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# Attitudes towards Uncertainty and Randomization: An Experimental Study

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**Abstract**

Individuals exhibit a randomization preference if they prefer random mixtures of two bets to each of the involved bets. Such preferences provide the foundation of various models of uncertainty aversion. However, it has to our knowledge not been empirically investigated whether uncertainty-averse decision makers indeed exhibit such preferences. Here, we examine the relationship experimentally. We find that uncertainty aversion is not positively associated with randomization preferences. Moreover, we observe choices that are not consistent with the prevailing theories of uncertainty aversion: a non-negligible number of uncertain-averse subjects seem to dislike randomization.

Keywords: uncertainty aversion, randomization preference, ambiguity, Choquet expected utility model, maxmin expected utility model, experiment

JEL-Codes: D8, C9

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# 1 Introduction

The canonical paradigm for economists to model choice behavior under uncertainty is that of subjective expected utility theory (Savage, 1954; Anscombe and Aumann, 1963). Ellsberg (1961) challenged this paradigm by suggesting a series of experiments. Consider, for example, two urns that are filled with yellow and white balls. In one urn, half of the balls are yellow, the other white. In the other urn, the proportion of yellow and white balls is unknown. A ball is drawn and subjects receive 100 if they guess the color correctly, and nothing otherwise. Many subjects are indifferent between yellow and white but prefer betting on the urn with known proportions (urn K) to betting on the urn with unknown proportions (urn U). They are *uncertainty-averse* and their choices violate subjective expected utility theory; moreover, their behavior is not consistent with probabilistic sophistication in the sense of Machina and Schmeidler (1992).

In a direct comment on Ellsberg's thought experiment Raiffa (1961) suggested the following. After drawing a ball from urn U, subjects flip a fair coin to decide on which color to bet. By tossing a fair coin and betting on yellow when heads appear and on white otherwise, the objective chances of winning the bet are 50% and thus identical to those when betting on urn K. This seems to contradict the idea that betting on urn K is preferable to betting on urn U. Indeed, Raiffa proposes the randomization to 'undermine the confidence' of uncertainty-averse subjects in their choices. However, subjects who value bets on urn K and randomized bets on urn U equally may still exhibit uncertainty aversion, if they prefer a coin toss to determine the color of the winning ball rather than betting on either white or yellow when they face uncertainty. In short, subjects may agree with Raiffa's argument and still be uncertainty-averse if they have a *randomization preference*.

In view of the overwhelming empirical evidence pointing to uncertainty aversion (see the survey article by Camerer and Weber, 1992), various alternatives to subjective expected utility theory have been proposed. Many of these alternative theories, including Schmeidler's (1989) Choquet expected utility model with convex capacities, the multiple prior model of Gilboa and Schmeidler (1989), the smooth second-order prior model of Klibanoff, Marinacci, and Mukerji (2005) and the variational preferences model of Maccheroni, Marinacci, and Rustichini (2006), adopt the idea of randomization preferences to formally model uncertainty aversion. Currently, there is a theoretical debate whether uncertainty-averse subjects exhibit randomization preferences—see Epstein (2009) and Klibanoff, Marinacci, and Mukerji (2009). Moreover, predicting equilibria in games depends on whether uncertainty-averse players prefer randomization (Klibanoff 1996 and Lo 1996), or not (Dow and Werlang 1994, Eichberger and Kelsey 2000, and Marinacci 2000). However, it has to our knowledge not been empirically investigated whether uncertainty-averse subjects prefer randomization. We examine the relationship between different attitudes towards uncertainty and randomization in an experimental study.

Subjects in the experiment were faced with three random devices: a coin, an urn with a known proportion of yellow and white balls, and an urn with an unknown proportion. We offered bets based on these devices (called tickets) and elicited subjects' valuations for these tickets. We then classify subjects by their uncertainty attitude. The definition that we use captures the intuition that an uncertainty-averse subject values otherwise identical bets more if they are based on urn K rather than urn U. It coincides with the general definition proposed by Epstein (1999). Randomization attitude is measured using a ticket that mimics Raiffa's idea and which we call *chameleon ticket*. This chameleon ticket involves deliberate randomization between betting on white and on yellow when facing urn U. A subject who prefers the chameleon ticket to betting on urn U is classified as *randomization-loving*. The employed notions of uncertainty and randomization attitude are independent of each other and are hence suited to empirically study the relationship between uncertainty aversion and randomization preference without foreclosing results.

Existing theories restrict the relationship between uncertainty and randomization attitude in several ways that we can directly test with our experimental setup. First, the notion of mixture over bets embodied in Schmeidler's definition of uncertainty aversion coincides with our definition of randomization loving for subjects who are indifferent between betting on yellow and white given urn U. This notion, which is at the heart of uncertainty aversion in various models, suggests our first hypothesis: randomization and uncertainty attitude are negatively related, i.e., uncertainty aversion is associated with randomization-loving preferences.

Second, and somewhat more specifically, the most prominent approach to model uncertainty aversion is the Choquet expected utility model with convex capacities. Depending on how the randomization device is modeled, this theory leads to different predictions with respect to randomization attitudes. The more popular way is to model the device in the tradition of Anscombe and Aumann (1963) as part of the consequence space (C-approach). For this approach, Schmeidler (1989) proves that decision makers with convex capacities are always randomization-loving. On the other hand, the randomization device can also be modeled à la Savage (1954) by extending the state space (S-approach).[1] For the S-approach, Eichberger and Kelsey (1996) show that decision makers with convex capacities are randomization-neutral.[2] These two diverging predictions yield the second hypothesis: subjects who are indifferent between betting on white and yellow when facing urn U are randomization-loving (C-approach) or randomization-neutral (S-approach).

The main finding is that uncertainty and randomization attitude seem to be unrelated; the hypothesis that they are independent cannot be rejected at any conventional level. If anything, association measures suggest that uncertainty-averse subjects are randomization-averse rather than loving. This finding questions that

[1]Choquet expected utility preferences in the Savage (1954) setting were axiomatized by Gilboa (1987) and Sarin and Wakker (1992).

[2]See Ghirardato (1997) and Klibanoff (2001) for theoretical contributions on the role of randomization for Choquet expected utility preferences with convex capacities.

the notion of randomization preference underpins uncertainty aversion.

The second finding is that uncertainty-averse subjects who are indifferent between betting on white and yellow when facing urn U are more likely to be randomization-neutral rather than loving. The S-approach thus fits our data better than the C-approach.

Both hypotheses apply by construction only to subjects who exhibit specific preferences. Being concerned about selection effects, we check for selection on observables and re-examine results on the full sample. There is no indication for selection and the two findings are robust.

The rest of the paper is organized as follows. The next section describes the experimental design. In Section 3, we derive our hypotheses. Section 4 presents the results. The article ends with some concluding remarks.

# 2 Experimental design

In order to examine the relationship between uncertainty and randomization attitude, information about both attitudes from the same subject is required. We elicited the value of various bets, which are based on three random devices. This section describes the random devices, the bets, and the elicitation mechanism.

## 2.1 Random devices

During the experiment, we used three different random devices: an urn with 20 table tennis balls of which half were white and the other half yellow (urn with known proportions or short: urn K), an urn with 20 table tennis balls with an unknown proportion of yellow and white balls (short: urn U), and a coin.

Subjects were informed that only white and yellow balls are used in the experiment. Urn K's contents were shown to the subjects before the experiment, while urn U's contents were only revealed after the experiment. During the experiment, both urns were placed on a table in view of the subjects to convince them that their contents were not manipulated. For similar reasons, the coin was volunteered by one of the subjects and not by us.

## Tickets

While subjects knew that they would be offered different bets involving the three random devices, they did not know which or how many bets they would face. Tickets were then presented and evaluated by the subjects in the following order. In the description of the tickets, as in the experiment, outcomes are expressed in Taler, our experimental currency unit.

In order to check whether subjects regard the coin as fair, we introduced the following tickets.

1. **Head ticket, $h$:** 100 Taler are paid if the coin lands heads up and nothing otherwise.

2. **Tails ticket, $t$:** 100 Taler are paid if the coin lands tails up and nothing otherwise.

To elicit uncertainty attitude, we ask the subjects to evaluate the following tickets for urn K.

3. **White ticket for urn K**, $w^K$: 100 Taler are paid if the drawn ball from urn K is white and nothing otherwise.

4. **Yellow ticket for urn K**, $y^K$, 100 Taler are paid if the drawn ball from urn K is yellow and nothing otherwise.

Uncertainty attitude is then detected by comparing the value of these tickets with that of the following similar tickets for urn U.

5. **Yellow ticket for urn U**, $y^U$: 100 Taler are paid if the drawn ball from urn U is yellow and nothing otherwise.

6. **White ticket for urn U**, $w^U$: 100 Taler are paid if the drawn ball from urn U is white and nothing otherwise.

The next ticket was designed in the spirit of Raiffa's idea. It involves two random devices: the coin and urn U. The subject always receives a ticket for urn U. Whether this ticket will be yellow or white is determined by flipping the coin. Since the color of the ticket changes with the outcome of the coin toss, we use the name chameleon ticket.

7. **Chameleon ticket for urn U,** $c^U$**:** If the coin lands heads up, the subject receives a yellow ticket for urn U. If the coin lands tails up the subject receives a white ticket for urn U.[3]

By comparing the certainty equivalent for the chameleon ticket with that of a yellow or white ticket for urn U, we can draw some inference about a subject's randomization preference.

For our predictions later, it must be possible to identify whether subjects are indifferent between yellow and white tickets on urn U. This necessitates that subjects are asked about both tickets, which in principle allows them to hedge against uncertainty. The danger of hedging against uncertainty is that subjects no longer exhibit uncertainty aversion. We tried to reduce this danger by not informing subjects about the number and types of bets and switching the order in which tickets are presented for urn U. Consequently, subjects do not know that there will be a hedging opportunity when evaluating the yellow ticket for urn U. As we will see later, our method was successful in the sense that the proportion of uncertainty-averse subjects in our experiment is in line with that of similar experiments.

[3]Put differently, the subject receives 100 Taler in two cases: if the coin lands heads up and the drawn ball from urn U is yellow and if the coin lands tails up and the ball drawn from urn U is white. In the other two cases, the subject receives nothing.

## Eliciting ticket values

In order to elicit ticket values, we used the following procedure. For each ticket, the subject had to make twenty choices. The first choice was between a ticket and a payment of 2.5 Taler. The second was between a ticket and a payment of 7.5 Taler etc. The payments offered to the subject increased in steps of 5 Taler until the last choice, in which the subject had to choose between a ticket and 97.5 Taler. The point at which the subject switches from the ticket to the payment then reveals the value of the ticket to the subject (up to 5 Taler). All of the subject's choices were implemented and affected the subject's payoff. To ensure independence, a separate draw was carried out for each ticket. The draws took place after all choices were made to avoid wealth effects.

Many experiments employ less time-consuming and laborious elicitation mechanisms that combine the choices over bets with additional randomization. For example, Holt and Laury (2002) propose to randomly select only one of many choices to be payoff relevant. Another popular mechanism, which has been used in experiments on uncertainty aversion (Halevy, 2007; Hey, Lotito, and Maffioletti, 2008), is that of Becker, DeGroot, and Marschak (1964). In the Becker-DeGroot-Marschak mechanism, the subject receives a ticket and states the certainty equivalent. Then, a random offer is generated and the subject has to sell the ticket if the offer exceeds the stated value.

Despite the considerable effort involved, we decided to pay all decisions rather than employing a mechanism that relies on additional randomization. We do so for two reasons. First, as Karni and Safra (1987) point out a method based on additional randomization, such as the Becker-DeGroot-Marschak mechanism, is no longer guaranteed to elicit the true (subjective) value for subjects who violate the independence axiom.[4] Since uncertainty-averse subjects violate the independence

[4] A similar observation has been made by Holt (1986). The Becker-DeGroot-Marschak mechanism also fails to elicit true valuations if the compound lottery axiom is violated (Segal, 1988).

axiom and we are interested in their valuations, we cannot use this mechanism.[5]

Second, had we introduced another source of randomness, all bets faced by the subject would have been compounded; none would have been purely based on the three devices that we are interested in (coin, urn K, urn U). By implementing all choices, we avoid that randomization preferences interact with other sources of randomness.

# 3 Uncertainty and randomization attitude

In this section, we define randomization and uncertainty attitude, relate them to concepts from the literature, and derive empirical predictions. Let $\mathcal{L}$ be the set of tickets faced by subjects in our experiment. The binary relation $\succcurlyeq$ represents subjects preferences over $\mathcal{L}$. Denote by $\mu(l)$ a subject's certainty equivalent or value of ticket $l$ in $\mathcal{L}$. For any two tickets $k$ and $l$ in $\mathcal{L}$, we say that subjects weakly prefer $k$ to $l$, written $k \succcurlyeq l$, if and only if $\mu(k) \geqslant \mu(l)$.

## 3.1 Definitions

Comparing the certainty equivalents for the white and yellow ticket for urn U with that for the chameleon ticket, we can classify subjects according to their randomization attitudes. Consider a subject who favours the yellow ticket $y^U$ to the white ticket $w^U$ for urn $U$, i.e., $y^U \succcurlyeq w^U$. Such a subject is *randomization-averse* if she values the chameleon ticket even less than the white ticket $w^U$. Conversely, such a subject is *randomization-loving* if she values the chameleon ticket even more than the yellow ticket $y^U$. If a subject values the chameleon ticket weakly more than the white ticket $w^U$ but weakly less than the yellow ticket $w^U$, we say she is

[5] Apart from the theoretical argument, there is empirical evidence that preference reversals in measurements of uncertainty aversion occur when using the Becker-DeGroot-Marschak mechanism—see Trautmann, Vieider, and Wakker (2009).

*randomization-neutral.* The next definition formalizes this idea, where $s^U$ and $t^U$ stands for the favorite and least favorite ticket on urn U.

**Definition 1** (**Randomization attitude**). *A subject with* $s^U \succcurlyeq t^U$, *where* $s^U, t^U \in \{y^U, w^U\}$, *is:* (i) *randomization-averse if* $s^U \succcurlyeq t^U \succ c^U$,

(ii) *randomization-neutral if* $s^U \succcurlyeq c^U \succcurlyeq t^U$,

(iii) *randomization-loving if* $c^U \succ s^U \succcurlyeq t^U$.

As will become clear later, this definition coincides with the idea of a preference for convex combinations embodied in Schmeidler's (1989) uncertainty aversion axiom for subjects who are indifferent between the yellow and white ticket on urn U.

Subjects are typically regarded to be uncertainty-averse if they prefer betting on the urn with known proportions of yellow and white balls. Let us be more precise about this statement by considering a subject who weakly prefers the yellow to the white ticket on both urns ($y^K \succcurlyeq w^K$ and $y^U \succcurlyeq w^U$). Suppose this subject compares her two favorite tickets ($y^K$ and $y^U$) and her two least favorite tickets ($w^K$ and $w^U$) across urn K and urn U. Then this subject is *uncertainty-averse* if she weakly prefers the tickets on urn K to those on urn U for her favorite as well as least favorite tickets and her preference is strict in at least one case: $y^K \succcurlyeq y^U$ and $w^K \succcurlyeq w^U$ with at least one strict preference ($\succ$). Conversely, she is *uncertainty-loving* if she weakly prefers the tickets based on urn U in both cases and strictly in at least one case: $y^U \preccurlyeq y^K$ and $w^U \preccurlyeq w^K$ with at least one strict preference ($\prec$). Finally, she is *uncertainty-neutral* if she either prefers another urn for her favorite tickets than for her least favorite tickets or if she is indifferent between urns for the favorite as well as least favorite tickets: $y^U \succ y^K$ but $w^K \prec w^U$, or $y^U \succ y^K$ but $w^K \succ w^U$, or $y^U \sim y^K$ and $w^U \sim w^K$. The following definition generalizes this idea to arbitrary preferences, where $q^K$ and $r^K$ stands for the favorite and least favorite ticket on urn K, and $s^U$ and $t^U$ for the favorite and least favorite ticket on urn U. The definition is complete in the sense that each preference ordering is either uncertainty-averse, uncertainty-loving, or uncertainty-neutral.

**Definition 2 (Uncertainty attitude).** *A subject with* $q^K \succcurlyeq r^K$ *and* $s^U \succcurlyeq t^U$*, where* $q^K, r^K \in \{y^K, w^K\}$ *and* $s^U, t^U \in \{y^U, w^U\}$*, is:*

*(i)* *uncertainty-averse if* $q^K \succcurlyeq s^U$ *and* $r^K \succcurlyeq t^U$ *with at least one* $(\succ)$*,*

*(ii)* *uncertainty-loving if* $q^K \preccurlyeq s^U$ *and* $r^K \preccurlyeq t^U$ *with at least one* $(\prec)$*,*

*(iii)* *uncertainty-neutral otherwise, i.e.,*

$$\begin{aligned} &\text{if} \quad q^K \sim s^U \quad \text{and} \quad r^K \sim t^U, \\ &\text{or} \quad q^K \succ s^U \quad \text{and} \quad r^K \prec t^U, \\ &\text{or} \quad q^K \prec s^U \quad \text{and} \quad r^K \succ t^U. \end{aligned}$$

It is customary to view urns with known proportions of balls and coins as risky. Based on exogenously given risky bets, Epstein (1999) derives a comparative foundation of uncertainty attitudes. Given that bets on urn K are risky, our definition coincides with that of Epstein (see appendix). Ghirardato and Marinacci (2002) propose an alternative comparative definition of uncertainty aversion without exogenously imposing that certain bets are risky. For this definition, it is necessary to hold the subject's risk attitude constant. Empirically, this requires measuring the risk attitude, which in turn is not possible without exogenous assumptions about which bets are risky. Accordingly, we cannot use this alternative approach to determine uncertainty attitude in our experiment.

## 3.2 Predictions

The general definitions allow for any combination of uncertainty and randomization attitude. For example, a subject may in principle be uncertainty-neutral but like randomization or it may be averse to uncertainty and randomization. This section uses existing theoretical models to restrict the relationship between uncertainty and randomization attitude and derive predictions.

In order to represent uncertainty aversion, a large class of models appeals to Schmeidler's (1989) notion that a mixture between two bets is preferred to each of the bets itself. In the specific framework used by Schmeidler, bets are mappings from events to probability distributions over the set of payoffs, so that the convex combination of two bets, $f$ and $g$: $\alpha f + (1-\alpha)g$ with $\alpha \in (0,1)$ is well defined. Schmeidler calls a subject with $f \succeq g$ uncertainty-averse if

$$\alpha f + (1-\alpha)g \succeq g.$$

For subjects who violate the independence axiom, the convex combination is strictly preferred. Interpreting $\alpha$ as the probability of obtaining a yellow ticket for urn U and $1-\alpha$ as the probability of obtaining a white ticket for urn U, this means that an uncertainty-averse subjects prefers the chameleon ticket, i.e., the mixture of two bets, to the least favorite ticket on urn U. Restricting attention to subjects with $y^U \sim w^U$, we get: $c^U \succ w^U \sim y^U$. Schmeidler's notion then coincides with the definition of randomization-loving (see Definition 1). In perfect analogy, subjects are (strict) uncertainty-loving according to Schmeidler if $\alpha f + (1-\alpha)g \prec f$, which means that $c^U \prec w^U \sim y^U$ for subjects with $y^U \sim w^U$; the dislike for mixtures then is equivalent to randomization aversion in Definition 1.

For subjects who are indifferent between the yellow and white ticket for urn U, Schmeidler's notion of preferences for mixtures thus coincides with our definition of randomization attitude. Based on the various models that appeal to preferences for mixtures to explain uncertainty attitude, we hence predict uncertainty-averse subjects to be randomization-loving and uncertainty-loving subjects to be randomization-averse (given $y^U \sim w^U$).

**Hypothesis 1**

*For subjects who are indifferent between the yellow and white ticket on urn U, $y^U \sim w^U$, uncertainty and randomization attitude are negatively associated: uncertainty-averse subjects are randomization-loving and vice versa.*

As the null hypothesis, we consider that there is no relationship between uncertainty and randomization attitude.

If uncertainty aversion is modeled using Choquet expected utility models with convex capacities, the relationship between uncertainty and randomization attitude depends on whether the randomization device is modeled as part of the consequence space (C approach) or as an extension of the state space (S approach). As Eichberger and Kelsey (1996) show that uncertainty-averse decision makers who are indifferent between two acts based on an uncertain urn, $y^U \sim w^U$, and who regard the randomization device as fair, $h \sim t$, are randomization-loving in the C-approach but are randomization-neutral in the S-approach. This directly leads to the hypotheses.

**Hypothesis $\mathbf{2_C}$**

*Uncertainty-averse subjects with $y^U \sim w^U$ and $h \sim t$ are randomization-loving.*

**Hypothesis $\mathbf{2_S}$**

*Uncertainty-averse subjects with $y^U \sim w^U$ and $h \sim t$ are randomization-neutral.*

We test these two alternatives against the null hypothesis that uncertainty-averse subjects with $y^U \sim w^U$ and $h \sim t$ are equally likely to be randomization-neutral and randomization-loving.

## 4 Implementation

We ran a total of 5 sessions with 90 subjects. All sessions were conducted in the experimental laboratory at the University of Mannheim in late September 2008. Subjects were primarily students who were randomly recruited from a pool of approximately 1000 subjects using an e-mail recruitment system. Each subject only participated in one of the sessions. Ticket values were elicited electronically using the software z-tree (Fischbacher, 2007).

After the subjects' arrival at the laboratory, they were randomly seated at the computer terminals. Instructions were read out loud and ticket types were practically explained. Then, the subjects were given time to study the instructions (see appendix for a translation of the instructions). Finally, they were asked to answer a series of questions to test their understanding of the instructions. During all this time, subjects could ask the experimenters clarifying questions. This part lasted about 30 minutes. It was followed by the evaluation of the tickets. In order to simplify the input for subjects, we programmed a slider that allowed them to specify their value for each ticket. The program then automatically selected choices that were consistent with this ticket value. Using the slider was not obligatory and a subject could arbitrary alter its choice until he or she decided to finish evaluation of a specific ticket (see Figure 6 in the appendix for a screen shot). After the evaluation of tickets, we asked subjects questions about their demographics and attitudes toward uncertainty. We also gave them some problems to test their statistics knowledge and cognitive ability. Subjects took about 30 minutes for this second part. The last and final part required drawing balls and flipping coins in order to determine payoffs. With 8 types of tickets and twenty choices between ticket and fixed payment for each type, subjects could obtain up to 160 tickets. This last part required roughly 30 minutes so that the whole experiment lasted about 90 minutes.

At the end of the experiment, we paid each subject privately in cash. All payoffs were initially explained in Taler that were later converted using the rate that 100 Taler=10 cents. Subjects earned on average 11.35 Euro.

# 5 Results

Two subjects violated transitivity in their choices, which leaves us with 88 independent observations. In line with previous experimental studies (see Camerer and Weber, 1992), many subjects exhibit the Ellsberg paradox: a share of about 55% prefer betting on the risky urn, while ca. 9% prefer betting on the uncertain urn, and roughly 36% are indifferent.

## 5.1 Main findings

In order to formally check Hypothesis 1, we restrict our sample to subjects who value white and yellow ticket on urn U equally, so that Schmeidler's notion of mixture preference co-incides with the definition of randomization attitude. Since about a third of the subjects prefer a ticket of one color on urn U, the analysis is based on 53 observations.

**Result 1.** *For subjects who value white and yellow tickets on urn U equally, uncertainty and randomization attitude are not negatively associated.*

From the literature, we expect uncertainty-averse subjects to be randomization-loving and uncertainty-loving subjects to be randomization-averse. Accordingly, observations should lie on the diagonal from the top-left to the bottom-right in Table 1. While 19 out of the 53 observations exhibit this relationship, about two thirds of the observations lie off the diagonal. Using Fisher's exact test, we cannot reject the null hypothesis that there is no relationship at any conventional level (p-value=0.118).[6] Moreover, the number of observations that lie on the other diagonal and are consistent with a positive relationship (25 out of 53) is higher. Accordingly, Goodman and Kruskal's $\gamma$ as well as Kendall's $\tau_b$, which can be used to measure the association between the two ordinally scaled attitudes, are both positive. If there is any tendency to reject independence it is hence in favor of a positive rather than a negative relationship.

Recall that S- and C-approach lead to diverging predictions about the randomization preferences for subjects who are uncertainty-averse, regard the coin as fair, and value white and yellow ticket on urn U equally. This concerns 29 subjects in

[6] Neither Pearson's $\chi^2$ (p-value=0.163) nor the likelihood ratio test (p-value=0.083) are significant.

| | | *Uncertainty Attitude* | | | |
|---|---|---|---|---|---|
| | | *Averse* | *Neutral* | *Loving* | *Total* |
| *Randomization Attitude* | *Loving* | 6 | 0 | 1 | 7 |
| | *Neutral* | 17 | 12 | 2 | 31 |
| | *Averse* | 12 | 2 | 1 | 15 |
| | *Total* | 35 | 14 | 4 | 53 |

Table 1: Uncertainty and randomization attitude for subjects who value white and yellow ticket on urn U equally

our sample. The C-approach predicts these subjects to like randomization, while the S-approach predicts them to be randomization-neutral. The following result is based on the 20 observations that are in line with one of these predictions.

**Result 2.** *Consider uncertainty-averse subjects who regard the coin as fair and value the yellow and white ticket on urn U equally. These subjects are more likely to be randomization-neutral than to prefer randomization.*

Sixteen of the 20 subjects are randomization-neutral, while four prefer randomization—see Figure 1. The hypothesis that subjects are equally likely to be randomization-loving or neutral can be rejected at any conventional level (The respective binomial test has a p-value below 0.01): a significantly larger fraction of subjects is randomization-neutral.

This result can be extended to uncertainty-loving subjects, who are supposed to dislike randomization according to the C-approach and to be randomization-neutral according to the S-approach. Two uncertainty-loving subjects are randomization-neutral and one is randomization-averse. Overall, 18 of 23 observations are in line with the S-approach and only 5 with the C-approach. Again, a uniform distribution of randomization preferences can be rejected in favor of the predictions consistent with the S-approach at any conventional level (p-value below 0.01).

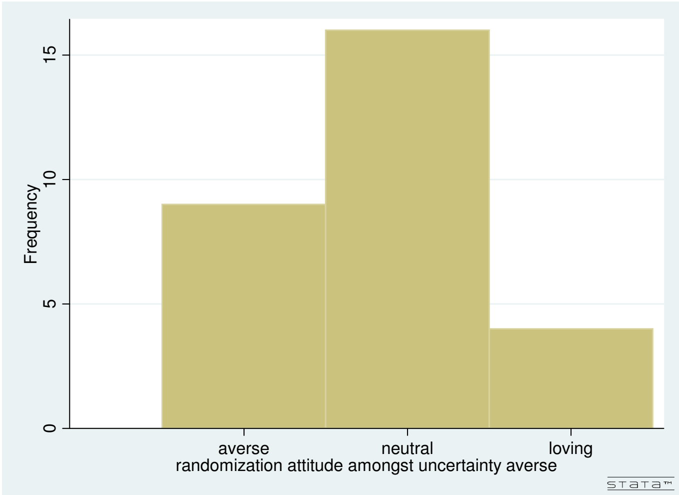


Figure 1: Randomization attitudes of uncertainty-averse subjects who regard the coin as fair and value white and yellow ticket on urn U equally

## 5.2 Robustness

The theoretical results, which underpin Hypothesis 1 and 2, only apply to subjects with specific preferences. Consequently, Result 2 and 3 are based on a selected sample of subjects, which may not only differ by their preferences but by other characteristics.

We check whether any selection on observables has taken place by running two probit regressions. Hypothesis 1 requires subjects to be indifferent between the yellow and white ticket on urn U. This indifference, however, does not seem to be related to observables: the null hypothesis that no observable affects the probability of being indifferent cannot be rejected (p-value of the likelihood ratio test: 0.43, see Table 4 in the appendix). For Hypothesis 2, subjects must additionally regard the coin as fair. This time there is some indication that observables affect selection (p-value for the likelihood ratio test: 0.04). More specifically, subjects who correctly compute the probability of two independently thrown dice (variable: stats knowledge 2) are significantly more likely to be in the sample (see Table 5 in the appendix).

Accordingly, we expect these subjects to be more in line with theoretical predictions.

Subjects on which we test our hypotheses may also differ in unobservable ways. The independence between uncertainty and randomization attitude could, for example, be driven by the fact that subjects who are indifferent between white and yellow tickets on urn U systematically differ from other subjects. In order to refute this idea, we re-examine the relationship between uncertainty and randomization attitude without restricting attention to certain preferences. Of course, Hypotheses 1 and 2 no longer apply in this case. If, however, results are similar, we can be confident that they do not hinge on an alternative explanation such as a general trait to value tickets equally. Table 2 exhibits the attitudes when all subjects are considered. Both findings are confirmed. First, the null hypothesis that uncertainty aversion and random preference are unrelated cannot be rejected (p-value of Fisher's exact test: 0.18). As before, the data suggests that uncertainty aversion is associated positively with randomization aversion. Second, uncertainty-averse subjects tend to be randomization-neutral rather than randomization-loving and uncertainty-loving subjects are more likely to be randomization-neutral than to be randomization-averse (p-value for the two-sided binomial test is below 0.01). This robustness of results gives us some confidence that they are not driven by selection effects.

| | | *Uncertainty Attitude* | | | |
|---|---|---|---|---|---|
| | | *Averse* | *Neutral* | *Loving* | *Total* |
| *Randomization Attitude* | *Loving* | 10 | 2 | 2 | 14 |
| | *Neutral* | 24 | 23 | 6 | 53 |
| | *Averse* | 14 | 5 | 2 | 21 |
| | *Total* | 48 | 30 | 10 | 88 |

Table 2: Uncertainty and randomization attitude: all subjects

## 5.3 Other findings

In addition to these results, which directly relate to our hypotheses, we also want to report on two additional and unexpected findings.

The first concerns randomization- and uncertainty-averse subjects. We expected to find very few of them because they are not backed by the most prevalent models of uncertainty-aversion—irrespective of whether they are axiomatized in the S- nor in the C-approach.

**Result 3.** *A non-negligible fraction of uncertainty-averse subjects dislikes randomization.*

Of the 48 uncertainty-averse subjects, 14 express a dislike for randomization (see Table 2). If we restrict attention to subjects for whom behavior can be predicted using the S- or C-approach because they regard the coin as fair and have no color preference on urn U, a similar picture emerges: 9 out of 29 uncertainty-averse subjects prefer the pure tickets over the mixture—see Figure 1. In both cases, the share is statistically not distinguishable at any conventional level from the naive prediction by someone who does not know any of these theories and expects randomization aversion to occur in a third of the cases.

The observed combination of randomization and uncertainty aversion is puzzling. The respective subjects prefer to know whether the ticket, which they receive, is white or yellow—although they are indifferent between receiving a white and a yellow ticket. Possible reasons are that knowing the color has a value in itself to these subjects, that they assign lower values to tickets when complexity is involved, or that they dislike the loss of control associated with the coin.[7]

[7]Keren and Teigen (2008) argue that such decision makers like to maintain control. Dittmann, Kübler, Maug, and Mechtenberg (2008) find that experimental subjects are willing to pay a premium for exerting the right to vote even if the probability that this affects the outcome is very low. On the other hand, Cettolin and Riedl (2008) observe that subjects prefer a random draw when having to decide between risky and uncertain prospects.

Our second finding is related to a theoretical result by Klibanoff (2001). Klibanoff shows that if a randomizing device is stochastically independent and Choquet-expected utility preferences are modeled in the S-approach, preferences cannot exhibit uncertainty-aversion. This implies for our context that subjects whose preferences can be modeled using the S-approach because they are uncertainty-averse and randomization-neutral should regard the coin to be correlated with urn U. In order to test this, we constructed a bet in which a ball is drawn from urn U; the subject then receives a head ticket if the ball is yellow and its certainty equivalent of a head ticket if the ball is white. Subjects who view coin and ball draw as independent should attach the same value to this bet, which we call *combination ticket*, and a head ticket. We restrict attention to subjects who regard the coin as fair, value white and yellow tickets on urn U equally, and are randomization-neutral. Following Klibanoff's argument, we expect these subjects to be less likely to attach different values to the combination and head ticket if they are uncertainty-neutral. Indeed, the respective share of subjects is lower amongst uncertainty-neutral subjects (20%) than amongst other uncertainty-averse subjects (31%); however, the difference is not significant at any conventional level (p-value of one-sided two-sample test of proportion: 0.26). More surprising, the proportion of *all* subjects who value the head ticket more than the combination ticket is 37%. Put differently, these subjects prefer a head ticket to a mixture of head ticket and its certainty equivalent. While a possible explanation is that subjects regard coin throw and ball draw as correlated, there is an interesting link between this finding and randomization aversion: subjects who favor the heads to the combination ticket also tend to favor tickets of a specific color to the chameleon ticket (Kendall's $\tau_b$=0.1966, p-value: 0.0559). A first tentative conclusion may thus be that both results are driven by the same explanation, e.g., a distaste for complexity.

# 6 Conclusions

We started our analysis with the classical observation from the two-color experiment by Ellsberg (1961): individuals prefer to bet in situations about which they are better informed. Existing explanations for such behavior often rely on the idea that access to an objective randomization device mitigates the problem of lacking information. Accordingly, uncertainty-averse individuals are supposed to prefer randomization. The data from our experiment, however, does not support this view: there is no negative association between uncertainty and randomization attitude. Uncertainty-averse subjects are more likely to be randomization-neutral than randomization-loving. Their behavior is consistent with modeling uncertainty aversion in a Savage framework (S-approach) rather than using the consequence space in the tradition of Anscombe-Aumann (C-approach). None of the prevailing theories of uncertainty aversion, however, explains another phenomenon observed in our experiment: a considerable number of uncertainty-averse subjects exhibits a contempt for randomization. This could indicate that for many subjects, the randomization device does not reduce but enhances the problem of missing information.

# Appendix

## Uncertainty attitude

In this section we introduce a notation and show that under mild conditions our definition of uncertainty attitudes coincides with the definition proposed by Epstein (1999).

### Notation

All circumstances that affect subjects payoffs are represented by a state space $S$. An event, $E$, is a subset of $S$. The set of all possible payoffs is denoted by $X$. Objects of choice are bets, denoted by $f$, which are mappings from the state space $S$, to the set of all possible payoffs $X$. Binary bets $x_E y$ assign a constant payment $f(s) = x$ to each state of nature $s$ in $E$ and a constant payment $g(s) = y$ to each state of nature $s$ in $S \setminus E$, with $x, y \in X$. More general, bets $f_E g$ assign a payoff $f(s)$ to each state of nature $s$ in $E$ and a payoff $g(s)$ to each state of nature $s$ in $S \setminus E$. Let $\mathcal{F}$ be a set of all possible bets and let $\succcurlyeq$ be a binary relation that represents subjects' preferences over $\mathcal{F}$. For any bet $f, g, h \in \mathcal{F}$ we write $f \succcurlyeq \{g, h\}$ to denote $f \succcurlyeq g$ and $f \succcurlyeq h$.

### Result

Recently, Epstein (1999) proposed a two-stage approach to define uncertainty attitudes.[8] In this approach first a comparative notion of uncertainty aversion and then an absolute definition for uncertainty aversion is established. The comparative definition is based on the following idea: if a subject prefers an unambiguous bet to an ambiguous one, then a more uncertainty-averse subject will do the same. For Epstein, a bet is unambiguous if its payoffs depend on exogenously given unambigu-

[8] The two-stage approach is used also by Ghirardato and Marinacci (2002).

ous events, i.e., events which randomness is objectively known (for instance a fair coin, a roulette wheel, etc.). Let $\mathcal{F}^{ua}$ be the set of unambiguous bets. Consider two preference relations $\succcurlyeq_1$ and $\succcurlyeq_2$. Then, $\succcurlyeq_1$ is said to be more uncertainty-averse than $\succcurlyeq_2$ if for any unambiguous bet $h \in \mathcal{F}^{ua}$ and any bet $e \in \mathcal{F}$:

$$h \succcurlyeq_1 (\succ_1) e \;\Rightarrow\; h \succcurlyeq_2 (\succ_2) e. \tag{1}$$

An absolute definition of uncertainty attitudes is derived by choosing a benchmark order for uncertainty-neutral preferences. Epstein (1999) uses for the benchmark order, $\succcurlyeq^{PS}$, preferences that are probabilistically sophisticated in the sense of Machina and Schmeidler (1992). According to this theory subjects' subjective beliefs are represented by an unique and additive probability distribution, but preferences do not need to have expected utility representation. Then, $\succcurlyeq$ is said to be *uncertainty-averse* if there exists a probabilistically sophisticated preference relation $\succcurlyeq^{PS}$ such that for any $h \in \mathcal{F}^{ua}$ and any bet $e \in \mathcal{F}$:

$$h \succcurlyeq^{PS} (\succ^{PS}) e \;\Rightarrow\; h \succcurlyeq (\succ) e. \tag{2}$$

Conversely, $\succcurlyeq$ is said to be *uncertainty-loving* if there exists a probabilistically sophisticated preference relation $\succcurlyeq^{PS}$ such that for any $h \in \mathcal{F}^{ua}$ and any bet $e \in \mathcal{F}$:

$$h \preccurlyeq^{PS} (\prec^{PS}) e \;\Rightarrow\; h \preccurlyeq (\prec) e. \tag{3}$$

If $\succcurlyeq$ is both uncertainty-averse and uncertainty-loving then it is *uncertainty-neutral.*[9]

**Proposition 1.** *If urn $K$ is viewed as unambiguous, then our empirical definition coincides with that of Epstein (1999).*

*Proof.* Throughout, we consider a subject with the following preferences:

$$q^K \succcurlyeq r^K \;\text{ and }\; s^U \succcurlyeq t^U, \tag{4}$$

[9]Ghirardato and Marinacci (2002) use for the benchmark order preferences respecting subjective expected utility representation à la Savage (1954). As unambiguous bets they consider only constant bets, i.e., $h(s) = x$ for any $s \in S$ with $x \in X$.

where $q^K, r^K \in \{y^K, w^K\}$ and $s^U, t^U \in \{y^U, w^U\}$. Let $Q^K, R^K \in \{Y^K, W^K\}$, and $S^U, T^U \in \{Y^U, W^U\}$ be the corresponding events. Suppose that subjects being informed about the exact composition of white and yellow balls in the urn $K$ view it as unambiguous. In this situation payoffs of the yellow ticket $y^K$ and the white ticket $w^K$ depend upon the realization of unambiguous events $Y^K$ and $W^K$ to which subjects assign probabilities $\pi[Y^K]$ and $\pi[W^K]$. Thus, both tickets are unambiguous bets, i.e. $y^K, w^K \in \mathcal{F}^{ua}$.

Let us first consider the behavior of an uncertainty-neutral subject according to Epstein. Note that any probabilistically sophisticated order is equivalent to an order based on probabilities. All orders based on probabilities fall into one of the three following cases:

$$q^K \sim^{PS} s^U \succcurlyeq^{PS} t^U \sim^{PS} r^K, \tag{5}$$

$$q^K \succ^{PS} s^U \succcurlyeq^{PS} t^U \succ^{PS} r^K, \tag{6}$$

$$s^U \succ^{PS} q^K \succcurlyeq^{PS} r^K \succ^{PS} t^U. \tag{7}$$

The subsequent proof proceeds in three steps. In Step 1, we show that uncertainty-averse subjects according to Definition 2 are also uncertainty-averse according to Epstein. In Step 2 and 3, we do the same for uncertainty-loving and uncertainty-neutral subjects.

*Step 1: Uncertainty aversion.*

By assumption, $q^K \succcurlyeq s^U$ and $r^K \succcurlyeq t^U$ with at least one strict preference relation ($\succ$). We examine two cases: $q^K \sim r^K$ and $q^K \succ r^K$.

*Case 1:* $q^K \sim r^K$. In this case, we obtain:

$$q^K \sim r^K \succcurlyeq s^U \succcurlyeq t^U, \tag{8}$$

with at least one strict preference. Take $\succcurlyeq^{PS}$ with $\pi(Q^K) = \pi^{PS}(Q^K)$ as in (5) such that:

$$q^K \sim^{PS} s^U \sim^{PS} t^U \sim^{PS} r^K. \tag{9}$$

Comparing $\succcurlyeq$ from (8) with $\succcurlyeq^{PS}$ as in (9), we get:

$$q^K \sim^{PS} \{r^K, s^U, t^U\} \;\;\Rightarrow\;\; q^K \sim \{r^K\} \succcurlyeq \{s^U\} \succcurlyeq \{t^U\},$$
$$r^K \sim^{PS} \{q^K, s^U, t^U\} \;\;\Rightarrow\;\; r^K \sim \{q^K\} \succcurlyeq \{s^U\} \succcurlyeq \{t^U\},$$

where at least one of the weak preference is strict in each row. Thus, there exists $\succcurlyeq^{PS}$ such that $\succcurlyeq$ is more uncertainty-averse then $\succcurlyeq^{PS}$ according to Epstein—see (2).

*Case 2:* $q^K \succ r^K$. In this case, one of the following can occur:

$$q^K \succ r^K \succcurlyeq s^U \succcurlyeq t^U, \text{ or} \tag{10}$$

$$q^K \succcurlyeq s^U \succ r^K \succcurlyeq t^U, \tag{11}$$

with at least one strict preference in each case. Take $\succcurlyeq^{PS}$ with $\pi(Q^K) = \pi^{PS}(Q^K)$ as in (5) such that:

$$q^K \sim^{PS} s^U \succ^{PS} t^U \sim^{PS} r^K.$$

Comparing this $\succcurlyeq^{PS}$ with $\succcurlyeq$ as in (10), we get:

$$q^K \sim^{PS} \{s^U\} \succ^{PS} \{r^K, t^U\} \;\;\Rightarrow\;\; q^K \succ \{r^K, s^U, t^U\},$$
$$r^K \sim^{PS} \{t^U\} \;\;\Rightarrow\;\; r^K \succcurlyeq \{s^U, t^U\}.$$

Analogously, the comparison with $\succcurlyeq$ as in (11), yields:

$$q^K \sim^{PS} \{s^U\} \succ^{PS} \{r^K, t^U\} \;\;\Rightarrow\;\; q^K \succcurlyeq \{s^U\} \succcurlyeq \{r^K, t^U\},$$
$$r^K \sim^{PS} \{t^U\} \;\;\Rightarrow\;\; r^K \succ \{t^U\}.$$

Thus, for preference ordering $\succcurlyeq$ as in (10) and as in (11), there exists $\succcurlyeq^{PS}$ such that $\succcurlyeq$ is more uncertainty-averse then $\succcurlyeq^{PS}$ according to Epstein—see (2). Summarizing both cases, we have seen that for $q^K \succcurlyeq s^U$ or $r^K \succcurlyeq t^U$ with at least one strict preference relation ($\succ$), $\succcurlyeq$ is uncertainty-averse according to Epstein.

*Step 2: Uncertainty loving.*

By assumption, $q^K \preccurlyeq s^U$ and $r^K \preccurlyeq t^U$ with at least one strict preference relation ($\prec$). Again, we consider two cases: $q^K \sim r^K$ and $q^K \succ r^K$.

*Case 1:* $q^K \sim r^K$. In this case, we obtain:

$$s^U \succcurlyeq t^U \succcurlyeq q^K \sim r^K, \tag{12}$$

with at least one strict preference. Take $\succcurlyeq^{PS}$ with $\pi(Q^K) = \pi^{PS}(Q^K)$ as in (5) such that:

$$q^K \sim^{PS} s^U \sim^{PS} t^U \sim^{PS} r^K. \tag{13}$$

Comparing the respective $\succcurlyeq^{PS}$ with $\succcurlyeq$ from (12), we obtain:

$$\begin{aligned} q^K \sim^{PS} \{r^K, s^U, t^U\} \quad &\Rightarrow \quad q^K \sim \{r^K\} \preccurlyeq \{s^U\} \preccurlyeq \{t^U\}, \\ r^K \sim^{PS} \{q^K, s^U, t^U\} \quad &\Rightarrow \quad r^K \sim \{q^K\} \preccurlyeq \{s^U\} \preccurlyeq \{t^U\}, \end{aligned}$$

where at least one of the weak preference is strict in each row. Thus, there exists $\succcurlyeq^{PS}$ such that $\succcurlyeq$ is less uncertainty-averse then $\succcurlyeq^{PS}$. Hence, $\succcurlyeq$ is uncertainty-loving according to Epstein—see (3).

*Case 2:* $q^K \succ r^K$. In this case, one of the following can occur:

$$s^U \succcurlyeq t^U \succcurlyeq q^K \succ r^K, \text{ or} \tag{14}$$

$$s^U \succcurlyeq q^K \succ t^U \succcurlyeq r^K, \tag{15}$$

with at least one strict preference in each case. Take $\succcurlyeq^{PS}$ with $\pi(Q^K) = \pi^{PS}(Q^K)$ as in (5) such that:

$$q^K \sim^{PS} s^U \succ^{PS} t^U \sim^{PS} r^K. \tag{16}$$

Comparing this $\succcurlyeq^{PS}$ with $\succcurlyeq$ from (14), we obtain:

$$\begin{aligned} q^K \sim^{PS} \{s^U\} \quad &\Rightarrow \quad q^K \preccurlyeq \{t^U\} \preccurlyeq \{s^U\}, \\ r^K \sim^{PS} \{t^U\} \prec \{s^U, q^K\} \quad &\Rightarrow \quad r^K \prec \{q^K, t^U, s^U\}. \end{aligned}$$

Comparing the same benchmark with $\succcurlyeq$ from (15), we get:

$$\begin{aligned} q^K \sim^{PS} \{s^U\} \quad &\Rightarrow \quad q^K \preccurlyeq \{s^U\}, \\ r^K \sim^{PS} \{t^U\} \prec \{s^U, q^K\} \quad &\Rightarrow \quad r^K \preccurlyeq \{t^U\} \prec \{q^K, s^U\}. \end{aligned}$$

Thus, in both cases, there exists $\succcurlyeq^{PS}$ such that $\succcurlyeq$ is less uncertainty-averse then $\succcurlyeq^{PS}$ and we conclude that $\succcurlyeq$ is uncertainty-loving according to Epstein—see (3).

Hence, if $q^K \preccurlyeq s^U$ or $r^K \preccurlyeq t^U$ with at least one strict preference relation ($\prec$), then $\succcurlyeq$ is uncertainty-loving according to Epstein.

*Step 3: Uncertainty neutrality.*

Suppose now that $q^K \sim s^U$ and $r^K \sim t^U$, or $q^K \succ s^U$ and $r^K \prec t^U$, or $q^K \prec s^U$ and $r^K \succ t^U$. Then one of the following can occur:

$$q^K \sim s^U \succcurlyeq t^U \sim r^K, \tag{17}$$

$$q^K \succ s^U \succcurlyeq t^U \succ r^K, \tag{18}$$

$$s^U \succ q^K \succcurlyeq r^K \succ t^U. \tag{19}$$

Take $\succcurlyeq^{PS}$ with $\pi(Q^K) = \pi^{PS}(Q^K)$ as in (5), in (6) and in (7). Any $\succcurlyeq$ as in (17), in (18) and in (19) is order equivalent with $\succcurlyeq^{PS}$ as in (5), in (6) and in (7), respectively. Thus, for any $\succcurlyeq$ as in (17), in (18) and in (19) there exists $\succcurlyeq^{PS}$ such that both is true: $\succcurlyeq$ is more uncertainty-averse than $\succcurlyeq^{PS}$ and $\succcurlyeq$ is less uncertainty-averse than $\succcurlyeq^{PS}$. Therefore, $\succcurlyeq$ is uncertainty-neutral according to Epstein. $\square$

Table 3: Variable definitions

| **Variable name** | Dummy variables which take the value one if... |
|---|---|
| no color preference | subject indifferent between white and yellow ticket for urn U |
| coin fair | subject regards coin as fair |
| male | subject male |
| economics student | subject studies economics |
| business student | subject studies business administration |
| stats knowledge 1 | Prob(10-sided fair dice shows 2 or less) computed correctly |
| stats knowledge 2 | Prob(two 10-sided fair dice show two ones) computed correctly |
| stats knowledge 3 | Prob(10-sided fair dice shows 4\| even number)* computed correctly |
| stats knowledge 4 | Prob(10-sided fair dice shows 4\| odd number) computed correctly |
| stats knowledge 5 | average payoff of two bets, one which pays 100 in case of even the other pays 100 in case of odd computed correctly |
| cognitive ability 1 | correct answer to... A bat and a ball cost $1.10. The bat costs $1.00 more than the ball. How much does the ball cost? |
| cognitive ability 2 | correct answer to... 5 machines need 5 min to produce 5 pieces. How long do 100 machines need to produce 100 pieces? |
| cognitive ability 3 | correct answer to... A lake is covered by sea roses. The covered surface doubles every day. If 48 days are needed until the lake is entirely covered, how long does it take until half the lake is covered? |
| **Variable name** | Subjective agreement with following statements on a scale from 1 (totally disagree) to 7 (totally agree) |
| superstition | There are unlucky numbers. |
| god | God is important in my life. |
| religion | Religion gives me strength and support. |
| fate | What one achieves in life depends on fate and luck. |

* Prob($A|B$) denotes the conditional probability of event $A$ to occur after the occurence of $B$.

Table 4: Selection on observables: Hypothesis 1

| **Dependent variable: No color preference on urn U** ($y^U \sim w^U$) | | | |
|---|---|---|---|
| **Variable** | **Coefficient** | **Stand. Error** | $\mathbf{p-value}$ |
| male | 0.150 | 0.116 | 0.196 |
| economics student | -0.214 | 0.194 | 0.271 |
| business student | 0.188 | 0.130 | 0.147 |
| stats knowledge 1 | -0.021 | 0.181 | 0.906 |
| stats knowledge 2 | 0.143 | 0.131 | 0.275 |
| stats knowledge 3 | 0.243 | 0.146 | 0.094 |
| stats knowledge 4 | -0.124 | 0.177 | 0.480 |
| stats knowledge 5 | -0.046 | 0.143 | 0.747 |
| cognitive ability1 | -0.108 | 0.131 | 0.409 |
| cognitive ability2 | -0.009 | 0.140 | 0.947 |
| cognitive ability3 | 0.022 | 0.150 | 0.883 |
| superstitious | -0.017 | 0.042 | 0.681 |
| god | 0.083 | 0.069 | 0.222 |
| religion | -0.104 | 0.072 | 0.144 |
| fate | -0.004 | 0.038 | 0.923 |
| *Number of Obs.* = 88 | | $Prob > \chi^2$ = 0.43 | |
| *Log likelihood* = -51.495 | | *Pseudo* $R^2$ = 0.129 | |
| *Significance levels:*(5%), **(2%), ***(1%)* | | | |

Table 5: Selection on observables: Hypothesis 2

| **Dependent variable: fair coin ($t \sim h$) and no color preference ($y^U \sim w^U$)** | | | |
|---|---|---|---|
| **Variable** | **Coefficient** | **Stand. Error** | **$\mathbf{p-value}$** |
| male | 0.067 | 0.125 | 0.593 |
| economics student | -0.252 | 0.188 | 0.180 |
| business student | 0.183 | 0.144 | 0.205 |
| reference group: other fields of study (mostly: teaching, law, languages) | | | |
| stats knowledge 1 | 0.028 | 0.214 | 0.895 |
| stats knowledge 2 | 0.293* | 0.131 | 0.025 |
| stats knowledge 3 | 0.189 | 0.157 | 0.228 |
| stats knowledge 4 | -0.320 | 0.189 | 0.090 |
| stats knowledge 5 | -0.027 | 0.162 | 0.869 |
| cognitive ability1 | -0.094 | 0.138 | 0.493 |
| cognitive ability2 | 0.131 | 0.144 | 0.364 |
| cognitive ability3 | 0.204 | 0.150 | 0.175 |
| superstitious | -0.006 | 0.047 | 0.899 |
| god | 0.050 | 0.073 | 0.492 |
| religion | -0.064 | 0.076 | 0.401 |
| fate | -0.041 | 0.040 | 0.305 |
| *Number of Obs.* = 88 | | $Prob > \chi^2$ = 0.042 | |
| *Log likelihood* = -48.160 | | $Pseudo\ R^2$ = 0.210 | |
| *Significance levels:*(5%), **(2%), ***(1%)* | | | |

Table 6: Instructions, first page (translation from German)

**Instructions**

Welcome to our experiment! These instructions are the same for all participants. During the experiment, we ask you to remain silent and not to talk with other participants. Please switch off your mobile phones and leave them switched off until the end of the experiment. If you have any questions, please raise your hand and one of the experimentators will come to you.

**Aim and structure of the experiment**

This experiment is about decisions under uncertainty. You will be presented with different tickets and asked to value these tickets. To do so, you get a choice between the ticket and different fix payments. There are no „right“ or „wrong“ answers. Only your preferences count. Depending on your preferences, it may well be that you find this easy. Respond truthfully whether you prefer the ticket or the fix payment because these alternatives are real and not only hypothetical. So, if you decide for a ticket, you will actually get this ticket. If you decide for a fix payment, you will receive this payment.

Throughout the experiment, Taler are used as a currency unit, which are later converted at a rate of 100 Talern = 10 Cent. The amount will be rounded up to full cents and paid out. The deciscions of other participants have no effect on your payoff.

**Uncertainty**

Three sources of uncertainty play a role for the tickets.

- A **coin** will be thrown and the payoff depends on whether it shows tails or heads up. We will ask you or another participant to lend us the coin.
- A **Ball** will be drawn from a bucket and the payoff depends on whether the ball is yellow or white. There are two buckets. In both buckets there are 20 table tennis balls. We only use table tennis balls that are either white or yellow.
    - **Bucket H**: Half of the balls is white, the other is yellow.
    - **Bucket U**: It is not known how many of the balls are white and how many are yellow.

  This is the only difference between bucket H and bucket U.

There are the following simple tickets:

**Coin tickets**

- **Head ticket:** A head ticket pays 100 Taler if the coin lands heads up and nothing else.

- **Tail ticket:** A tail ticket pays 100 Taler if the coin lands tails up and nothing else.

**Color tickets**

- **White ticket:** A white ticket pays 100 Taler if the drawn ball is white and nothing else.

- **Yellow ticket:** A yellow ticket pays 100 Taler if the drawn ball is yellow and nothing else.

- **Chameleon ticket:** The color of the chameleon ticket is determined by a coin throw.
    - If the coin lands heads up, the chameleon ticket becomes a yellow ticket.
    - If the coin lands tails up, the chameleon ticket becomes a white ticket.

Table 7: Instructions, second page (translation from German)

For color tickets, it will be specified to which bucket they apply: H or U. A yellow ticket for bucket U thus means that a ball is drawn from the bucket with unknown proportions and that 100 Taler are paid if this ball is yellow..

Apart from these tickets there will be other variations that you will get to know during the experiment.

**Decitions and the value of tickets**

For each ticket there will be a set of questions. For example:

| | Head ticket | Fix payment of ... |
|---|---|---|
| Question 1 | ( ) | ...68 Taler ( ) |
| Question 2 | ( ) | ...96 Taler ( ) |

For Question 1 you have to decide between a head ticket or a fix payment of 68 Taler. For Question 2 between a head ticket and 96 Taler.

For each question concerning the same color ticket, a new ball will be drawn; already drawn balls are replaced. For each question concerning a coin ticket, the coin is thrown. All draws are hence *completely independent* of each other. Your payoff is hence maximized if you answer according to the value of the ticket.

If for example the ticket is worth 80 Taler to you, then you should prefer the ticket to a fix payment of 68 Taler (otherwise you lose 12 Taler). If you have the choice between the ticket and 96 Talern, you should choose 96 Taler (otherwise you lose sixteen Taler).

**Input assistant**

The close relationship between the value of a ticket and your decisions is used by the program to facilitate the input. You have the possibility to directly specify the value of a ticket in steps of 5 Taler using a slider. The program then automatically marks the corresponding decisions. If you want to you can change these decisions. The program then adjusts the value of the ticket. Note that the value of the ticket cannot always be computed. For example, if you select a fix payment of 58 Taler rather than the ticket but also choose the ticket rather than a fix payment of 63 Taler, this means that the ticket is worth less than 58 Taler to you but also more than 63 Taler. In this case, it is impossible to determine the value of the ticket to you.

**Sequence**

The experiment starts with a few problems, which should help you to acquaint yourself with the different types of questions. Moreover, we want to ensure that you have not misunderstood the instructions. Decisions during this part do not affect your payoffs. After the understanding part, the main part of the experiment begins. The decision during this part are for real. They hence affect your payoffs. Finally, we ask you some general questions. Altogether the experiment will take 90 minutes. You have enough time for your answers since the draws only start if all participants are ready.

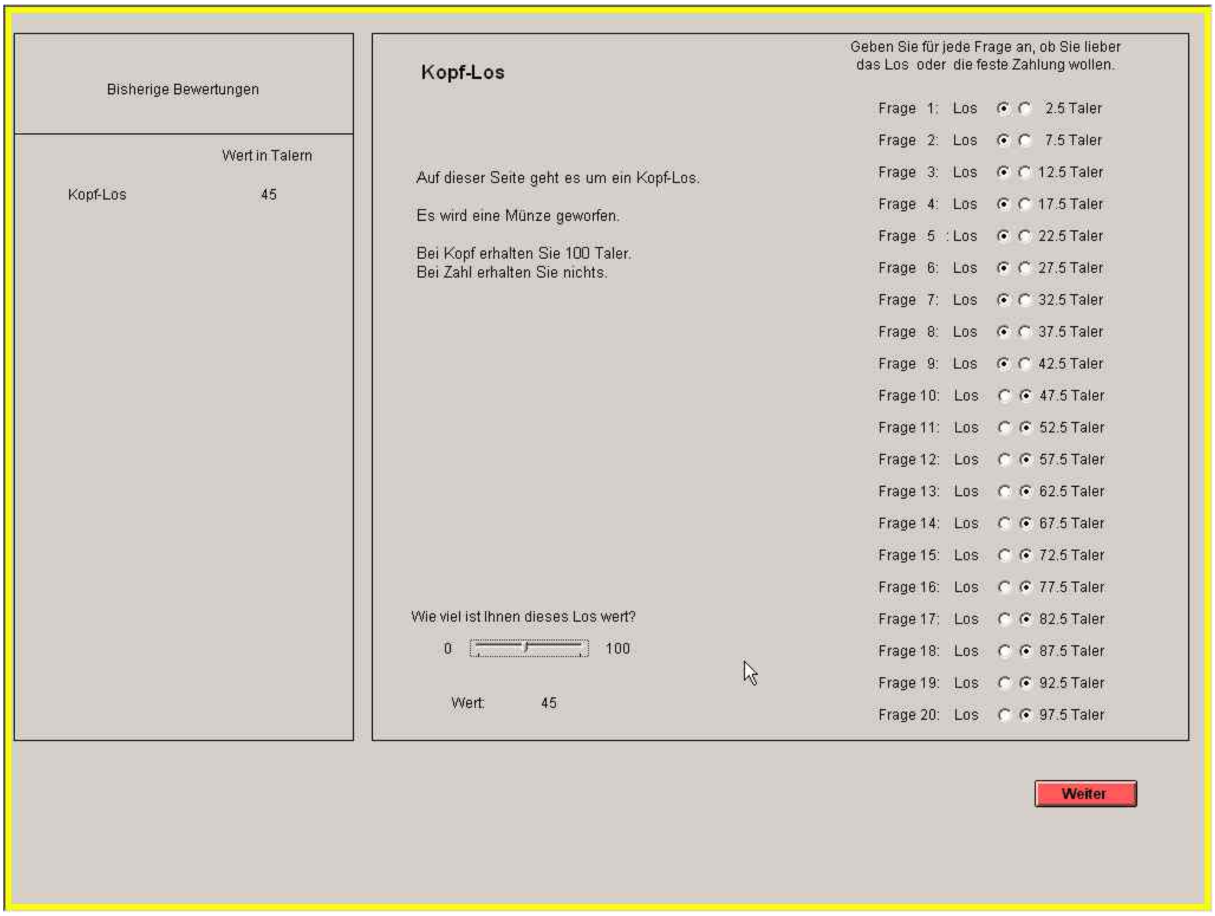


Figure 2: Valuation screen for head ticket (in German)

# References


Anscombe, F. J., and R. J. Aumann (1963): "A Definition of Subjective Probability," *Annals of Mathematical Statistics*, 34(1), 199–105.

Becker, G. M., M. H. DeGroot, and J. Marschak (1964): "Measuring Utility by a Single-Response Sequential Method," *Behavioral Science*, 9(3), 226–232.

Camerer, C., and M. Weber (1992): "Recent Developments in Modelling Preferences: Uncertainty and Umbiguity," *Journal of Risk and Uncertainty*, 5(4), 325–370.

Cettolin, E., and A. Riedl (2008): "Changing Ambiguity Attitudes and a Preference for Indifference," unpublished manuscript, Maastricht University.

Dittmann, I., D. Kübler, E. Maug, and L. Mechtenberg (2008): "Why Votes Have a Value," Discussion Paper 68, Department of Economics, Humboldt University Berlin.

Dow, J., and S. R. D. C. Werlang (1994): "Nash Equilibrium under Knightian Uncertainty: Breaking Down Backward Induction," *Journal of Economic Theory*, 64(2), 305–324.

Eichberger, J., and D. Kelsey (1996): "Uncertainty Aversion and Preference for Randomisation," *Journal of Economic Theory*, 71(1), 31–43.

Eichberger, J., and D. Kelsey (2000): "Non-Additive Beliefs and Strategic Equilibria," *Games and Economic Behavior*, 30(2), 183 – 215.

Ellsberg, D. (1961): "Risk, Ambiguity, and the Savage Axioms," *The Quarterly Journal of Economics*, 75(4), 643–669.

Epstein, L. G. (1999): "A Definition of Uncertainty Aversion," *Review of Economic Studies*, 66(3), 579–608.

——— (2009): "Three Paradoxes for the 'Smooth Ambiguity' Model of Preference," Working paper, Department of Economics, University of Boston.

Fischbacher, U. (2007): "Zurich Toolbox for Research in Economic Experiments," *Experimental Economics*, 10(2), 171–178.

Ghirardato, P. (1997): "On Independence for Non-Additive Measures with Fubini Theorem," *Journal of Economic Theory*, 73(2), 261–291.

Ghirardato, P., and M. Marinacci (2002): "Ambiguity Made Precise: A Comperative Foundation," *Journal of Economic Theory*, 102(2), 251–289.

Gilboa, I. (1987): "Expected Utility With Purely Subjective Non-Additive Probabilities," *Journal of Mathematical Economics*, 16(1), 65–88.

Gilboa, I., and D. Schmeidler (1989): "Maximin Expected Utility with Non-Unique Prior," *Journal of Mathematical Economics*, 18(2), 141–153.

Halevy, Y. (2007): "Ellsberg Revisited: An Experimental Study," *Econometrica*, 75(2), 503–536.

Hey, J. D., G. Lotito, and A. Maffioletti (2008): "The Descriptive and Predictive Adequacy of Theories of Decision Making Under Uncertainty/Ambiguity," Discussion Papers 08/04, Department of Economics, University of York.

Holt, C. A. (1986): "Preference Reversals and the Independence Axiom," *American Economic Review*, 76(3), 508–15.

Holt, C. A., and S. K. Laury (2002): "Risk Aversion and Incentive Effects," *American Economic Review*, 92(5), 1644–1655.

Karni, E., and Z. Safra (1987): "'Preference Reversal' and the Observability of Preferences by Experimental Methods," *Econometrica*, 55(3), 675–85.

Keren, G., and K. H. Teigen (2008): "Decisions by Coin Toss and the Limits of Rationality," unpublished manuscript, Tilburg Institute for Behavioral Economics Research.

Klibanoff, P. (1996): "Uncertainty, Decisions and Normal Form Games," unpublished manuscript, Kellog Graduate School of Economics, Northwestern University, Chicago.

——— (2001): "Stochastically Independent Randomization and Uncertainty Aversion," *Economic Theory*, 18(3), 605–620.

Klibanoff, P., M. Marinacci, and S. Mukerji (2005): "A Smooth Model of Decision Making under Ambiguity," *Econometrica*, 73(6), 1849–1892.

——— (2009): "On the Smooth Ambiguity Model: A Reply," Working paper, Department of Economics, University of Oxford.

Lo, K. C. (1996): "Equlibrium in Beliefs under Uncertainty," *Journal of Economic Theory*, 71(2), 443–484.

Maccheroni, F., M. Marinacci, and A. Rustichini (2006): "Ambiguity Aversion, Robustness, annd the Variational Representation of Preferences," *Econometrica*, 74(6), 1447–1498.

Machina, M. J., and D. Schmeidler (1992): "A More Robust Definition of Subjective Probability," *Econometrica*, 60(4), 745–80.

Marinacci, M. (2000): "Ambiguous Games," *Games and Economic Behavior*, 31(2), 191 – 219.

Raiffa, H. (1961): "Risk, Ambiguity, and the Savage Axioms: Comment," *The Quarterly Journal of Economics*, 75(4), 690–694.

Sarin, R. K., and P. Wakker (1992): "A Simple Axiomatization of Nonadditive Expected Utility," *Econometrica*, 60(6), 1255–1272.

Savage, L. J. (1954): *The Foundation of Statistics*. Wiley, New York.

Schmeidler, D. (1989): "Subjective Probability and Expected Utility Without Additivity," *Econometrica*, 57(3), 571–587.

Segal, U. (1988): "Does the Preference Reversal Phenomenon Necessarily Contradict the Independence Axiom?," *American Economic Review*, 78(1), 233–36.

Trautmann, S. T., F. M. Vieider, and P. P. Wakker (2009): "Preference Reversals for Ambiguity Aversion," Tilburg Institute for Behavioral Economics Research, Tilburg University.