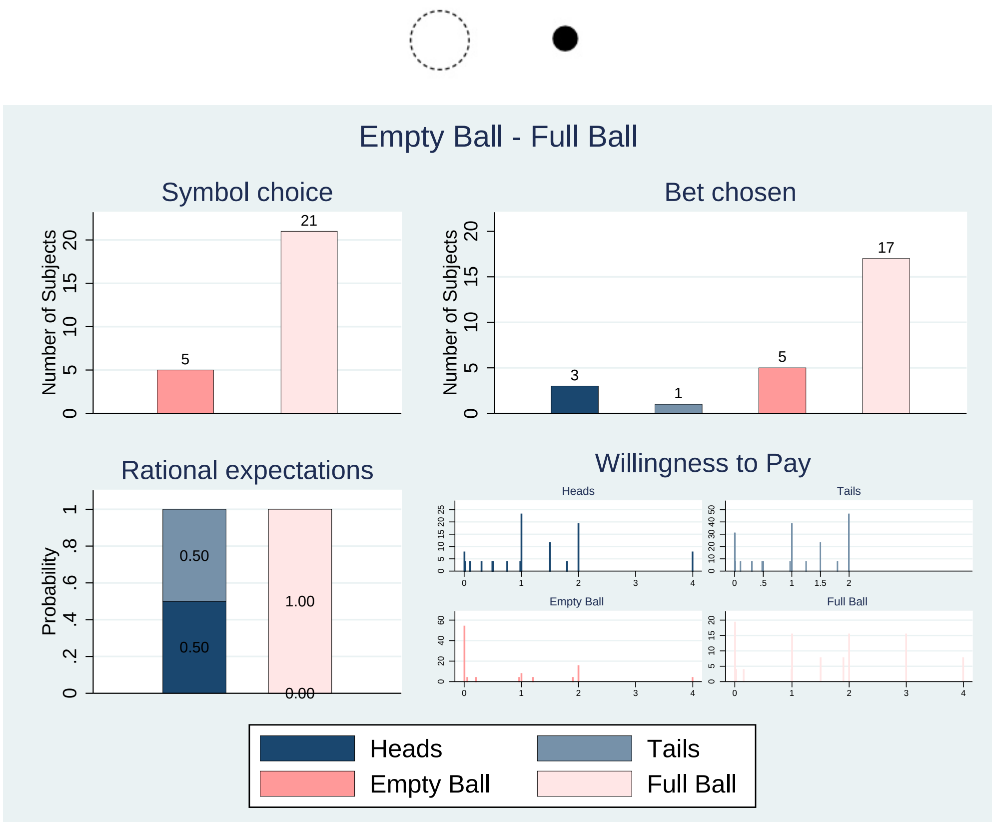
Appendix Figure C.6: Up-Right vs. Up-Left Angle



Appendix Figure C.7: Down-Left vs. Down-Right Angle (1/2)

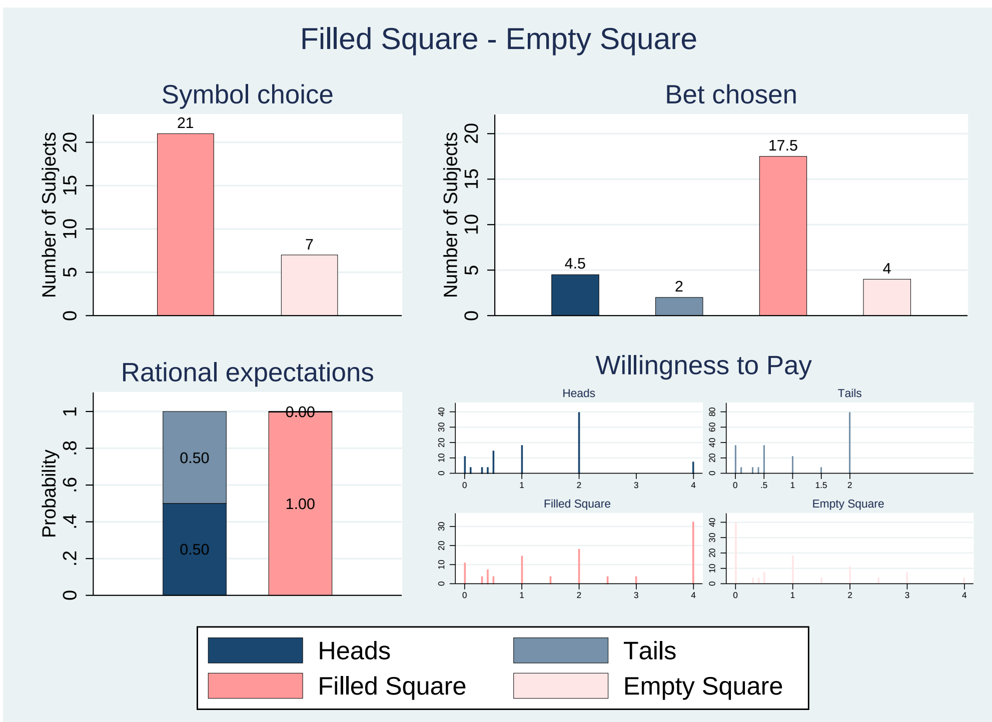


Appendix Figure C.8: Down-Left vs. Down-Right Angle (2/2)

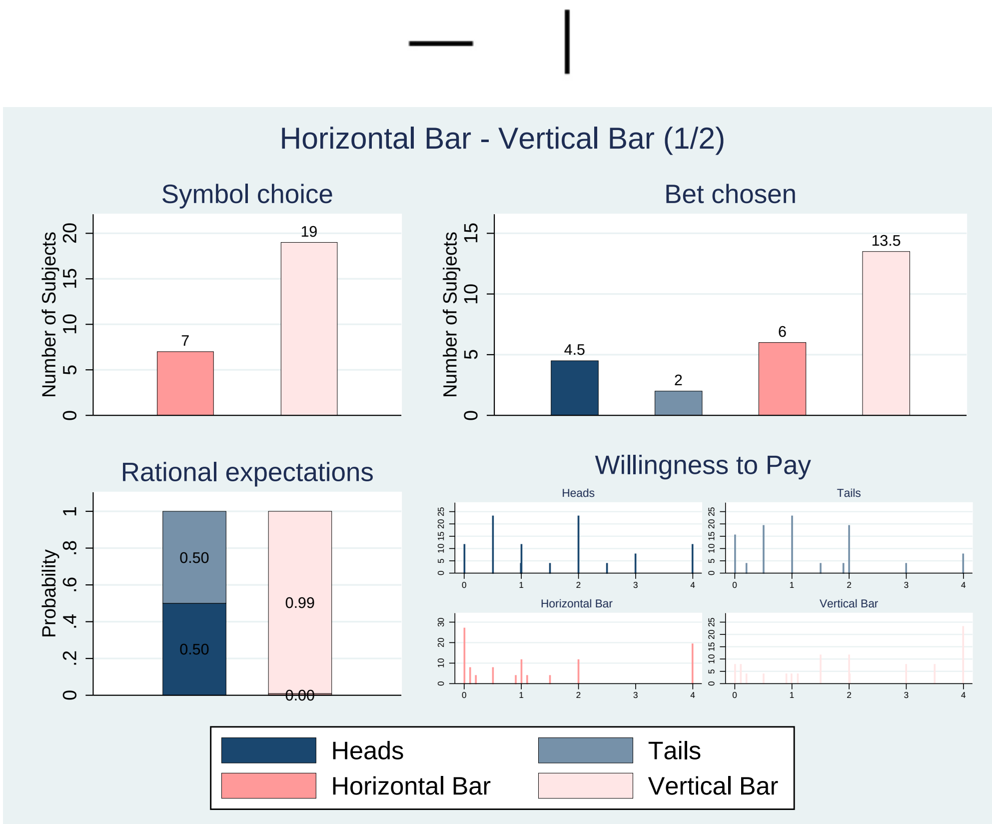


Appendix Figure C.9: Empty vs. Full ball

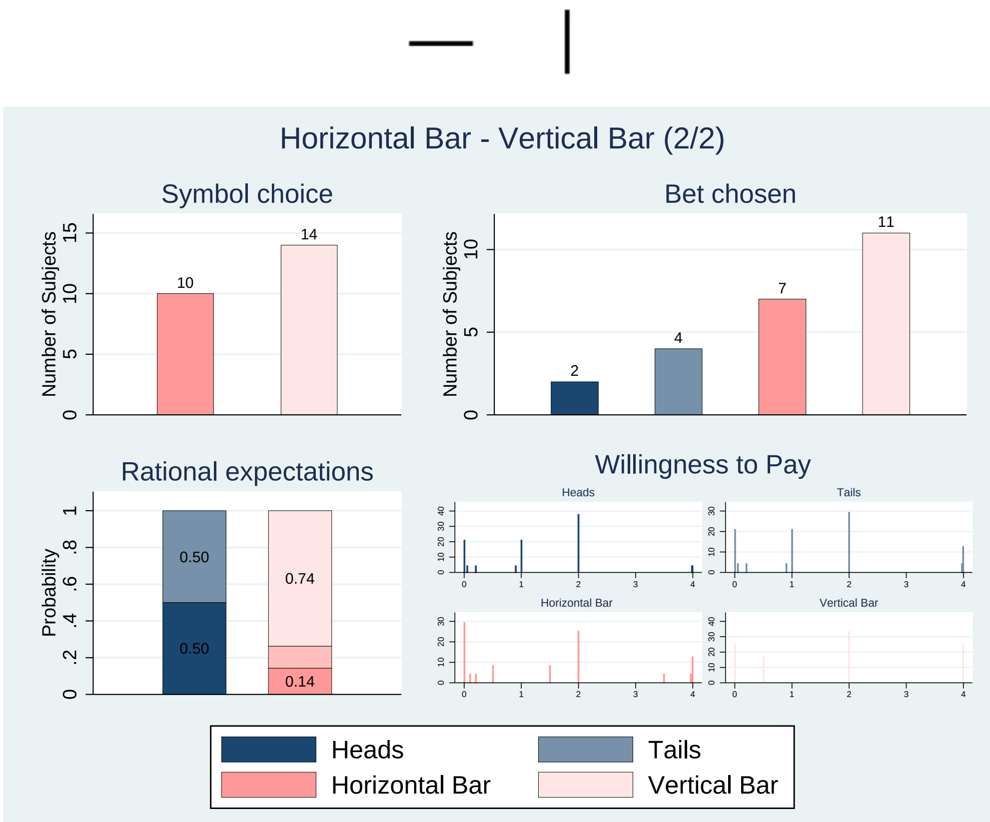
■ □



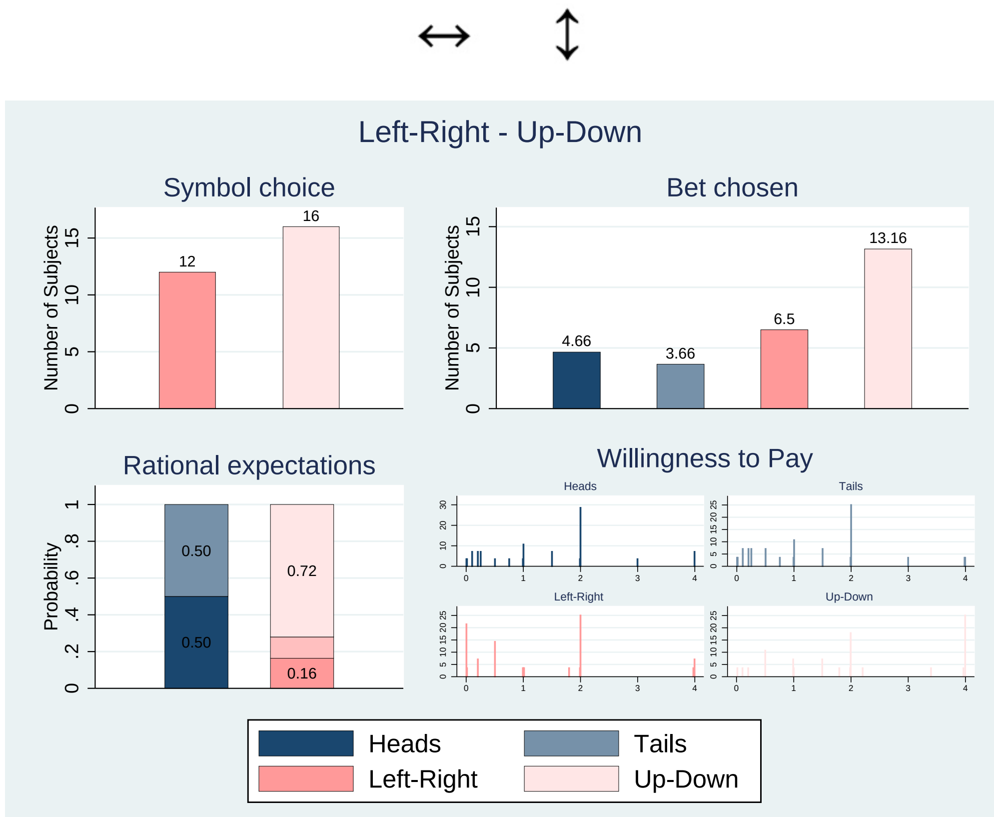
Appendix Figure C.10: Filled Square vs. Empty Square



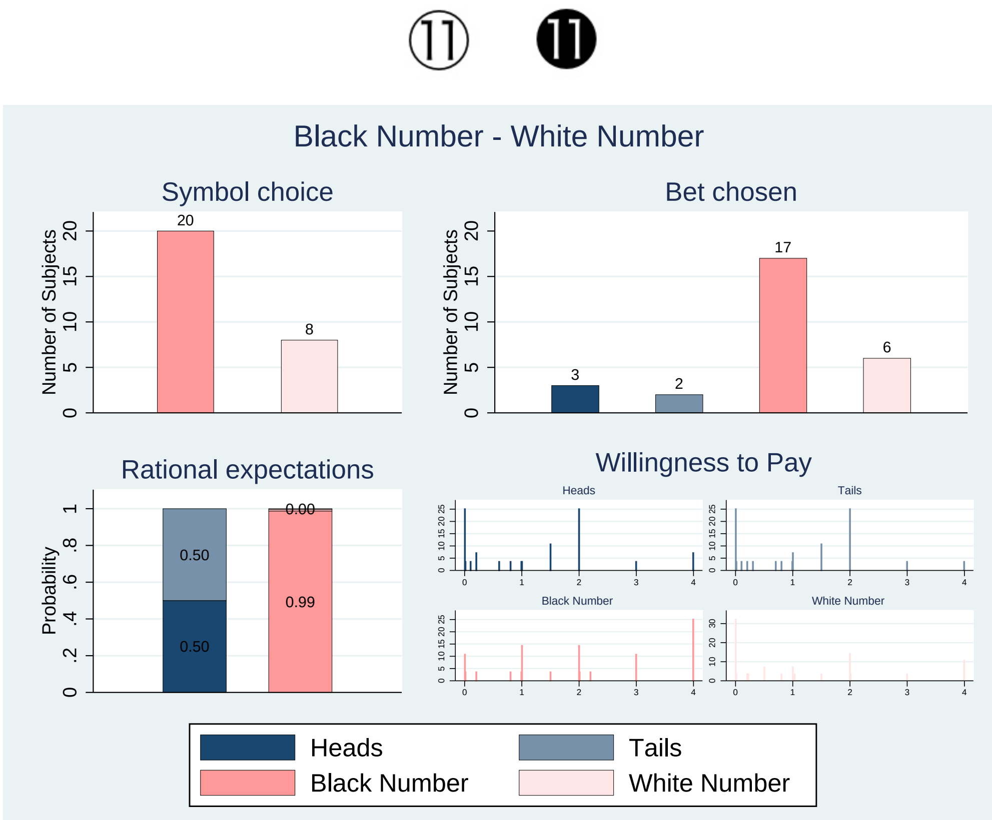
Appendix Figure C.11: Horizontal vs. Vertical Bar (1/2)



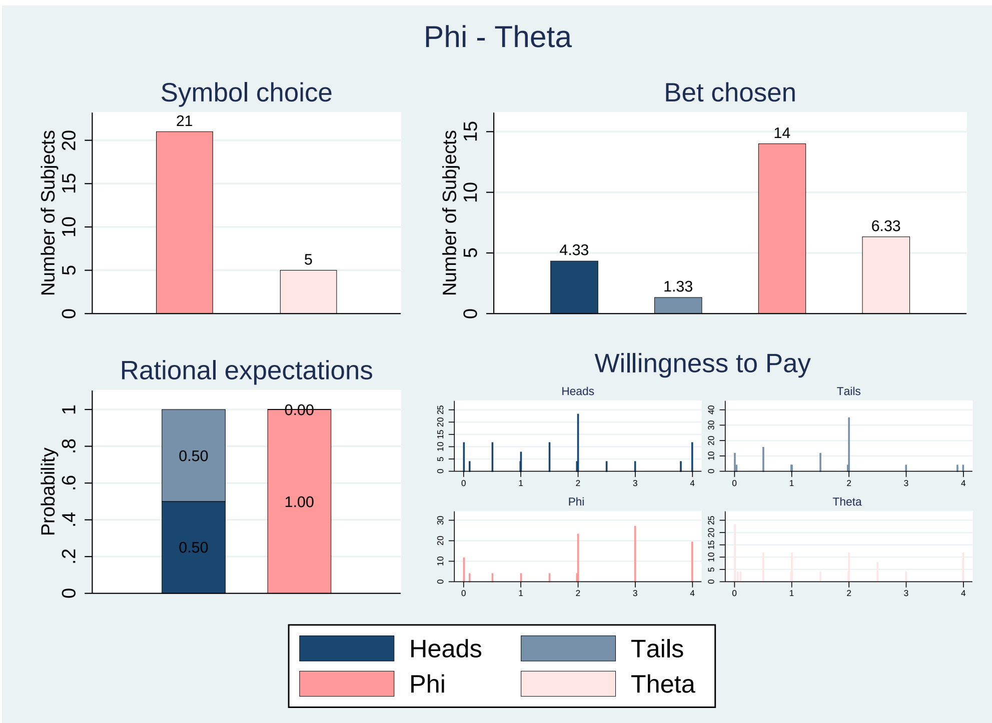
Appendix Figure C.12: Horizontal vs. Vertical Bar (2/2)



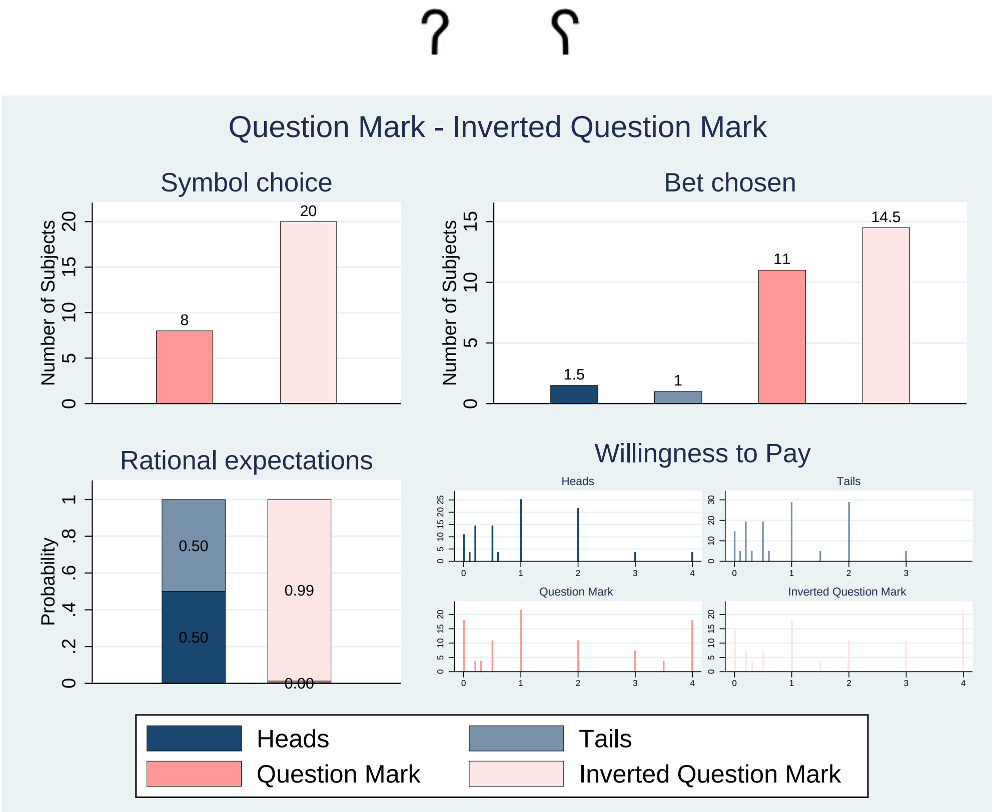
Appendix Figure C.13: Left-Right vs. Up-Down Arrow



Appendix Figure C.14: Black on White vs. Inverse ϕ θ



Appendix Figure C.15: Phi vs. Theta

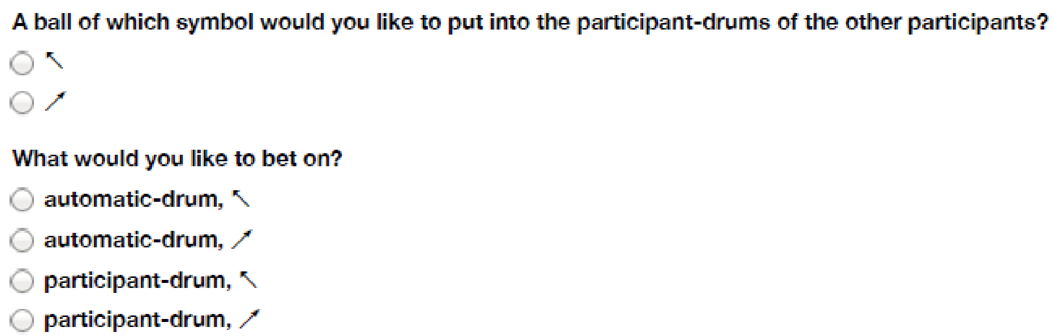


Appendix Figure C.16: Question Marks

D Participant-Generated Urn and Belief Elicitation

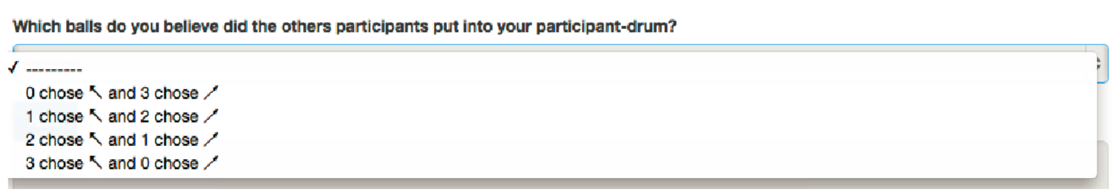
On the first screen, subjects are asked to send a symbol, and place a bet:

Appendix Figure D.1: Choice of symbol to send and choice of bet



On the second screen, their beliefs were elicited (non-incentivized, single prior):

Appendix Figure D.2: Belief elicitation



Appendix Figure D.3 shows the resulting game for $N = 3$, where participants have a choice to bet on either heart (h) or smiley (s). Prizes are 0 and 1 respectively, c denotes the certainty equivalent of the objective lottery that gives the two prizes 0 and 1 with equal probability. The game has 26 Nash equilibria in pure strategies: (Hh, Hh, Hh);(Hh, Hh, Sh);(Hh, Hs, Sh);(Hs, Hs, Sh), and permutations thereof by player order and symmetry in heart/smiley.

Appendix Figure D.3: Natural Source of Ambiguity: $N = 3$

Player 3 (Hh)

	(Hh)	(Hs)	(Sh)	(Ss)
(Hh)	$(1,1,1)$	$(1,0,1)$	$(c,1,c)$	$(c,0,c)$
(Hs)	$(0,1,1)$	$(0,0,1)$	$(c,1,c)$	$(c,0,c)$
(Sh)	$(1,c,c)$	$(1,c,c)$	$(c,c,0)$	$(c,c,0)$
(Ss)	$(0,c,c)$	$(0,c,c)$	$(c,c,0)$	$(c,c,0)$

Player 3 (Hs)

	(Hh)	(Hs)	(Sh)	(Ss)
(Hh)	$(1,1,0)$	$(1,0,0)$	$(c,1,c)$	$(c,0,c)$
(Hs)	$(0,1,0)$	$(0,0,0)$	$(c,1,c)$	$(c,0,c)$
(Sh)	$(1,c,c)$	$(1,c,c)$	$(c,c,1)$	$(c,c,1)$
(Ss)	$(0,c,c)$	$(0,c,c)$	$(c,c,1)$	$(c,c,1)$

Player 3 (Sh)

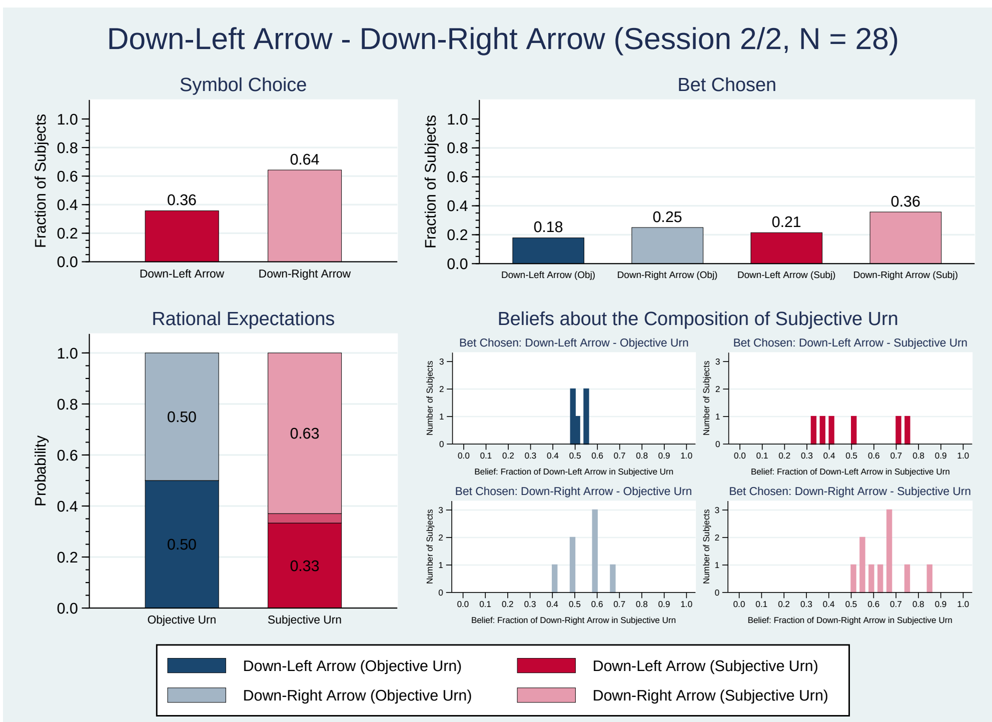
	(Hh)	(Hs)	(Sh)	(Ss)
(Hh)	$(c,c,1)$	$(c,c,1)$	$(0,c,c)$	$(0,c,c)$
(Hs)	$(c,c,1)$	$(c,c,1)$	$(1,c,c)$	$(1,c,c)$
(Sh)	$(c,0,c)$	$(c,1,c)$	$(0,0,0)$	$(0,1,0)$
(Ss)	$(c,0,c)$	$(c,1,c)$	$(1,0,0)$	$(1,1,0)$

Player 3 (Ss)

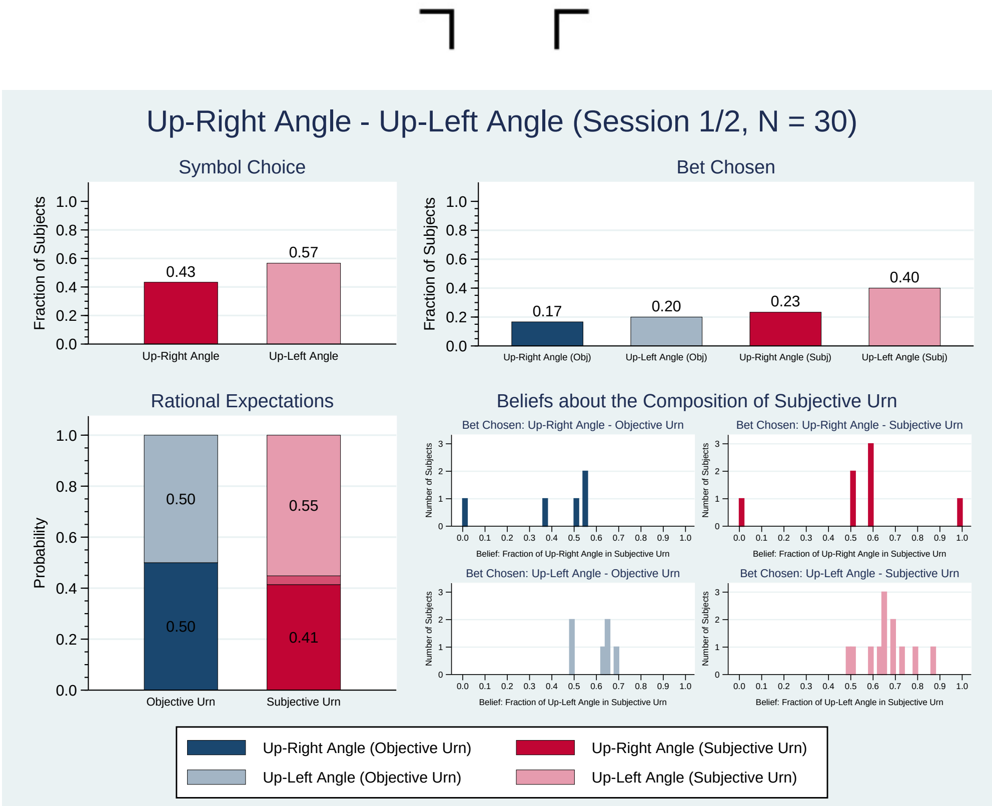
	(Hh)	(Hs)	(Sh)	(Ss)
(Hh)	$(c,c,0)$	$(c,c,0)$	$(0,c,c)$	$(0,c,c)$
(Hs)	$(c,c,0)$	$(c,c,0)$	$(1,c,c)$	$(1,c,c)$
(Sh)	$(c,0,c)$	$(c,1,c)$	$(0,0,1)$	$(0,1,1)$
(Ss)	$(c,0,c)$	$(c,1,c)$	$(1,0,1)$	$(1,1,1)$

E Results from Participant-Generated Urn Design

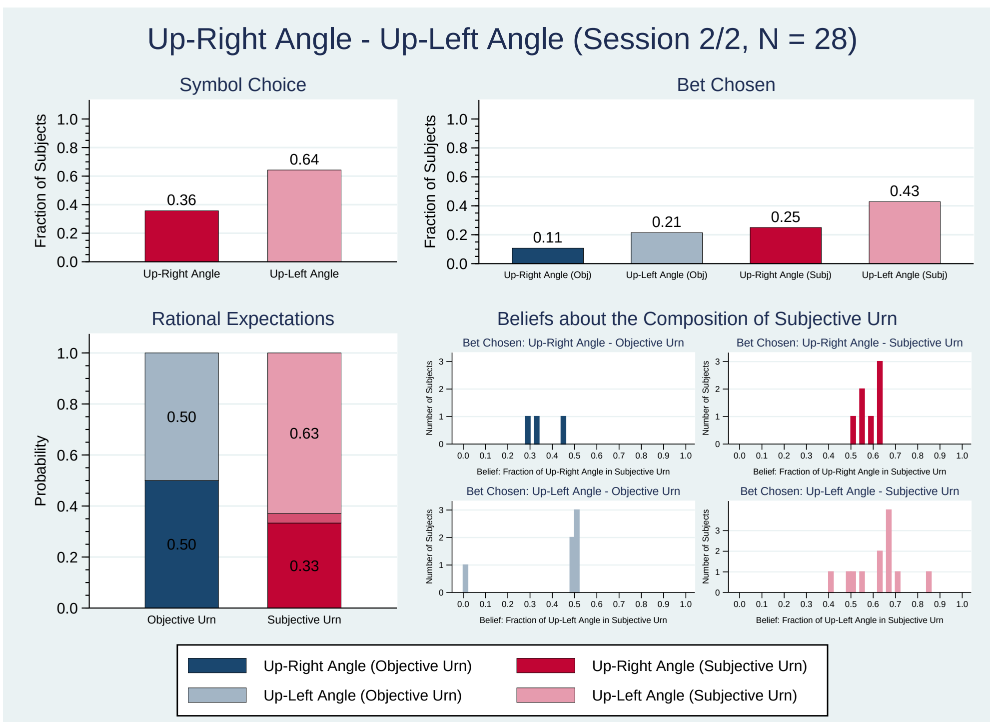
Appendix Figure E.1: Down-Left vs. Down-Right Arrow (Session 1/2)



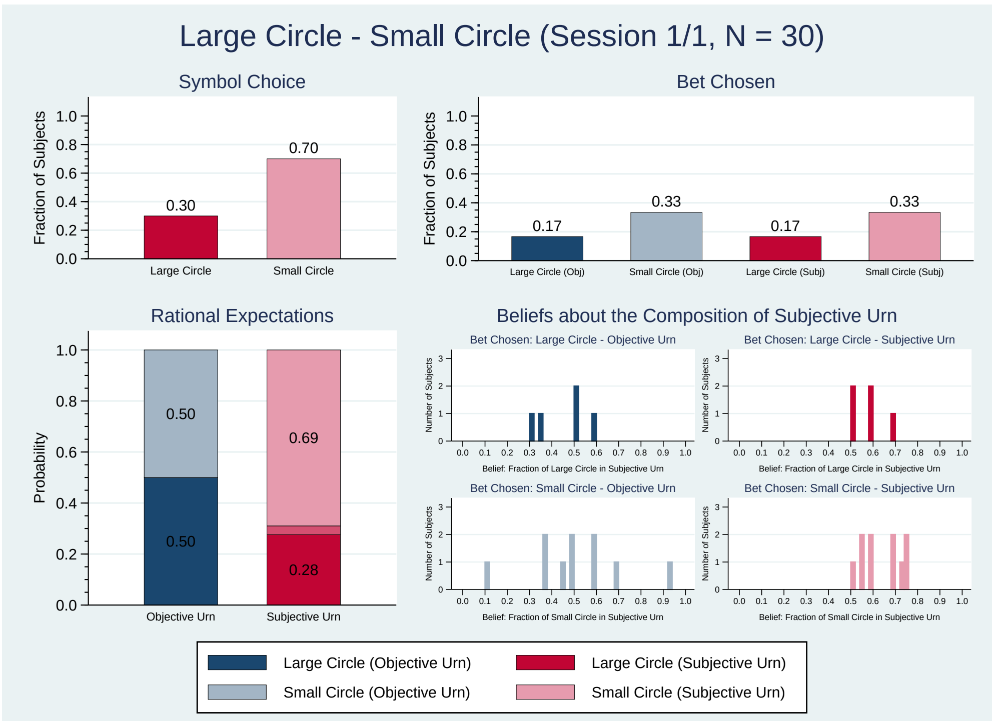
Appendix Figure E.2: Down-Left vs. Down-Right Arrow (Session 2/2)



Appendix Figure E.3: Up-Right vs. Up-Left Angle (Session 1/2)



Appendix Figure E.4: Up-Right vs. Up-Left Angle(Session 2/2)



Appendix Figure E.5: Large vs. Small Circle