IS AMBIGUITY AVERSION A PREFERENCE? AMBIGUITY AVERSION WITHOUT ASYMMETRIC INFORMATION

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Abstract Ambiguity aversion is the interpretation of the experimental finding (the 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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"Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns – the ones we don't know we don't know. And if one looks throughout the history of our country and other free countries, it is the latter category that tend to be the difficult ones." (Donald Rumsfeld, Department of Defense News Briefing, Feb. 12, 2002).

1. INTRODUCTION

The development of the normative and positive theory of behavior under uncertainty is characterized by a series of thought experiments to which scholars or lay people often give the "wrong" answer, which is why they are known as paradoxes. The first thought experiment, the St.-Petersburg-Paradox, was proposed by Nicolas Bernoulli (see de Montmort, 1713) and challenged the notion that a lottery will be evaluated by its expected value. Daniel Bernoulli (1738) proposed a theory that accommodates the observed behavior by using a concave utility function instead of the payoffs themselves. Centuries later that theory of using utility was put on normative foundations by von Neumann and Morgenstern (1944). Allais then challenged that theory, proposing his thought experiment which shows that many people do not exhibit the behavior suggested by Bernoulli and von Neumann and Morgenstern. Expected utility theory concerns situations where a probability distribution is given or uncontroversial. Savage (1954) proposed to expand this theory to situations where no probability distribution is given, and gave axioms that imply that a decision-maker would have a single subjective probability distribution. Ellsberg (1961) proposed a thought experiment that challenges this notion. Empirical papers followed (for a survey see Camerer and Weber, 1992), showing that there is a "paradox", i.e. that people behave differently than normative theory prescribes. New models were proposed to accommodate the behavior that exhibits ambiguity non-neutrality in the Ellsberg experiment.[1]

Ambiguity aversion is now used to explain puzzles and promote policies. For example, some

[1]Famous ones are Schmeidler's (1989) Choquet model (or Rank-Dependent Expected Utility); Gilboa and Schmeidler's (1989) maximin expected utility; the smooth ambiguity model by Klibanoff et al. (2005); the Variational Preferences Model by Maccheroni et al. (2006); Segal (1987)'s recursive ambiguity model; and most recently Gul and Pesendorfer (2010)'s Expected Uncertain Utility Theory.

financial economists, like 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." The DeLong and Magin (2009) survey article on the equity premium puzzle writes:

> "Maenhout (2003) proposes another behavioral approach to the equity premium puzzle based on ambiguity aversion. The stock market is an ambiguous gamble–investors do not know its probability distribution for sure–and so an ambiguity-averse investor may require a high equity premium. The dominant assessment of this line of research appears similar to that of the literature on nonstandard preferences: promising, but not yet a complete explanation. Humans know that they have psychological biases. Humans build social and economic institutions to compensate for such biases and to guide them into framing problems in a way that is in their long-term interest. Humans have built a variety of mechanisms that can compensate for the cognitive biases that produce myopia and imprudence: some examples include automatic payroll deductions, inducing caution by valuing assets at the lower of cost and market, and putting assets into trusts. 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."

Health economists interested in targeting public health initiatives advocate policies contingent on correlations between measures of ambiguity aversion and unhealthy behavior (Sutter et al., 2013). It is in law, however, where the concept of ambiguity aversion appears to have made the most headway. Potential defendants are ambiguity averse (Nagin, 1998). Ambiguity aversion is argued to result in plea bargaining that is too harsh, as defendants are typically more ambiguity averse than the prosecutor who faces a repeated situation. The criminal process therefore is systematically affected by asymmetric ambiguity aversion, which the prosecution can exploit by forcing defendants into harsh plea bargains, as Segal and Stein (2005) contend. According to Segal et al., "An ambiguity-averse person increases the subjective probability of the unfavorable prospect, which is what criminal defendants typically do when they face a jury trial.” The prosecution is not ambiguity averse. Being a repeat player interested in the overall rate of convictions, it can depend upon any probability, however indeterminate it may be. The criminal process therefore is systematically affected by asymmetric ambiguity aversion, which the prosecution can exploit to force defendants into more severe plea bargains. The authors demonstrate that asymmetric ambiguity aversion foils criminal justice and propose legal reform to fix the problem.

Uncertain risks surrounding environmental protection and medical malpractice have led to calls to provide more scientific data to ameliorate the relevance of ambiguity aversion in individuals' policy preferences by e.g. Viscusi and Zeckhauser (2006). Farber (2010) also applies ambiguity aversion to environmental regulation policy. Lawsky (2013) introduces a model of tax compliance that models an ambiguity averse decision-maker who does not know the probability of audits. The paper proposes reforms to whether government should reveal information about its approach to audits, whether the government should use anti-abuse rules to attack tax shelters, and whether tax professionals should be subject to penalties for providing certain kinds of tax advice. And the theory and practice of statutory interpretation is rife with ambiguity, as Farnsworth et al. (2010) argue in a paper that investigates the crucial and analytically prior question: What is ambiguity in law? Does a claim that a text is ambiguous mean the judge is uncertain about its meaning? Or is it a claim that ordinary readers of English, as a group, would disagree about what the text means? The paper finds that asking respondents whether a statute is “ambiguous” in their own minds produces answers that are strongly biased by their policy preferences. But asking respondents whether the text would likely be read the same way by ordinary readers of English does not produce answers biased in this way. They interpret the results in the following manner: ambiguity aversion in statutory interpretation causes respondents to judge statutory texts to be clear and to have strong policy preferences about them.

Elsewhere in law, ambiguity aversion has been used to explain incomplete contracts: an ambiguity-averse decision maker 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 it. As a consequence, the effect of ambiguity aversion is to reduce the marginal gains from including more details in a contract (Mukerji, 1998). Talley (2009) finds that contract provisions in corporate acquisitions are consistent with ambiguity aversion. It is also proposed to explain volatility in stock markets. When ambiguity-averse investors process news of uncertain quality, they 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 (Epstein and Schneider, 2008). It is proposed to explain selective abstention in elections. Ambiguity aversion about the candidates' policy positions can make abstention look to the voter a smaller "mistake" than voting for one of the candidates (Ghirardato et al., 2000). Ambiguity averse individuals visualize disaster with unknown probabilities. Ambiguity aversion is now modeled to cause polarization in beliefs when individuals are interpreting identical information (Baliga et al., 2013).

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 (the 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). 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. 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. 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. We present an experiment that takes away the informational disadvantage subjects have vis-à-vis the experimenter but leaves ambiguity in place.

In 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 either 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.[2] Thus an experimental finding like the Ellsberg paradox could be due to subjects misunderstanding the situation or applying the heuristic of avoiding situations of disadvantageous informational asymmetry rather than ambiguity aversion. A prominent study seeking to investigate the prevalence of ambiguity aversion, Halevy (2007), discovered that many subjects exhibit neutral feelings towards ambiguity. More specifically, those who are indifferent to ambiguity can successfully reduce compound lotteries. In contrast, those sensitive to ambiguity often struggle with these lotteries and almost always fail to reduce these lotteries. The presence of ambiguity decreases their willingness to pay similarly to introducing a compound lottery with equivalent probabilities from the original urn.

[2]"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."

Informational imbalances can lead to suspicion, with participants potentially believing that an experimenter might be manipulating outcomes for financial benefit. On the flip side, Heath and Tversky (1991) focused on competence and expertise. They began by assessing subjects' predictions of natural events. Subsequently, subjects were given a choice to bet on that event or a chance device with the same perceived probability. Participants typically chose based on their knowledge and confidence about the event. In another study, Heath and Tversky compared preferences in betting on or against events, highlighting different choices based on the level of expertise. Keppe and Weber (1995) and Lotito et al. (2023) also show that subjects' competence in natural events can explain the degree of ambiguity aversion. In our study design, subjects will have no differential expertise relative to the experimenter in making predictions about the event.

One way to attenuate the problem of informational asymmetry, which might be a confound for ambiguity aversion, is to use a source of ambiguity that, unlike Ellsberg's subjective 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.[3] 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 and transparent device which clearly cannot be manipulated by the experimenter to pick a

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

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. 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 (when participants adjust their behavior based on perceived expectations from the researcher conducting the study) can affect behavior (Cilliers et al. 2015). Li et al. (2020) has fellow subjects fill the urn and they find that the ambiguity aversion is absent. Dominiak and Duersch (2019), referencing our work, introduce two variations to the Ellsberg game. In the first, another participant fills the urns and shares the same payoff as the Ellsberg decision-maker. In the second, the urn-filler loses an amount equivalent to the decision-maker's payoff. While our studies can be considered similar in concept, it's worth noting that experimenter demand might be more pronounced when payoffs are aligned.

Some experimental results may be consistent with experimenter demand. For instance, when subjects are presented with two choices that vary only in subjective uncertainty but hold equal value under subjective expected utility, they might naturally gravitate towards the option with less uncertainty. Trautmann et al. (2008) used a design where a participant's preference between two DVDs remains private, ensuring the experimenter is unaware of the probability of the participant receiving their preferred prize. The instructions stressed the importance of keeping this preference secret, possibly amplifying the sense of adversarial asymmetric information. In contrast, our study operates within the classical Ellsberg game's framework and eliminates this asymmetric information. Outside the classical framework, Li et al. (2019) examine the trust game in the context of ambiguity attitudes concerning the choices of fellow participants. Li et al. (2018) further analyze ambiguity attitudes in various scenarios. They found no ambiguity aversion in decisions related to a charitable initiative in rural India or a treatment for severe diseases. Stecher et al. (2011) programmatically generates ambiguity in the laboratory.[4]

Ambiguity aversion has a long history in the study of individual decision making in psychology. In vignette studies, even after being advised about the Ellsberg paradox, 80% of subjects still exhibit ambiguity aversion (Slovic and Tversky, 1974). It has also been the subject of much theoretical modeling in economics. As Levine (2012) writes, "In the other direction are what I would describe as not part of mainstream economics, but rather works in progress that may one day become part of mainstream economics. The idea of level-k thinking is one such. Another that I did not discuss is the idea of ambiguity aversion. This captures the fascination economists have had since Frank Knight's 1921 work with distinguishing mere risk from uncertainty." That is, risk—uncertainty with known probabilities—as opposed to ambiguity—uncertainty with unknown probabilities.

[4]The method draws random numbers from a distribution with divergent quantiles and moments. This makes it impossible for subjects to learn the true probabilities, even with large samples. It uses draws from a Cauchy distribution to generate an ambiguous sequence. The researchers test the method in an experiment based on Ellsberg's two-color urn. Subjects choose between a risky penny (Bernoulli distribution) and an ambiguous penny (generated using the method described). Before making any choices, subjects view 100 histograms of the ambiguous penny, each with 3000 draws. This gives them direct experience of the ambiguity. Results show subjects treat the risky and ambiguous penny differently, suggesting the method effectively generates ambiguity.

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[5], while mistakes should not. 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. This is why we propose an altogether new design: participant-generated source of ambiguity. 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 a vignette experiment. Section 3 presents an incentivized experiment. Section 4 provides a discussion.

2. VIGNETTE EXPERIMENT

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[6] in unknown combination. We follow Halevy (2007) in setting the number of subjective balls at 10.[7]

FIGURE 1.— *

Ellsberg experiment

	1-3 5 balls	10 balls	
Urns	Red	Black	White
	$n_R = 5$	n^t_B	n^t_W

- 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.

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

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

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

- Bet on Black: If a black ball is drawn you get $\$x+\varepsilon$. Else you get \$0.

Recapitulating the literature, 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".To see why, consider a probabilistically sophisticated decision maker (DM) who has some subjective probability distribution for experiment t, such that $p^t_R = \frac{1}{3}$, $p^t_W + p^t_B = \frac{2}{3}$ (if in addition to probabilistic sophistication she accepts informational symmetry between W and B, then in particular $p^t_W = p^t_B = \frac{1}{3}$). Thus the bets can be written as the following lotteries $\left(\frac{1}{3}; x, \frac{2}{3}; 0\right)$ for red, $\left(p^t_W; x+\varepsilon, \frac{2}{3} - p^t_W; 0\right)$ for white, $\left(p^t_B; x+\varepsilon, \frac{2}{3} - p^t_B; 0\right)$ 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 $p^t_W < \frac{1}{3}$, which in turn implies that $p^t_B > \frac{1}{3}$ meaning that "Bet on Black" stochastically dominates "Bet on Red".

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

2.1. *Majority determines outcome*

An even number (N) of participants come to a laboratory session, facing two types of uncertainty: objective and ambiguous. The objective uncertainty is straightforward: a computer determines a standard fair coin toss.

The ambiguous uncertainty is a bit more involved. Each participant selects one of two symbols to send to the others, without any personal payoff consequence. For any participant 'i', if the majority of the other participants choose symbol A over B, their ambiguous coin falls on symbol A; otherwise, it lands on B. This selection process is like a "majority rule" draw from the ambiguous urn. To prevent biases (as A and B have natural orders), we use varying pairs of symbols without such order, for example, "heart" and "smiley".

Every participant not only sends a symbol to others but also chooses one of four bets: betting on heads or tails (objective) or symbol A or symbol B (ambiguous). Winning the bet yields EUR4. Participants express how much they value each bet, and they're given the most valued bet for free. The decision-making process, including sending a symbol and selecting a bet, is displayed on one screen. The original instructions can be found in Appendices A and B.

For clarity: if the majority of participants select "heart" over "smiley", participant 'i's metaphorical coin lands on "heart"; otherwise, "smiley".

We've ensured randomness in presenting the bets, explicitly notifying participants about this, to avoid any bias based on the order of appearance.

Those who understand probabilities well hold one belief about the odds. If they believe there's a 50% chance, they're indifferent to all four bets. If not, there's a preferred symbol to bet on over heads or tails. Our design lets participants show indifference and state their valuation for each option, as illustrated in Appendix Figure A.1.

2.2. *Results*

We conducted experiments in Zurich using the oTree platform (Chen et al. 2016). These experiments spanned 16 sessions with a total of 418 participants. Throughout these sessions, we utilized 11 unique symbol pairs. Notably, the symbol pairs "heart vs. smiley" and "down-left vs. down-right angle" were used in two sessions each, and the "large vs. small circle" pair appeared in three sessions. Our discussions will primarily reference the initial session of the thrice-used pair.

In this session, the symbols in question were a large, empty circle and a smaller, filled circle. These symbols can be found in the appendix. There's an inherent conflict in selecting between these symbols: one might choose based on size (large over small) or content (filled over empty).

It's essential to understand that participants' symbol selections did not influence their own monetary outcomes but affected others who chose to bet on the ambiguous outcome. An illustration, Figure 2, breaks down the session's results. Here's a guide:

Top Left Subpanel: Displays participants' symbol choices. Out of 28 participants, 13 picked the large empty circle and 15 opted for the small filled circle.

Bottom Left Subpanel: Represents estimated winning probabilities. For objective uncertainty, the chances of heads or tails are each 50% - a constant across sessions. Estimating the probability for the ambiguous outcome is more challenging. We aimed for symbol pairs to be interchangeable, assuming a 50% chance for each symbol being the majority pick. Based on participants' choices, we then calculated probabilities of either symbol being the majority choice.

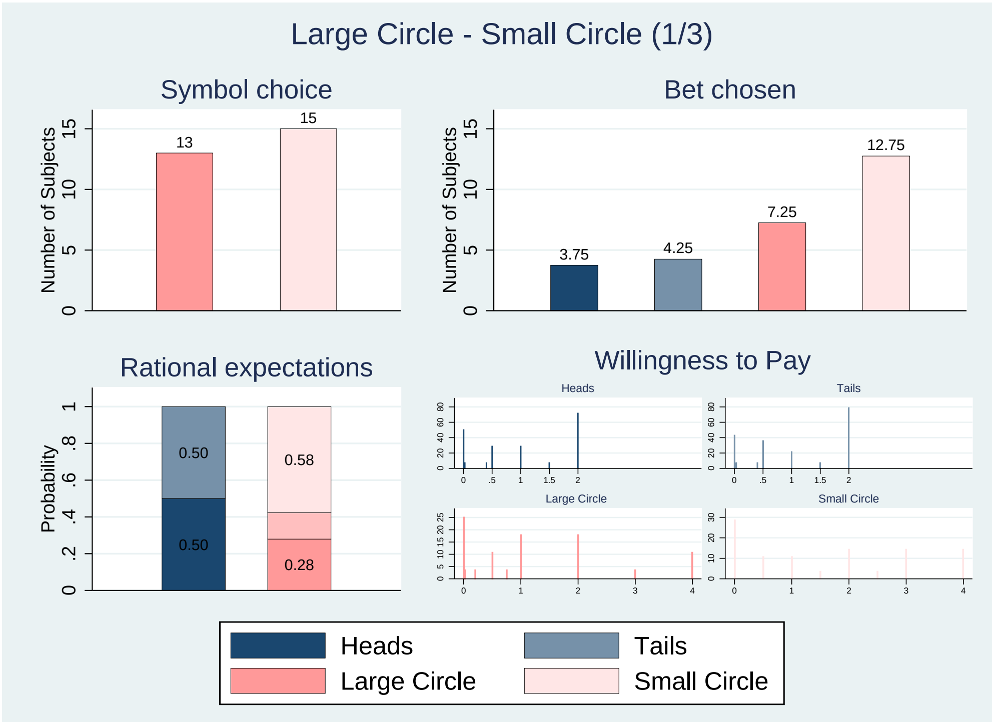
Top Right Subpanel: Shows participants' bets. They expressed how much they'd pay for each bet, ultimately receiving the bet they valued most. In this chart, bets on either symbol were more popular than objective bets on heads or tails.

Bottom Right Panel: Features the distribution of participants' stated bet values. It's worth noting that despite the lack of direct incentives, studies have shown that many participants lean toward ambiguity aversion.

Summarized Results:

Subjective or ambiguous bets consistently outperformed objective ones. Participants in 14 out of 16 sessions showed a stronger preference for bets with ambiguous outcomes than objective ones. This trend is illustrated in Figure 2 and goes against typical expectations of ambiguity aversion. Analogous figures for each of the other 15 sessions are in Appendix C.

FIGURE 2.— Results from 1 of 16 Sessions



2.3. *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 (Note: We labeled one of the symbols as "A" for clarity); (ii) Risk aversion, a measure of risk aversion; (iii) P(A wins), the likelihood that symbol A was the majority pick among 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.

From this analysis: There's no notable link between risk aversion and opting for the objective bet. Players tend to bet on the symbol they chose for others. The actual probability of a symbol being the majority pick doesn't significantly influence players' betting preference for that symbol.

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

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

3. REVEALED PREFERENCE EXPERIMENT

3.1. *Participant-generated Ellsberg urn*

In Section 2.1, participants influenced a metaphorical coin's outcome by choosing either a "heart" or "smiley." The result was determined by the majority's choice. In Section 3, we now introduce a different mechanism: participants draw a ball from an urn whose exact composition is unknown, though the total number of balls is known. This mirrors the original Ellsberg-urn concept, but here, the urn's composition is influenced by the participants themselves, who select symbols for other participants' urns.

Previously, participants indicated their most valued bet, but there wasn't a reward for this choice. However, if participants were indifferent and chose randomly, we'd expect an even distribution of preferences. Instead, we found that bets based on subjective criteria were favored over objective ones. In this section, choosing the right bet comes with a reward.

Here's the process: Participants choose from four options: two based on objective acts and two on subjective acts. The objective options revolve around predicting the outcome of a fair coin flip; if they guess right, they win EUR4. To ensure fairness, the coin flip's outcome is announced openly, eliminating any chance for the experimenter to manipulate the results.

The subjective options are more intricate. They bet on the contents of a virtual urn, which is populated based on symbol choices made by other participants. Each participant's Ellsberg urn contains N−1 balls (representing the other participants), labeled either "smiley" or "heart". A ball is then drawn, and participants learn both its symbol and the overall urn composition simultaneously. Detailed instructions and game strategies can be found in Appendix D.

It's essential to note a nuanced difference in this section: instead of using the majority symbol count to determine a virtual coin's outcome, we directly draw from a virtual urn filled with these symbols. In addition, symbols were chosen based on their perceived interchangeability from the vignette experiment described in Section 2.

3.2. *Results*

The experiment's outcomes are shared through visuals and regression analyses. We detail the results of one session in the main text, while the results from the other four sessions can be found in Appendix E.

In Figure 3, the blue shades signify objective uncertainty: dark blue represents 'heads' and light blue stands for 'tails'. Red shades depict subjective uncertainty. On the top left of the figure, the symbols chosen by participants are displayed. A participant's symbol choice doesn't affect her outcome but influences others who bet based on subjective uncertainty. In this session, out of 30 participants, 40% opted for the down-left arrow and 60% for the down-right arrow.

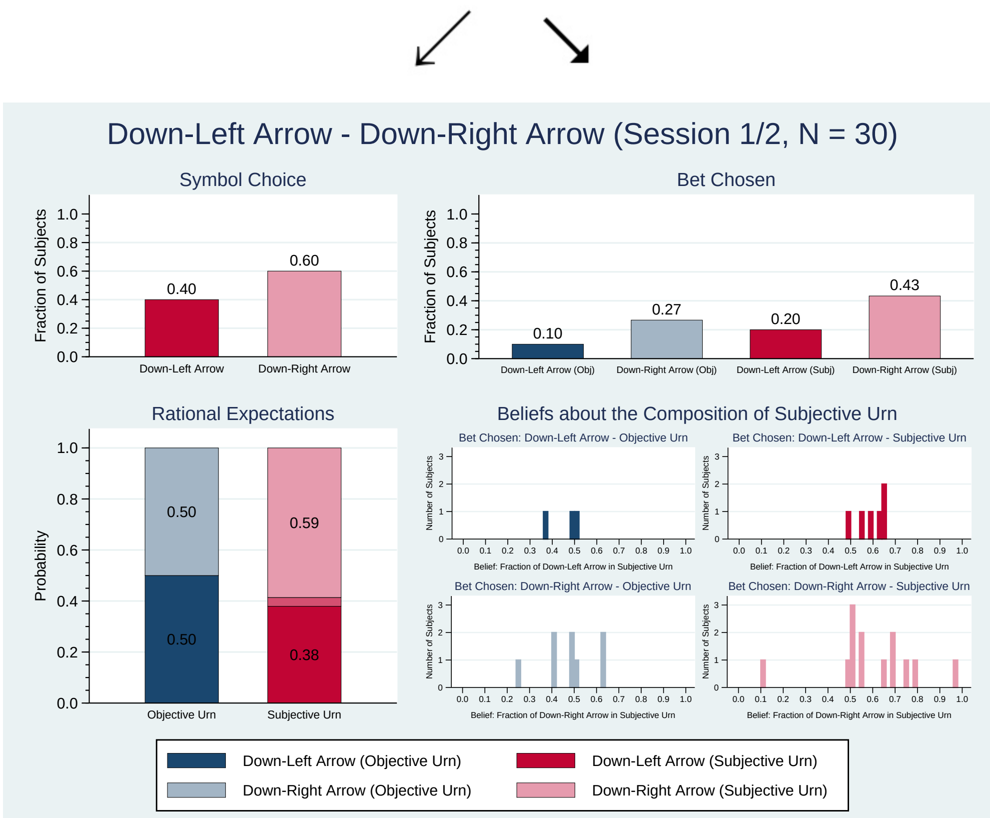
The bottom left section attempts to convey how a rational player might predict the winning symbol's chances: For objective uncertainty (heads or tails), the probability is consistently 50%, shown in the left bar. The next bar envisions a participant having an almost uncanny insight into the symbols chosen by others.

The top right segment showcases the bets made by participants. They indicated their choice among four bet options.

The bottom right section offers histograms, showing participants' assumptions about the ambiguous urn's contents. It's crucial to note that no rewards were provided for these assumptions, making the data somewhat speculative.

In summary, participants in this setup were more inclined towards bets based on subjective acts than objective acts, challenging the typical expectations of ambiguity aversion.

FIGURE 3.— Down-Left vs. Down-Right Arrow



3.3. *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, 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.

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

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

Not surprisingly, people bet on the symbol in the ambiguous urn that they believed to be more prevalent.[8] In addition, there is no significant impact of displaying the objective urn first (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.

4. CONCLUSION

Ambiguity aversion, an active area of research with implications for puzzle-solving and policy suggestion, continues to prompt questions about whether it is a preference or a misap-

[8]However, this belief elicitation was not incentivized and was asked after making the bet, so cognitive dissonance may drive subjects to increase their perceived prevalence of the symbol they bet on.

plication of a heuristic. This paper set out to examine if economically substantial ambiguity aversion truly exists as a preference. We proposed and implemented a novel thought experiment - an Ellsberg-type experiment where the uncertainty is generated by participants rather than the experimenter, eliminating asymmetric information. Our findings indicate that very few people, if any, are ambiguity averse to an economically meaningful extent. This suggests two potential interpretations: (i) ambiguity neutrality/probabilistic sophistication and people judge the odds of the urn to be 50%, (ii) a small amount of ambiguity aversion which is overcome by what people think are better odds of the subjective urn. Intriguingly, subjects who chose the subjective urn could also be ambiguity-seeking, reflecting the heterogeneity in decision-making in one-round experiments. A complementary interpretation is that subjects in the experiment believed others to be similar to oneself when making the decision and this self-confidence outweighed the small amount of ambiguity aversion they might have had. In summary, these findings underline that future research may need to explore whether unlearning the wrong heuristic predicts changes in behavior, such as becoming more likely to choose the ambiguous urn over time. Further probing of ambiguity aversion and its economic implications is warranted.

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Web Appendix For Online Publication

APPENDIX 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

APPENDIX B: ENGLISH TRANSLATION OF INSTRUCTIONS

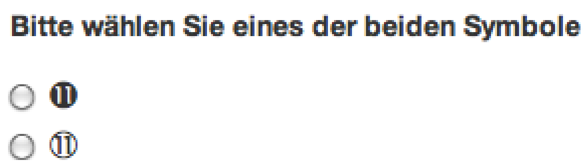
In this experiment you can bet on the result of two coin throws. The two coin throws differ as follows:

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].

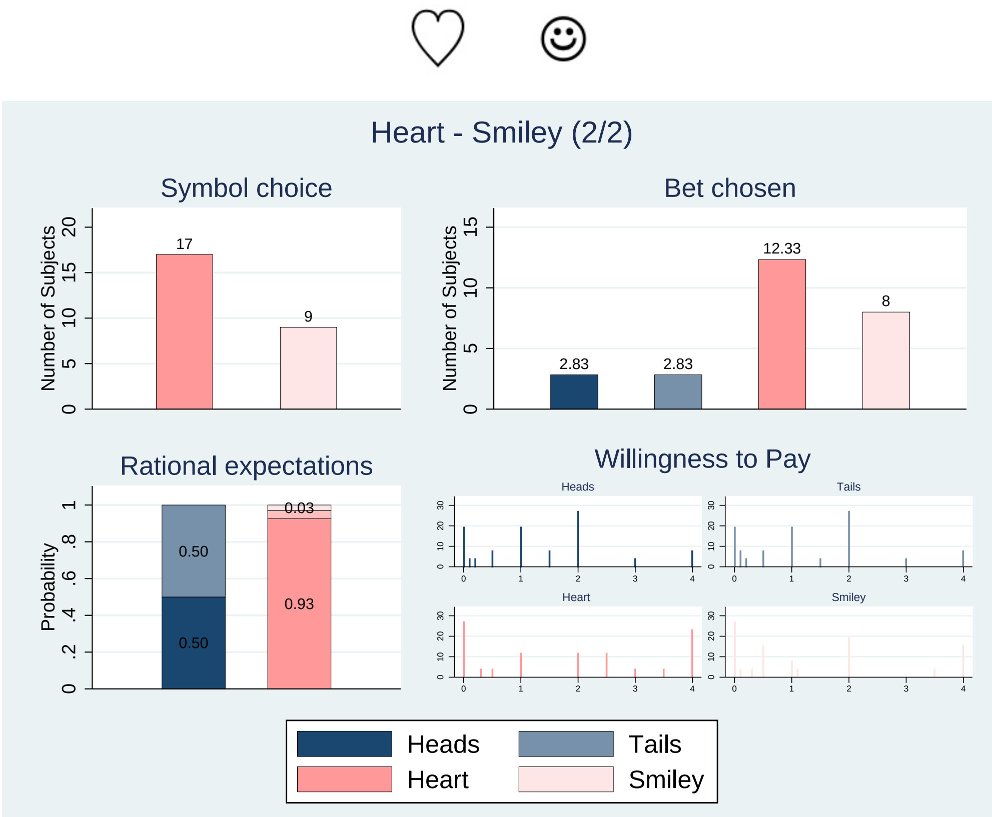
Appendix Figure A.3.— How much is this lottery worth?

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

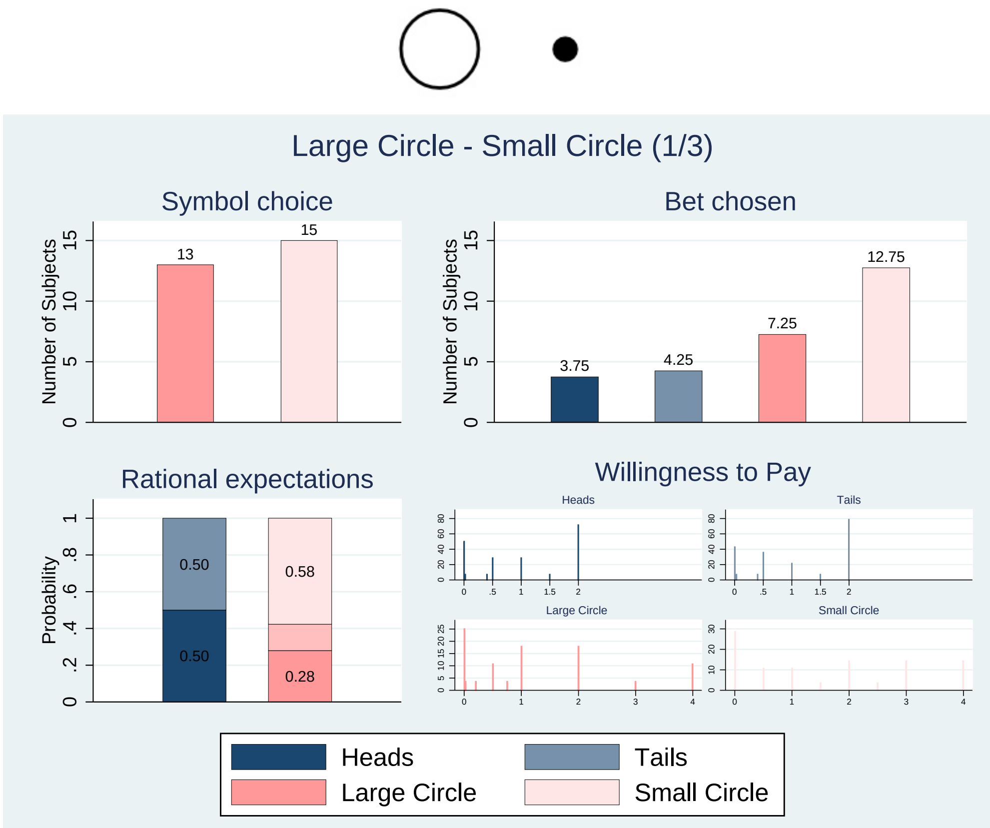
Wie viel ist Ihnen Lotterie 1 wert? (In Cent)

APPENDIX C: RESULTS FROM MAJORITY DETERMINES OUTCOME DESIGN

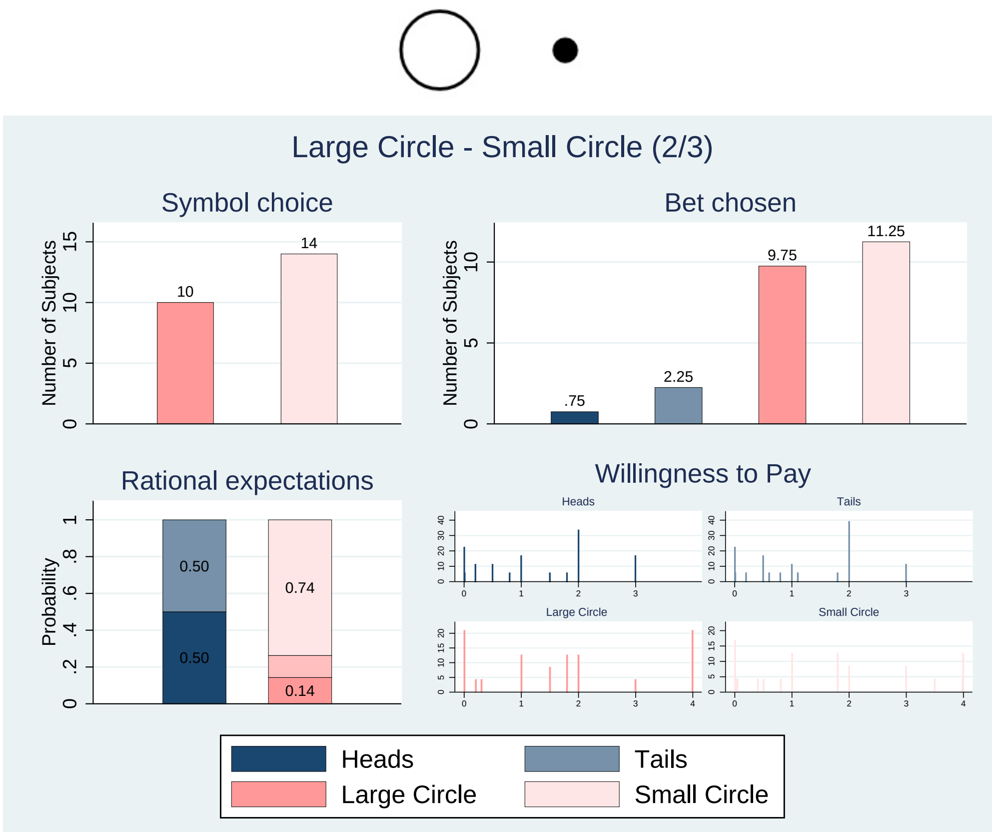
Appendix Figure C.1.— Heart vs. Smiley (1/2)



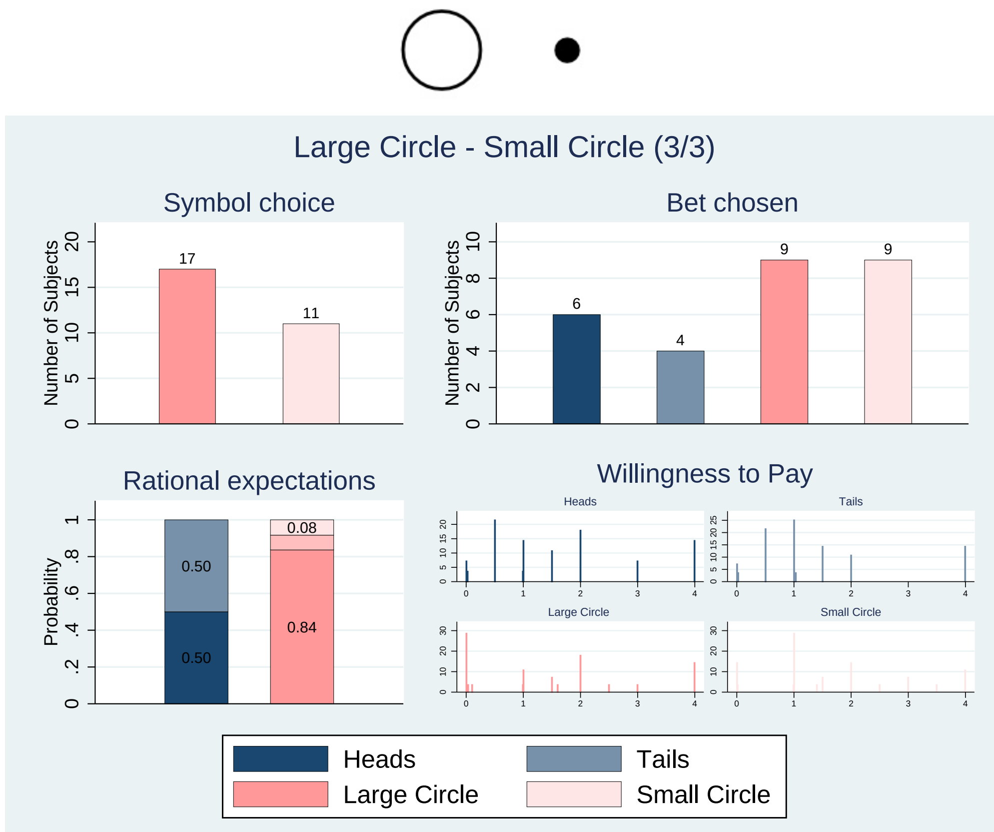
Appendix Figure C.2.— Heart vs. Smiley (2/2)



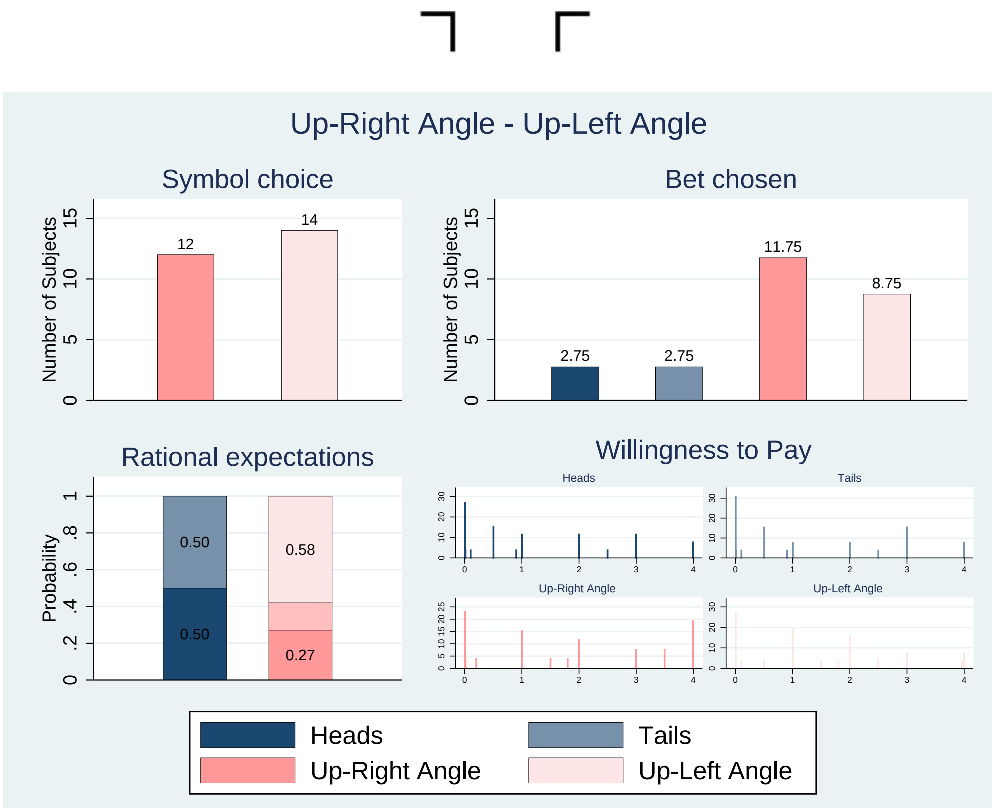
Appendix Figure C.3.— Large vs. Small Circle (1/3)



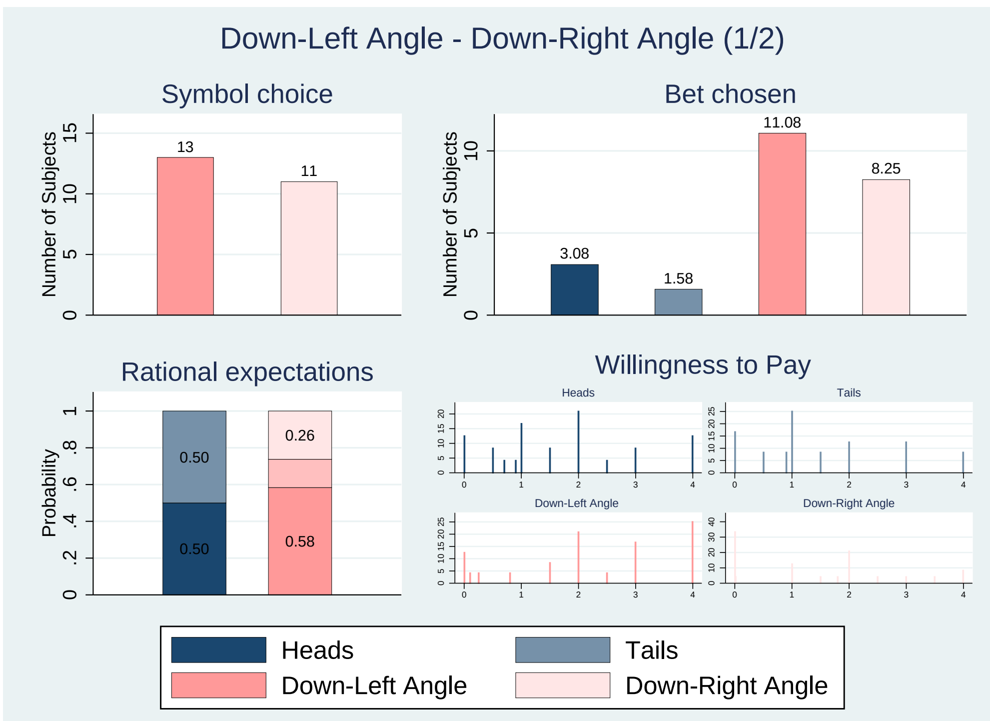
Appendix Figure C.4.— Large vs. Small Circle (2/3)



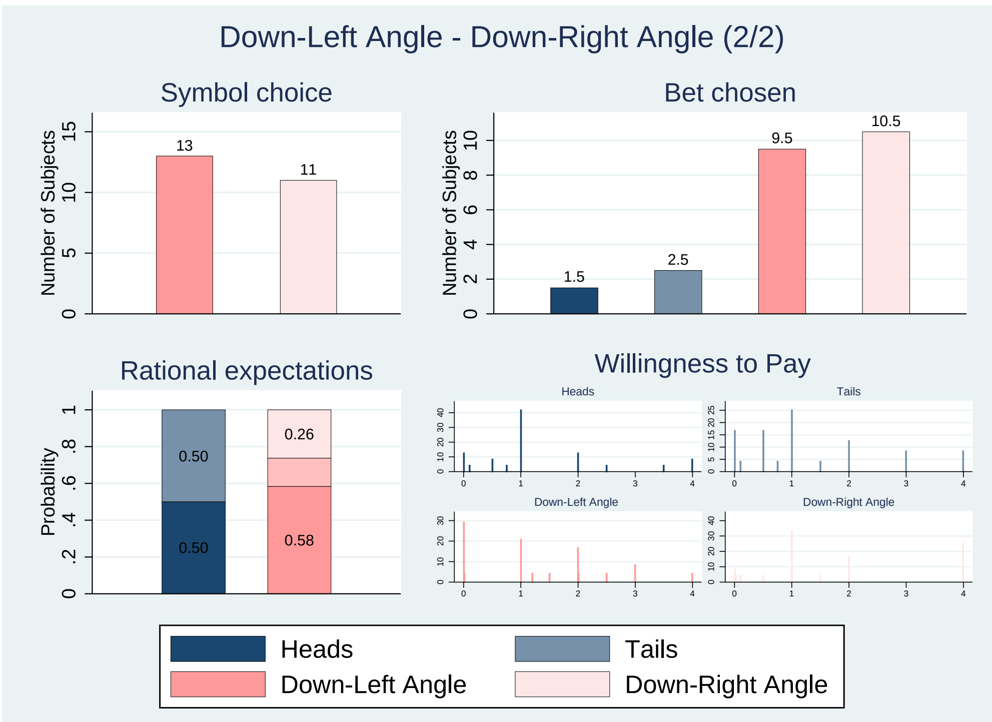
Appendix Figure C.5.— Large vs. Small Circle (3/3)



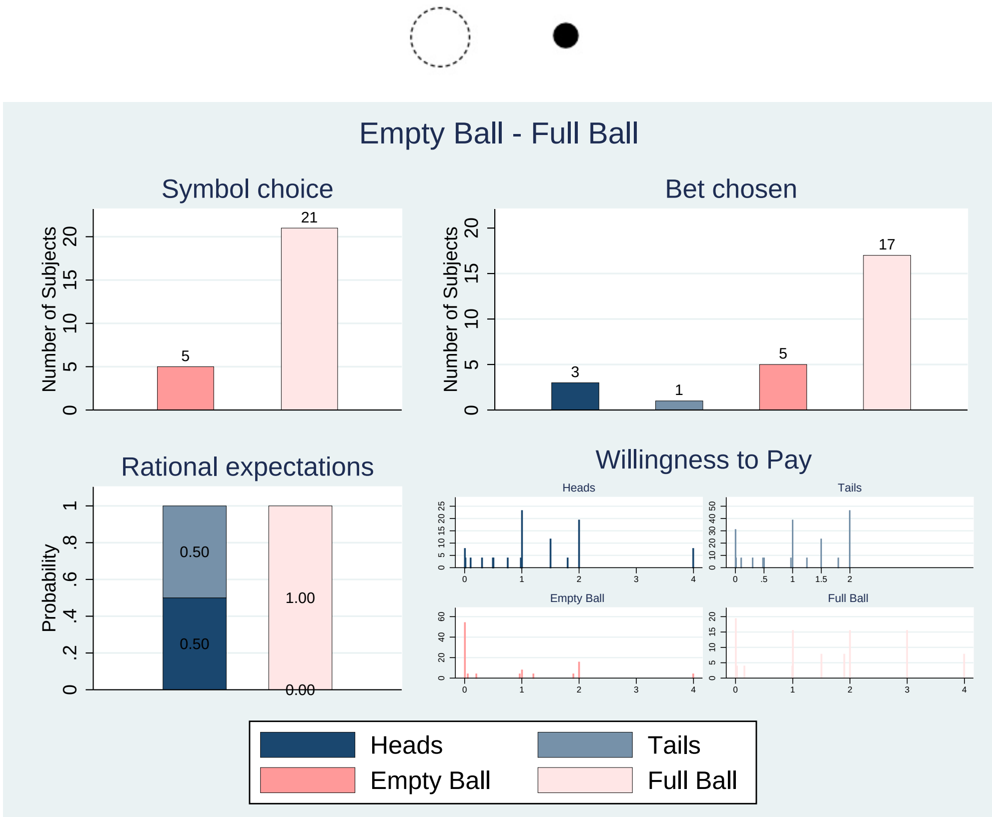
Appendix Figure C.6.— Up-Right vs. Up-Left Angle



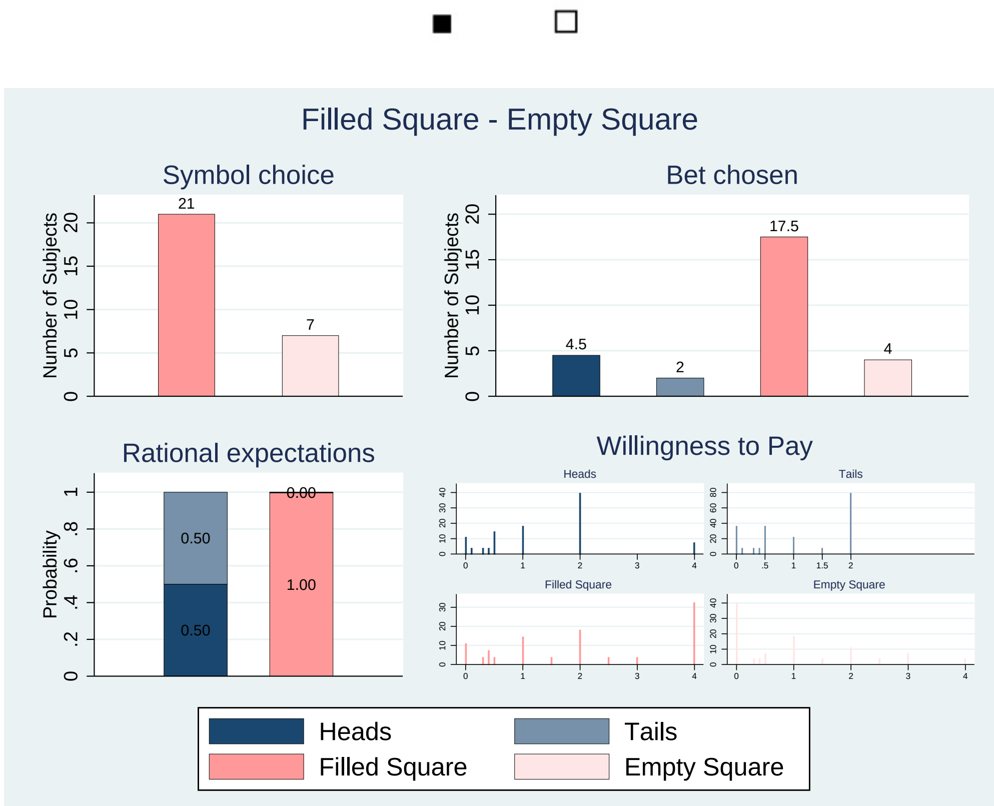
Appendix Figure C.7.— Down-Left vs. Down-Right Angle (1/2)



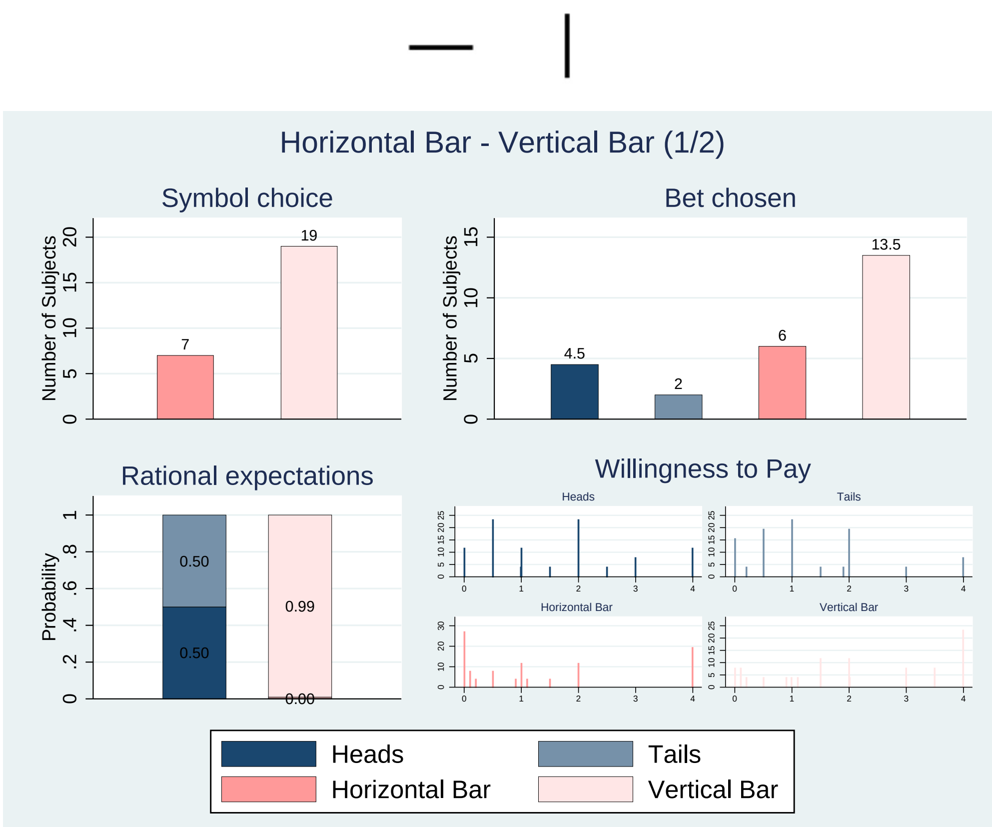
Appendix Figure C.8.— Down-Left vs. Down-Right Angle (2/2)



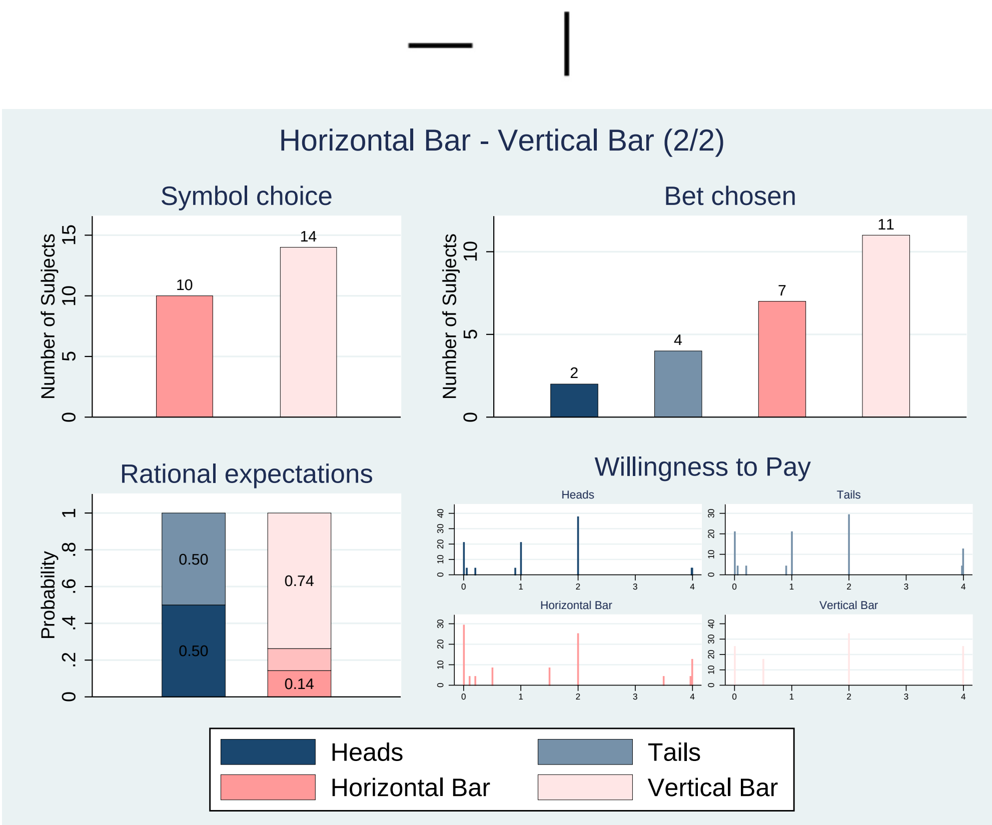
Appendix Figure C.9.— Empty vs. Full ball



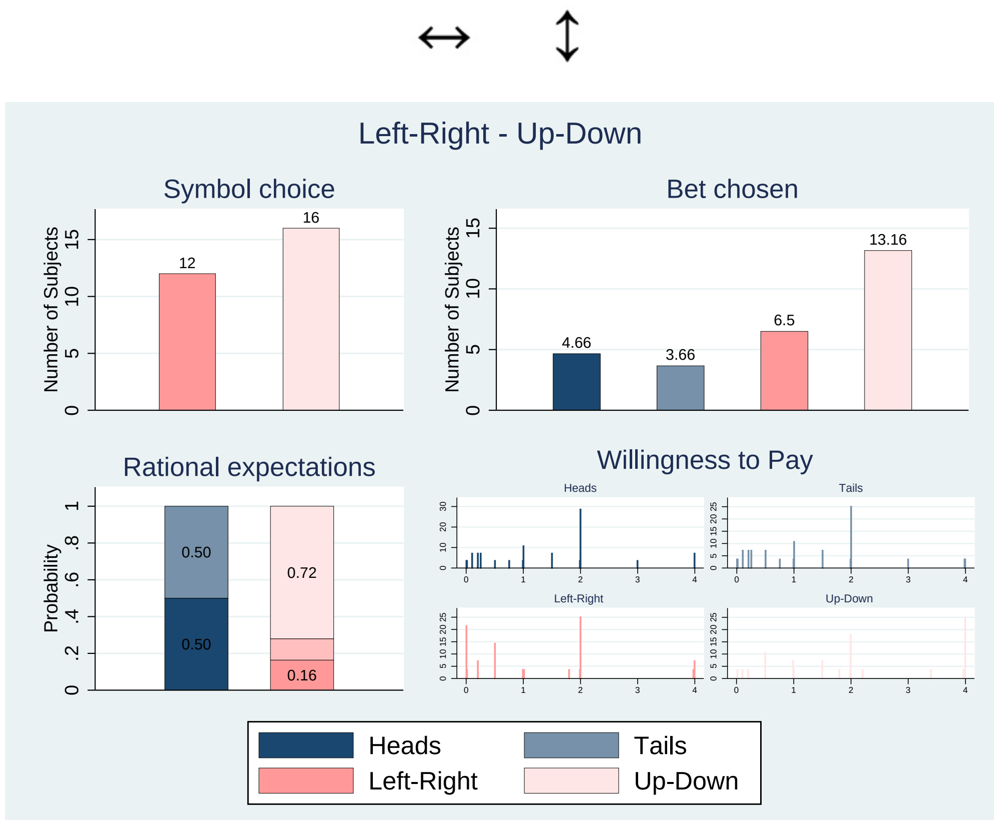
Appendix Figure C.10.— Filled Square vs. Empty Square



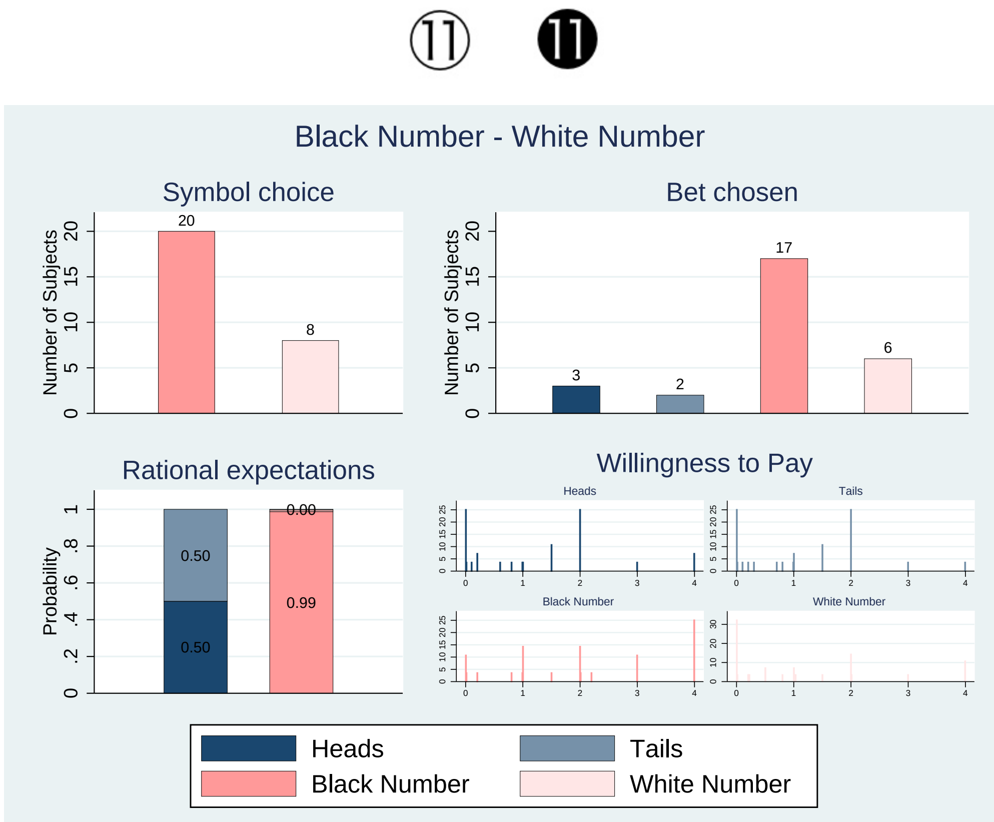
Appendix Figure C.11.— Horizontal vs. Vertical Bar (1/2)



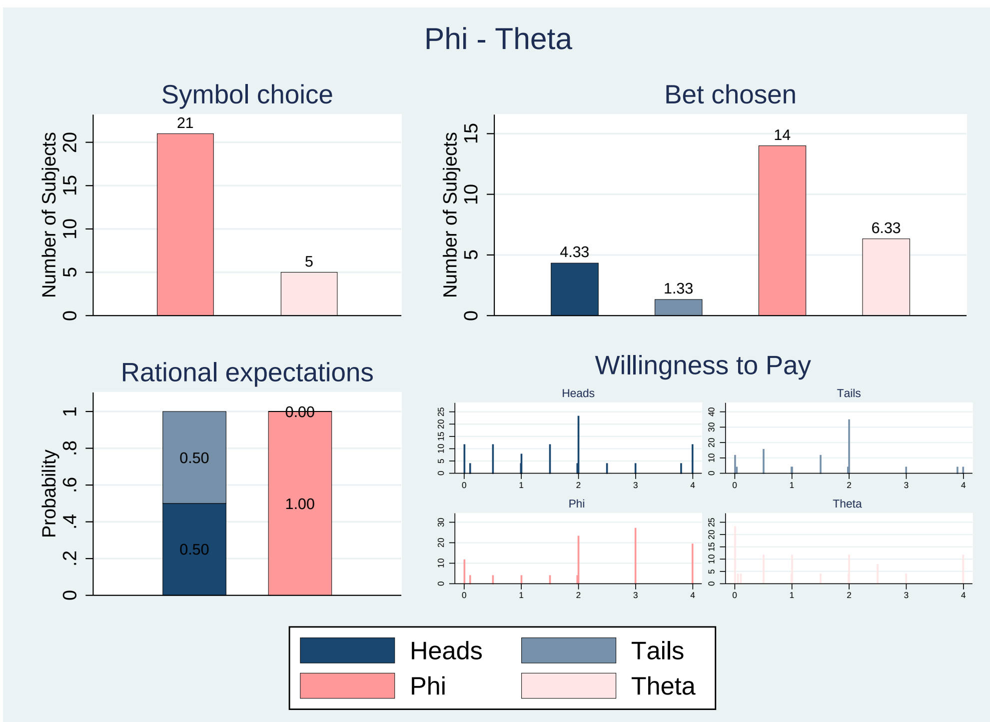
Appendix Figure C.12.— Horizontal vs. Vertical Bar (2/2)



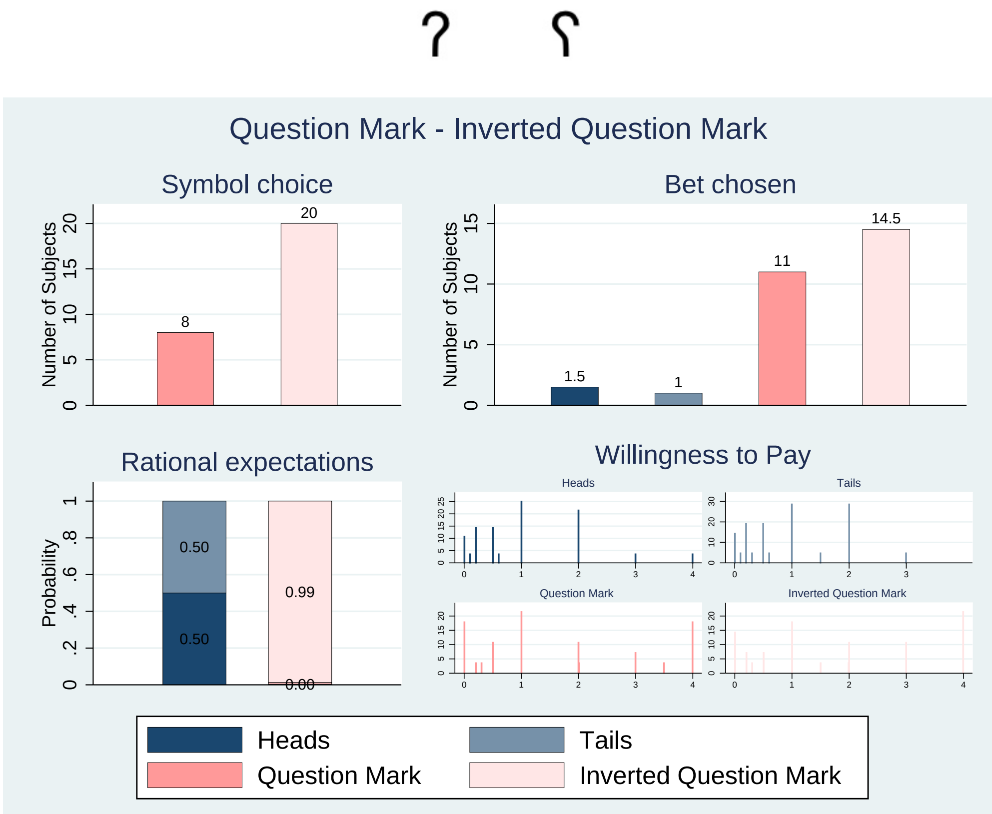
Appendix Figure C.13.— Left-Right vs. Up-Down Arrow



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



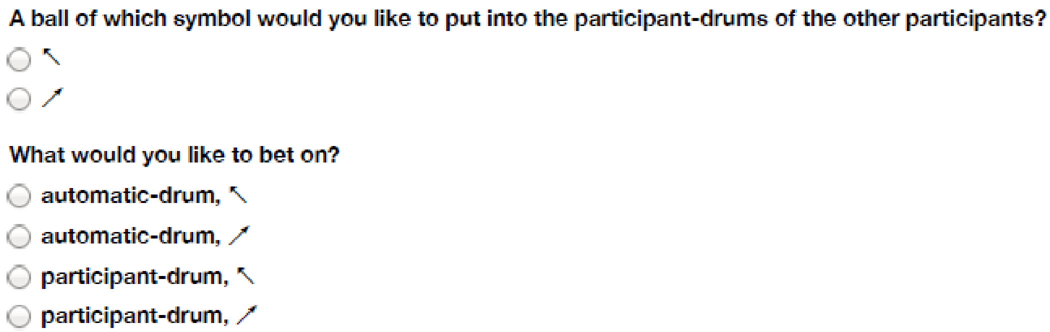
Appendix Figure C.15.— Phi vs. Theta



Appendix Figure C.16.— Question Marks

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


A ball of which symbol would you like to put into the participant-drums of the other participants?

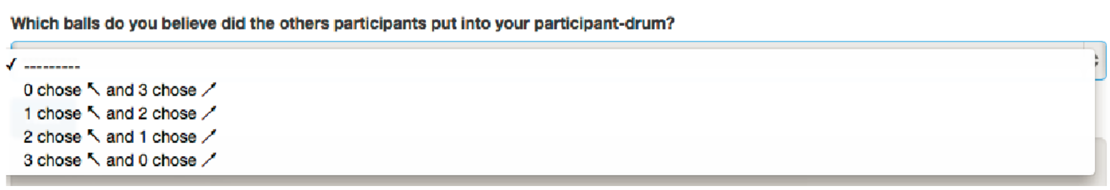
- ↖
- ↗

What would you like to bet on?

- automatic-drum, ↖
- automatic-drum, ↗
- participant-drum, ↖
- participant-drum, ↗

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

Appendix Figure D.2.— Belief elicitation


Which balls do you believe did the others participants put into your participant-drum?

✓ ---------
0 chose ↖ and 3 chose ↗
1 chose ↖ and 2 chose ↗
2 chose ↖ and 1 chose ↗
3 chose ↖ and 0 chose ↗

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)

-1

	(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)

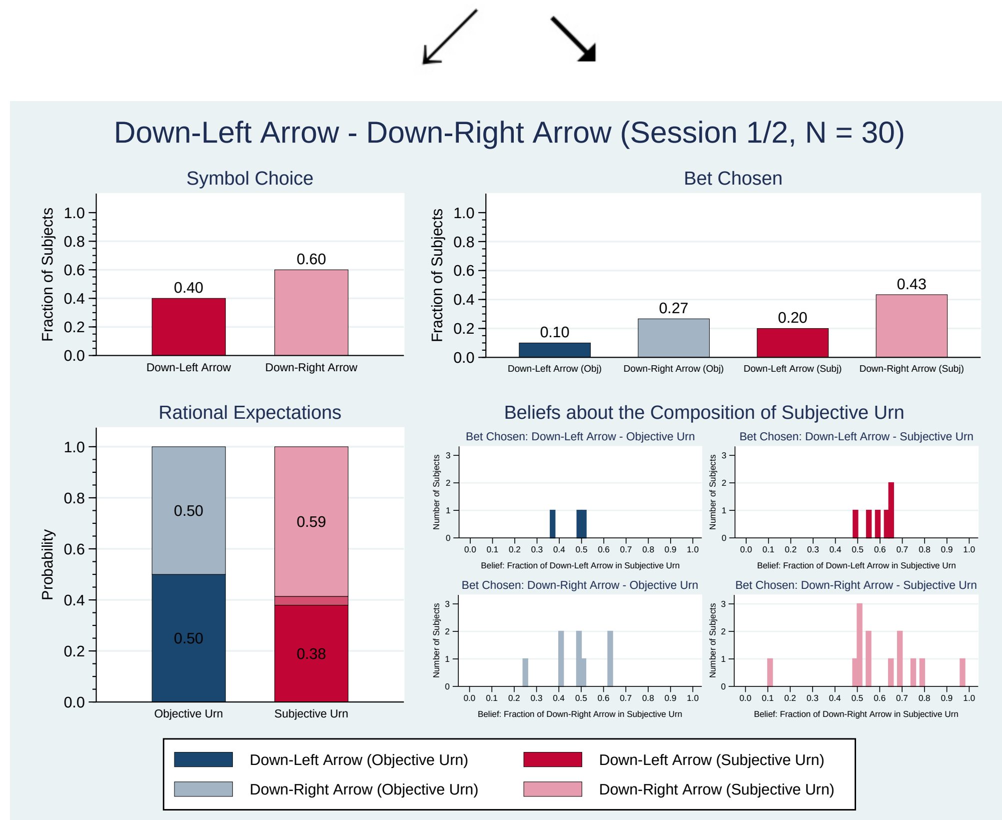
	(Hh)	(Hs)	(Sh)	(Ss)
(Hh)	$(c, c, 1)$	$(c, c, 1)$	$(0, c, c)$	$(0, c, c)$
(Hs)	$(c, c, 1)$	$(c, c, 1)$	$(1, c, c)$	$(1, c, c)$
(Sh)	$(c, 0, c)$	$(c, 1, c)$	$(0, 0, 0)$	$(0, 1, 0)$
(Ss)	$(c, 0, c)$	$(c, 1, c)$	$(1, 0, 0)$	$(1, 1, 0)$

Player 3 (Ss)

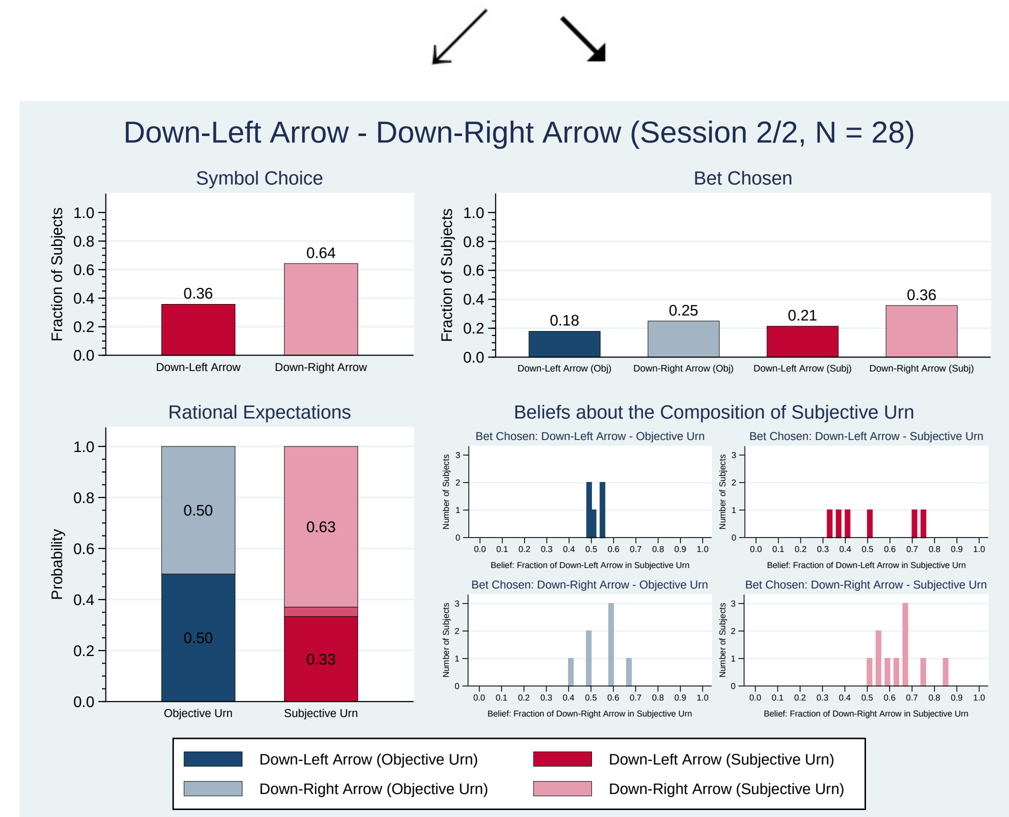
	(Hh)	(Hs)	(Sh)	(Ss)
(Hh)	$(c, c, 0)$	$(c, c, 0)$	$(0, c, c)$	$(0, c, c)$
(Hs)	$(c, c, 0)$	$(c, c, 0)$	$(1, c, c)$	$(1, c, c)$
(Sh)	$(c, 0, c)$	$(c, 1, c)$	$(0, 0, 1)$	$(0, 1, 1)$
(Ss)	$(c, 0, c)$	$(c, 1, c)$	$(1, 0, 1)$	$(1, 1, 1)$

+1

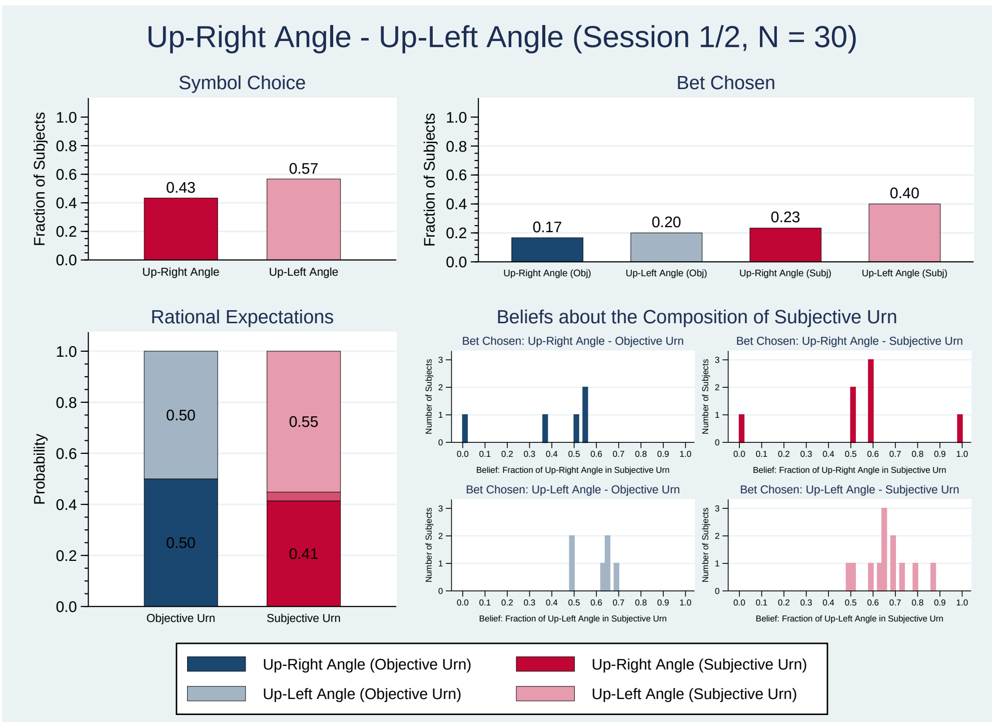
APPENDIX E: RESULTS FROM PARTICIPANT-GENERATED URN DESIGN



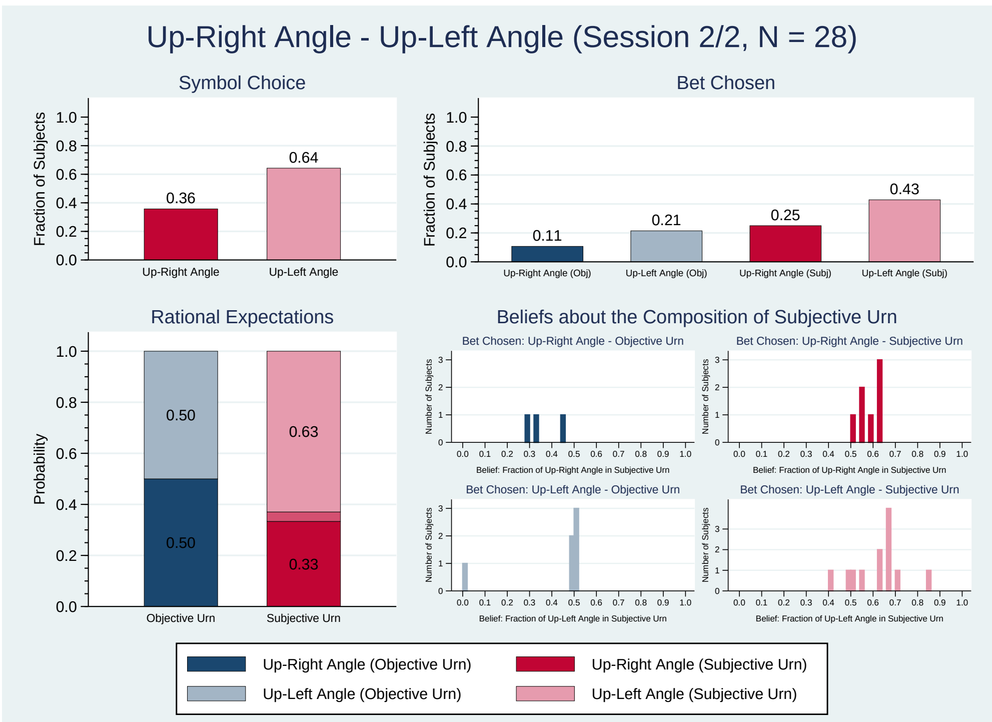
Appendix Figure E.1.— Down-Left vs. Down-Right Arrow (Session 1/2)



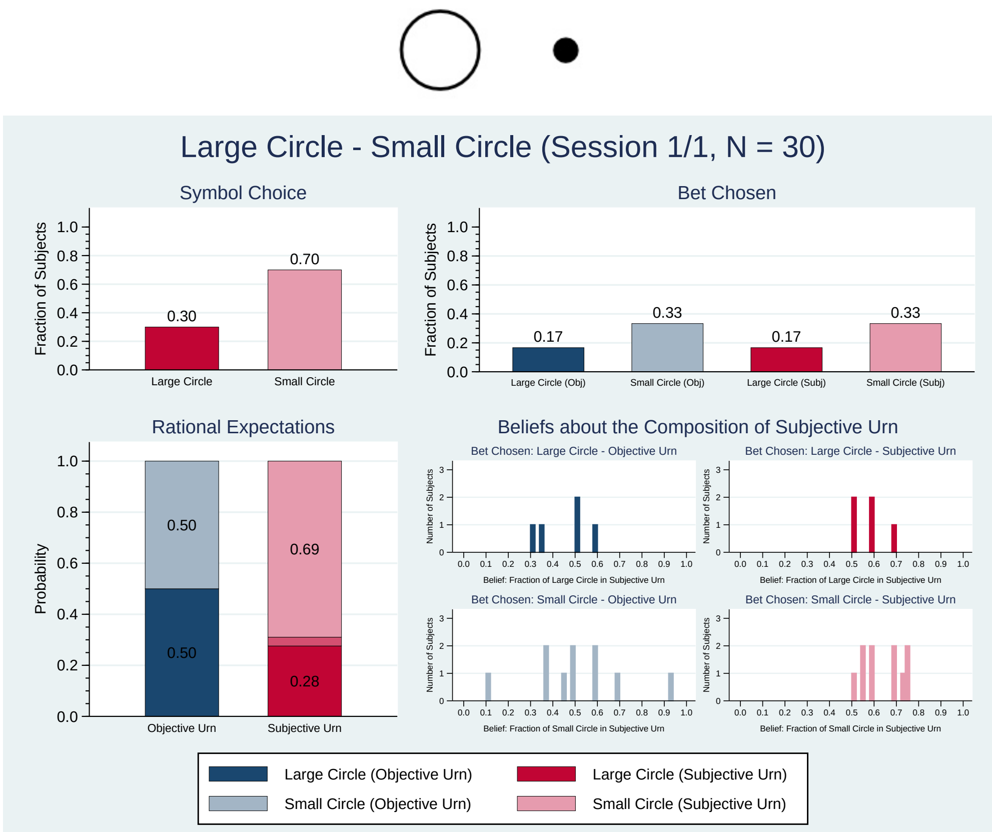
Appendix Figure E.2.— Down-Left vs. Down-Right Arrow (Session 2/2)



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