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# PROBABILITY WEIGHTING UNDER TIME PRESSURE: APPLYING THE DOUBLE-RESPONSE METHOD

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**Probability weighting under time pressure: applying the double-response method**

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**Abstract**

We conduct a laboratory experiment to investigate the impact of deliberation time on behavior under risk and uncertainty. Towards this end we let our participant make quick, intuitive evaluations of a number of lotteries and modify them, should they wish to do so, after deliberation. Both certainty equivalents are incentivized (a double-response method). The main finding is that additional deliberation time reduces pessimism, especially in the case of lotteries involving unknown probabilities.

**Keywords:**
probability weighting, prospect theory, time pressure

**JEL:**
D81, C91

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# 1. INTRODUCTION

A typical human choice involves uncertain consequences and must be made very quickly. This may be particularly true in the dynamic landscape of the digital era, with new bits of information arriving continuously and requiring swift yet efficient processing. That necessity is particularly clear in the lives of traffic controllers (Joslyn and Hunt, 1998), traders (Nursimulu and Bossaerts, 2014), and medical professionals (Zakay, 1985), to name but a few examples. Much beyond these specializations, millions of people routinely engage in hasty and risky endeavors, such as bidding, often in the last minute, in Internet auctions (Roth and Ockenfels, 2002; El Haji et al, 2016). It appears clear therefore that studying impact of time pressure on decision making under risk and uncertainty is of utmost importance.

The dual-system approach (Stanovich and West, 2000, Kahneman, 2011) has been proposed as one theoretical framework that may help us understand the role of time pressure in decision making. Roughly, it proposes that two separate modes of decision making exist. System 1 is crude, intuitive, emotional, unconscious and old from evolutionary viewpoint (‘the reptilian brain’). System 2 is more precise, deliberative, conscious and only evolved later (‘the mammalian brain’). Critically, System 2 tends to be much slower, meaning that its role is severely limited under strict time pressure. In particular, that means that scarcity of deliberation time results in filtration, i.e. only the most salient aspects of the situation are taken into account (Maule et al., 2000). In the context of decision making under risk, this means that greater deviations from the normatively correct model of expected utility maximization are hypothesized, and indeed often observed, under time pressure (Hogarth, 1980; Kruglanski and Freund, 1983).

In particular, losses (as opposed to gains) have been proposed to be salient, and thus overweighed under time pressure. Ben Zur and Breznitz (1981) and Huber and Kunz (2007), among others, found that participants paid relatively much attention to negative consequences and their possible countermeasures when decision time was limited.

Likewise, embedding risky choices in a strategic game very similar to blackjack, Dror et al. (1999) observed that opponent’s card affected propensity to take a new card under low time pressure only. These authors also found that TP manipulation caused a polarization effect: compared to the baseline it made participants take another card less often when it was associated with a low probability of losing (current own card was low) but more often when it was associated with a high probability of losing.

Such results could be interpreted in terms of reduced probability sensitivity: when time is limited, the possibility of an outcome is taken into account, but just how likely it is to occur is largely disregarded (inverse-S probability weighting function in the parlance of Cumulative Prospect Theory). Indeed, Young, et al. (2012) found in their Experiment 3 that probability discriminability was reduced (discrepancy between correct probabilities and decision weights were greater) under time limit compared to no time limit. Additionally, they reported that the probability weighting function for gains was more elevated under time limit, which corresponds to greater risk attractiveness (Experiments 1 and 2). Greater risk acceptance under time pressure was also reported by Madan et al. (2015) in a study involving decisions from experience rather than description. By contrast, Kocher et al. (2013) found that their participants continued to avoid risks in positive prospects but switched from risk seeking to risk aversion for negative prospects when time limits were introduced.

Nursimulu and Bossaerts (2014) observed binary decisions whether or not to buy into a blackjack-like game under three different times limits (1, 3 or 5 seconds delay, then one second for the decision). Curiously, the authors reported more concave value function and relatively lower weights for high probabilities of winning, higher weights for low probabilities for shorter time limits. Curiously, it was under high time pressure that this weighting was correct, while underweighting of small probabilities and overweighting of large probabilities (the opposite of the often reported inverse-S) resulted in treatments with more time.

Isolated studies used other ways to affect the use of the two systems. For example, Deck and Jahedi (2015) observed that introduction cognitive load, which restricts availability of the circuitry associated with the deliberative system, made participants more risk-averse (see also studies cited therein).

Some studies investigated the link between deliberation time and ambiguity aversion (unwillingness to bet on uncertain chance of success). They typically looked at intuitive/affective vs. deliberative mode of decision making as a trait rather than result of an exogenous manipulation. Rubinstein (2013) found no correlation between (unconstrained) response time and choices in Ellsberg Paradox. Bechara et al. (1997) showed that brain lesions leading to impaired feeling of emotions led to inability to avoid risky and unprofitable choices in Iowa Gambling Task. Butler et al. (2014) found using a representative survey and large-scale behavioral experiments that individuals reporting being prone to use more intuitive (rather than also deliberative) reasoning style are less often averse to ambiguity (and also to well-defined risk), but see Bergheim and Roos (2013).

To sum up, recent studies do not show a very clear behavioural pattern and further research is certainly needed. A more comprehensive review can be found i.a. in Ordóñez et al. (2015).

In the current study we build upon previous experiments, yet with several important changes. First, we use a well-established method of Abdellaoui et al. (2011) to semi-parametrically elicit entire probability weighting function and value function. Therefore we obtain a comprehensive picture of participants' preference under risk. Second, we apply the Double-Response Method of Dyrkacz and Krawczyk (2015), which involves observing incentivized responses both after short and after longer deliberation in a given situation from the same participant. This allows a detailed insight into how time pressure causally affects contents of decisions under risk in specific individuals. By contrast, between-subject studies only allow comparing aggregate distributions. Still, to understand the impact of participants' willingness to behave consistently under long vs. short deliberation time and similar effects we also conduct control sessions with no time pressure. Finally, we link our results with a simple measure of readiness to reconsider the intuitive response, the Cognitive Reflections Test (Frederick, 2005). Our main finding is that, particularly in the case of ambiguity, additional deliberation time reduces the initial pessimism, bringing participants closer to correct probability weighting.

## 2. METHOD

### 2.1 Materials

The experiment consisted of the main decision task and a short questionnaire. It was coded in PhP, with printed instructions (see Appendix A).

#### *2.1.1 Decision task*

The design was based on that of Abdellaoui et al. (2011). In each round, the participants were asked to evaluate lotteries involving drawing from virtual, Ellsberg-like urns. Two types of urns were used: the known and the unknown. The known urn always contained one ball of each of eight colors. In the unknown urn there were also eight colored balls, but participants did not know the particular composition. For example, there could be three blue balls, zero green balls etc. In each case each ball had the same probability to be drawn. The same was true of each *color* in the known urns only.

At the beginning of each round a clock would start counting down from sixty seconds. Participants saw the graphical representation of the urn (known or unknown) and the information how much money they could win when particular color was drawn, see Figure 1. They were asked to type in the amount they considered just as good as the lottery. They did so twice in each round. Upon confirming their initial (and typically rapid) choice, participants saw their selected amount displayed below the picture and were invited to rethink it and amend it or type in the same one again if they were sure it correctly represented their preference. Thus each participant was allowed to change his or her mind at most once per round. Once the second amount (the same as the first one or a different one) was typed in and confirmed or when the time was gone, the participant could move on to the second round.

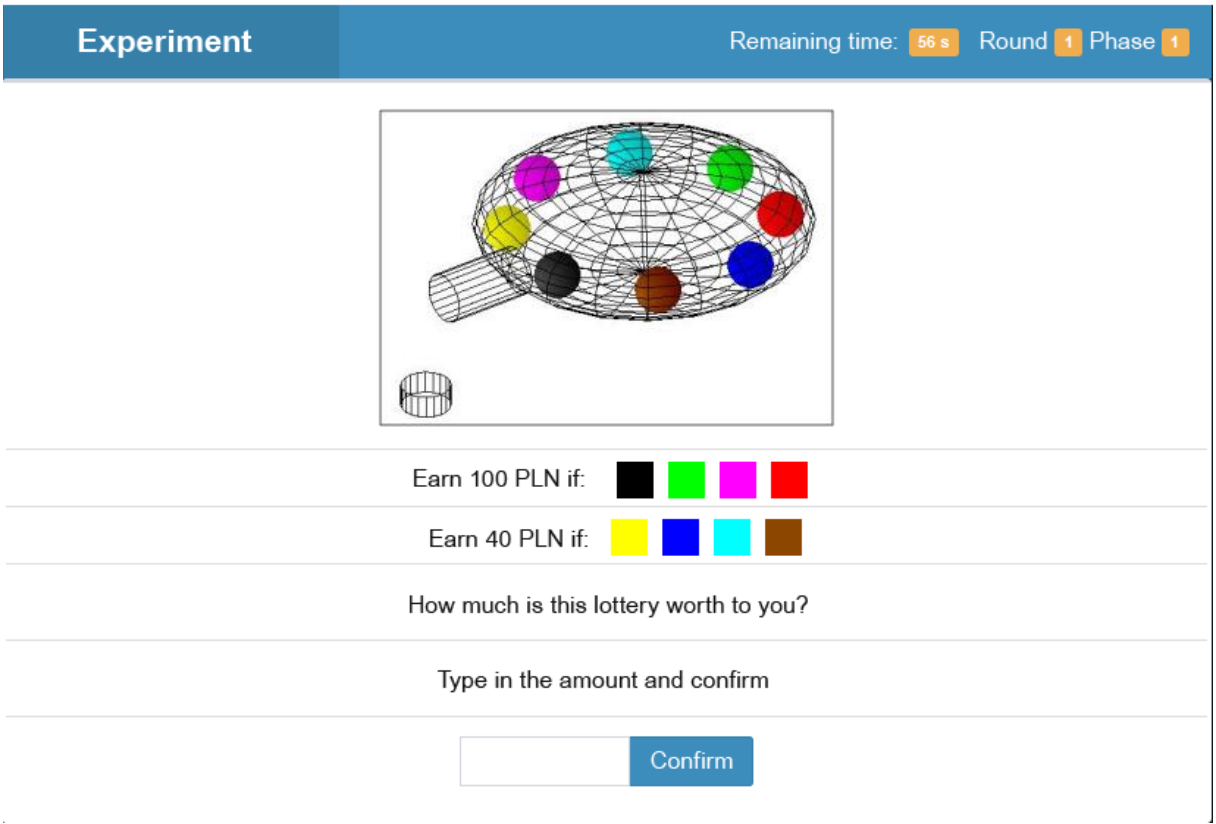


Fig. 1. Decision screen

Similarly to (Dyrkacz and Krawczyk, 2015), at the end of the experiment the computer randomly selected: one round, one second of this round and an amount of money $X$ that could be obtained for sure, drawn from the range of possible payoffs in this round (e.g. from 40 to 100 in Figure 1) to determine participants' payoffs. If the participant in the selected second of the round had been indicating that her certainty equivalent of the lottery was lower than $X$, she received $X$. If she indicated it was higher than $X$, the lottery was played out and she received one of the possible outcomes (a Becker-DeGroot-Marschak procedure). In the case a second was selected in which no decision had been made yet, the lottery or the $X$ would be assigned randomly. Thereby participants were motivated to make their first decision as quick as possible and then to indicate if they changed their mind after consideration.

For example, assume that the computer drew round 20, in which the respondent could win 100 PLN with probability 6/8, or 0 PLN otherwise. Furthermore, the $25^{th}$ second of this round was selected, and sure amount X equal to 70. Suppose that in the fifth second of Round 20 the participant had evaluated the lottery at 64 and then she amended it to 68 in the $21^{st}$ second. Because 68 is smaller than X=70, in the $25^{th}$ second of the round she was revealing that she liked X better than the lottery. She would thus receive 70 for sure. Now suppose she typed in 72 in the third second and only changed it to 65 in the 30-th second. Then, in the 25-th second she was indicating that she liked the lottery better, so the lottery would be played out. In such a case, the participant would win 100 PLN with probability 6/8 and 0 PLN otherwise.

In addition to the Double Response Treatment described above, a No Time Pressure Treatment was also run, in which participants took as much time as they wanted to make a decision. Only the final decision mattered (and was incentivized using an analogous Becker-DeGroot-Marschak procedure).

At the end of the experiment participants received information about which round, second and amount of money would determine their payoff. Then they completed Frederick's (2005) Cognitive Reflection Test (CRT) and a short post-experimental questionnaire (sex, age and field and year of study).

### *2.1.2 Decision task parameters and estimation of probability weights*

In total, participants made their decisions in 32 paid rounds, preceded by two practice rounds, with possible payoffs ranging from 0 PLN to 100 PLN (ca. 24 euro), see Table 3. Some of the rounds were identical up to the coloring of the winning balls, allowing assessment of consistency in participants' choices. Half of the participants played the 13 rounds with known urns first and then 19 rounds with unknown urns (we will refer to this condition as "Known First"), whereas the order was reversed for the other half ("Unknown First").

It can be noted that some of the tasks involved 50/50 chances to get different non-zero rewards. Following the semi-parametric method of Abdellaoui et al. (2009, 2011), the certainty equivalents from these rounds were used to estimate the parameter of power value function, with the weight of .5 as an additional parameter. Non-linear least squares method was applied. Resulting values of each possible reward, together with certainty equivalents provided in remaining rounds involving probabilities other than 50/50 for 100 PLN (zero otherwise) were subsequently used to calculate weights for these probabilities. Indeed, if for some $j \in \{1, \ldots 3{,}5, \ldots 8\}$ we call the amount reported to be as good as 100 PLN with probability $j/8$ the certainty equivalent (CE), we conclude that $w(j/8) = (CE/100)^{\rho}$, where $\rho$ stands for the individual parameter of the power value function. The seven probability weights can then be used to estimate parameters of Prelec's (1998) two-parameter probability weighting function,

$$w(p) = \exp\left(-\beta(-\ln(p))^{\alpha}\right)$$

Correct probability weighting, $w(p) = p$ results from $\alpha = \beta = 1$. Typically reported lower values of α correspond to low sensitivity to changes in probability away from the reference points of absolute impossibility and absolute certainty (inverse-S), while higher values would signify lower sensitivity near these thresholds. Low values of $\beta$ characterize elevated probability weighting curves (optimism) while high $\beta$ means pessimism. This procedure was applied separately to each participant's choices under specific conditions (e.g. initial choices in known urns). As a result we have four separate sets of estimates of $r$, $w(p)$'s for each $j \in \{1, \ldots, 8\}$, α, and $\beta$ for each participant making decisions under Double Response and two for each participant making decisions under No Time Pressure.

Analogously, we consider an alternative specification, under which the probability weights are subject to simple linear regression on the unit interval, $p=c+sp$. Following Abdellaoui et al., we focus on $a=1-s$ as an index of likelihood insensitivity and $b=1-s-2c$ (which is the difference between the "dual" intercept arising when we flip the picture 180 degrees and the standard intercept) as an index of pessimism.

### 2.2 Participants

In total, 184 volunteers took part in our experiment. As is typical in similar experiments, some made decisions in the main task that were very difficult to justify. Applying the criterion we discuss later on, we excluded 33 participants, leaving 151 for further analysis. Of these, about 60% were male, 32% studied economics, 41% studied other fields and 27% were non-students. Mean age was 28.62 (*SD* = 11.953). The distribution of these variables in the entire sample of 184 was similar, with a slightly higher fraction of females and non-economists. All the participants had been recruited using ORSEE (Greiner, 2004). None of them had participated before in a similar study. The experiment was conducted at the University of Warsaw Laboratory of Experimental Economics and lasted up to about 45 minutes. Earnings ranged between 5 PLN and 105 PLN with a mean of 56 PLN including a guaranteed 5 PLN show-up fee.

Table 1. Number of participants in each treatment

| **Treatment** | **Number of participants** |
|---|---|
| Double Response - Known First | 56 |
| Double Response - Unknown First | 57 |
| No Time Pressure - Known first | 20 |
| No Time Pressure - Unknown first | 18 |

## 3. RESULTS

As a check of the validity of the Double Response method we first inspect response times and fractions of decision changes. We then proceed to substantive findings: certainty equivalents and resulting probability weights.

### 3.1 Response times

The logic of the experimental design was that participants in the Double Response condition make their first (initial) decision quickly and then they have enough time to change their mind after consideration. One would thus expect that the final decisions under Double Response take roughly as much time as the decisions under no time pressure, while initial decisions are much quicker. Table 2 shows mean times of the first and the second decision in all the treatments.

Table 2. Response time: initial and final decisions (in seconds)

| | | Known urns | | Unknown urns | |
|---|---|---|---|---|---|
| | Statistics | Initial decision | Final decision[1] | Initial decision | Final decision |
| Double Response - Known First | Mean (s.d.) | 8.12 (3.13) | 13.98 (5.87) | 5.89 (2.07) | 9.95 (3.86) |
| | Median | 7.42 | 13.35 | 5.95 | 9.58 |
| Double Response - Unknown First | Mean (s.d.) | 6.40 (2.80) | 10.39 (4.46) | 6.81 (2.77) | 11.53 (4.92) |
| | Median | 6.08 | 9.62 | 6.11 | 10.47 |
| No Time Pressure - Known first | Mean (s.d.) | 14.46 (5.48) | | 8.69 (4.10) | |
| | Median | 14.31 | | 7.21 | |
| No Time Pressure - Unknown First | Mean (s.d.) | 9.81 (4.07) | | 11.18 (5.54) | |
| | Median | 8.77 | | 10.53 | |

It turns out that, as expected, most of the participants in the Double Response condition made their first decision very quickly, during the first six or seven seconds. Moreover, it seems that the rounds were sufficiently long in the sense that the final decisions came well before the deadline of 60 seconds passed.

To check whether mean times of final decision were different in the four treatments we conducted Kruskal-Wallis tests. The results showed that the differences between treatments were significant both for decisions made for known urns ($H(3) = 22.363$ , $p < 0.001$) and for the unknown urns ($H(3) = 9.125$ , $p = .028$). Comparisons between specific treatments were performed using the Mann-Whitney U test. First, we contrast final decision times under Double Response (both round orders) with the final decision times under No Time pressure (both round orders). As we hoped, there is no significant difference, neither for the known urns ($Z = -.266$, $p = .790$), nor the unknown urns ($Z = -1.497$, $p = .135$). By contrast, within DR condition, round order made a significant impact for the known urns ($Z = -3.647$, $p < .001$), and a marginally significant one for the unknown urns ($Z = -1.694$, $p = .090$). A similar pattern emerged for the NTP ($Z = -3.202$, $p = .001$ for known urns and $Z = -2.164$, $p = .030$ for unknown urns. To summarize, in each case differences between treatments in the speed of the decision for known and unknown urns depended only on the ordering of blocks: plausibly, participants became faster in later rounds.

### 3.2 Decision changes

Overall, participants changed 23% of their initial decisions: 25% decisions made for known urns and 21% for unknown urns. Table 3 shows the distribution of the number of decision changes made by participants for both urns.

[1] Note that the time of the final decision denotes time since the beginning of the round, not since the initial decision.

Most of the participants changed their mind once or a few times over the 32 rounds. Participants who more often changed their first decision needed more time between the initial and the final decision than participants who tended to repeat their first choice ($\rho = 0.374$, $p < 0.001$).

Table 3. Distribution of the number of decision changes (the Double Response condition).

| Number of changes | Number of participants | Percent of participants |
|---|---|---|
| 0 | 23 | 20.4 |
| 1 | 8 | 7.1 |
| 2 | 7 | 6.2 |
| 3 | 8 | 7.1 |
| 4 | 11 | 9.7 |
| 5 | 4 | 3.5 |
| 6 | 7 | 6.2 |
| 7 | 3 | 2.7 |
| 8 | 4 | 3.5 |
| 9 | 3 | 2.7 |
| 10 | 2 | 1.8 |
| 11 | 2 | 1.8 |
| 12 | 6 | 5.3 |
| 13 | 2 | 1.8 |
| 14 | 3 | 2.7 |
| 15 | 2 | 1.8 |
| 16 | 4 | 3.5 |
| 17 | 3 | 2.7 |
| 18 | 1 | 0.9 |
| 19 | 2 | 1.8 |
| 20 | 1 | 0.9 |
| 22 | 1 | 0.9 |
| 25 | 2 | 1.8 |
| 28 | 1 | 0.9 |
| 30 | 2 | 1.8 |
| 32 | 1 | 0.9 |

Very large changes were rare. On average, the absolute value of the difference between the final and the initial valuation was 1.33 PLN, thus nearly 5,78 for non-zero changes. This corresponds to about 10% of the expected value of a typical lottery.

### 3.3 Certainty equivalents

Table 4 shows mean certainty equivalents in all the treatments. In the Double Response Treatment, differences between the initial and the final decisions were very small, but usually the latter were less risk-averse (showed higher certainty equivalents). Overall, the initial decisions were modified downwards in 7% of the cases, upwards in 16% of the cases and left unchanged in 77%. For 18 out of 32 (problems number 3, 5, 6, 7, 11, 13, 14, 17, 18, 19, 20, 21, 22, 24, 28, 30, 31, and 32) these differences were significant at 10% (and for 14 of these at 5%) in a Wilcoxon test, see Table C1. Clearly, that is much more than 3.2 (and 1.6 respectively) significant differences that would be expected to arise by pure chance.

Comparing DR against NTP, final CEs were significantly different only in 7 out of 32 cases at 10% level (problems number 8, 19, 20, 21, 22, 23, and 29) and only in 1 out of 32 cases at 5% level in a Mann-Whitney U test, see Table C2. These figures are rather comparable to the null-hypothesis benchmarks of 3.2 and 1.6.

To summarize, reconsideration after longer deliberation period tended to make participants a bit less risk averse and their final decisions were, on average, quite similar to those made under no time pressure at all. In the next subsection we show how these tendencies translate into estimated probability weighting functions.

Table 4. Mean certainty equivalents by treatment

| | | | Double Response (n=113) | | | | No Time Pressure (n=38) | |
|---|---|---|---|---|---|---|---|---|
| | URN | LOTTERY | MEAN Initial decision | SD Initial decision | MEAN Final decision | SD Final decision | MEAN | SD |
| 1 | known | $\frac{1}{8}$ 100PLN; $\frac{7}{8}$ 0PLN | 31.58 | 28.28 | 31.17 | 27.99 | 28.79 | 25.86 |
| 2 | known | $\frac{2}{8}$ 100PLN; $\frac{6}{8}$ 0PLN | 36.50 | 23.34 | 36.37 | 22.59 | 35.68 | 21.72 |
| 3 | known | $\frac{3}{8}$ 100PLN; $\frac{4}{8}$ 0PLN | 44.46 | 19.69 | 45.10 | 19.85 | 44.50 | 20.93 |
| 4 | known | $\frac{4}{8}$ 100PLN; $\frac{4}{8}$ 0PLN | 53.73 | 19.26 | 54.39 | 19.57 | 53.39 | 21.06 |
| 5 | known | $\frac{5}{8}$ 100PLN; $\frac{3}{8}$ 0PLN | 62.81 | 19.39 | 64.16 | 19.13 | 61.68 | 21.19 |
| 6 | known | $\frac{6}{8}$ 100PLN; $\frac{2}{8}$ 0PLN | 73.25 | 16.19 | 74.99 | 16.40 | 73.42 | 19.99 |
| 7 | known | $\frac{7}{8}$ 100PLN; $\frac{1}{8}$ 0PLN | 84.92 | 16.74 | 86.35 | 15.29 | 82.68 | 20.24 |
| 8 | known | $\frac{4}{8}$ 60PLN; $\frac{4}{8}$ 0PLN | 35.92 | 12.56 | 36.28 | 12.59 | 32.18 | 12.06 |
| 9 | known | $\frac{4}{8}$ 100PLN; $\frac{4}{8}$ 40PLN | 65.97 | 14.12 | 66.42 | 13.21 | 64.97 | 12.93 |
| 10 | known | $\frac{4}{8}$ 40PLN; $\frac{4}{8}$ 0PLN | 23.00 | 9.34 | 23.12 | 9.05 | 22.00 | 9.33 |
| 11 | known | $\frac{4}{8}$ 60PLN; $\frac{4}{8}$ 20PLN | 40.12 | 10.44 | 41.04 | 9.84 | 38.95 | 9.51 |
| 12 | known | $\frac{4}{8}$ 80PLN; $\frac{4}{8}$ 40PLN | 59.88 | 10.42 | 59.95 | 9.98 | 59.66 | 11.07 |
| 13 | known | $\frac{4}{8}$ 100PLN; $\frac{4}{8}$ 60PLN | 77.65 | 10.42 | 79.16 | 10.05 | 79.11 | 9.92 |
| 14 | unknown | $\frac{1}{8}$100PLN; $\frac{7}{8}$ 0PLN | 25.88 | 23.37 | 27.34 | 23.39 | 25.26 | 25.03 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 15 | unknown | $\frac{1}{8}$100PLN; $\frac{7}{8}$ 0PLN | 30.66 | 25.79 | 31.04 | 25.92 | 25.08 | 23.56 |
| 16 | unknown | $\frac{1}{8}$100PLN; $\frac{7}{8}$ 0PLN | 33.42 | 27.85 | 34.02 | 27.20 | 29.00 | 27.76 |
| 17 | unknown | $\frac{2}{8}$ 100PLN; $\frac{6}{8}$ 0PLN | 38.70 | 23.51 | 39.93 | 26.61 | 33.84 | 25.80 |
| 18 | unknown | $\frac{2}{8}$ 100PLN; $\frac{6}{8}$ 0PLN | 36.72 | 21.81 | 37.95 | 22.28 | 31.13 | 20.56 |
| 19 | unknown | $\frac{2}{8}$ 100PLN; $\frac{6}{8}$ 0PLN | 40.36 | 24.70 | 41.11 | 25.39 | 32.61 | 22.84 |
| 20 | unknown | $\frac{2}{8}$ 100PLN; $\frac{6}{8}$ 0PLN | 38.86 | 23.20 | 41.03 | 24.46 | 32.63 | 24.24 |
| 21 | unknown | $\frac{3}{8}$ 100PLN; $\frac{5}{8}$ 0PLN | 47.97 | 24.36 | 49.55 | 24.28 | 41.03 | 22.86 |
| 22 | unknown | $\frac{4}{8}$ 100PLN; $\frac{4}{8}$ 0PLN | 52.52 | 23.19 | 54.05 | 22.98 | 45.42 | 23.02 |
| 23 | unknown | $\frac{4}{8}$ 100PLN; $\frac{4}{8}$ 0PLN | 53.37 | 21.575 | 54.14 | 20.71 | 45.34 | 23.58 |
| 24 | unknown | $\frac{5}{8}$ 100PLN; $\frac{3}{8}$ 0PLN | 62.32 | 21.45 | 63.22 | 22.33 | 55.26 | 24.17 |
| 25 | unknown | $\frac{6}{8}$100PLN; $\frac{2}{8}$ 0PLN | 69.51 | 22.77 | 70.53 | 22.06 | 63.45 | 25.72 |
| 26 | unknown | $\frac{7}{8}$ 100PLN; $\frac{1}{8}$ 0PLN | 78.72 | 23.49 | 79.96 | 21.94 | 73.82 | 26.98 |
| 27 | unknown | $\frac{4}{8}$ 60PLN; $\frac{4}{8}$ 0PLN | 36.12 | 14.94 | 35.94 | 15.01 | 31.39 | 16.49 |
| 28 | unknown | $\frac{4}{8}$ 100PLN; $\frac{4}{8}$ 40PLN | 61.88 | 14.07 | 62.95 | 13.47 | 62.16 | 12.13 |
| 29 | unknown | $\frac{4}{8}$ 40PLN; $\frac{4}{8}$ 0PLN | 23.60 | 10.90 | 23.89 | 10.58 | 20.29 | 10.15 |
| 30 | unknown | $\frac{4}{8}$ 60PLN; $\frac{4}{8}$ 20PLN | 38.23 | 10.34 | 39.39 | 9.56 | 37.03 | 9.17 |
| 31 | unknown | $\frac{4}{8}$ 80PLN; $\frac{4}{8}$ 40PLN | 58.45 | 10.10 | 59.12 | 9.36 | 57.00 | 10.12 |
| 32 | unknown | $\frac{4}{8}$ 100PLN; $\frac{4}{8}$ 60PLN | 76.67 | 10.48 | 78.09 | 10.20 | 77.66 | 9.58 |

### 3.4 Probability weights

Table 5 shows summary statistics as well as *p* values of tests for differences in probability weights by treatment. The following observations can be made. First, there is strong heterogeneity in the data. Second, central tendency diverges substantially from correct probability weights in all the treatments. Specifically, low probability of .125 tends to be overweighted and *p*s≥0.5 are underweighted. Third, the Double Response procedure does not seem to radically distort final responses: those made under DR are not different from those under No Time Pressure.[2] Fourth, weights for unknown urns are generally smaller than for known urns, the difference being most pronounced for larger probabilities. All of these largely replicate the findings of Abdellaoui et al. (2008). Crucially, deliberation time under DR also matters, as final choices are systematically different from initial choices. Specifically, for

[2] This is partly due to strong heterogeneity in the data and low number of observations under NTP. As a result, *initial* choices under DR are not different from those under NTP either.

unknown urns, final weights are generally higher (greater optimism, closer to correct probability weighting). By contrast, for known urns, the effect is less pronounced and only shows up for higher (underweighted) probabilities.

Table 5. Probability weights by treatment.

| **p** | **urns** | **treatment** | **median** | **mean** | **interquartile range** | ***t*-test *w*(*p*)=*p*** | **Wilcoxon test: Initial=Final** | **Mann-Whitney: DR-Final=NTP** |
|---|---|---|---|---|---|---|---|---|
| .125 | K | DR: Initial | 0.130 | 0.254 | 0.333 | 0.000 | 0.541 | 0.714 |
| | | DR: Final | 0.126 | 0.255 | 0.355 | 0.000 | | |
| | | NTP | 0.133 | 0.233 | 0.314 | 0.011 | | |
| | U | DR: Initial | 0.105 | 0.186 | 0.229 | 0.004 | 0.147 | 0.611 |
| | | DR: Final | 0.120 | 0.197 | 0.256 | 0.001 | | |
| | | NTP | 0.155 | 0.202 | 0.272 | 0.029 | | |
| .250 | K | DR: Initial | 0.228 | 0.281 | 0.300 | 0.203 | 0.377 | 0.927 |
| | | DR: Final | 0.250 | 0.292 | 0.366 | 0.090 | | |
| | | NTP | 0.217 | 0.279 | 0.307 | 0.439 | | |
| | U | DR: Initial | 0.222 | 0.248 | 0.292 | 0.923 | 0.041 | 0.690 |
| | | DR: Final | 0.237 | 0.274 | 0.302 | 0.277 | | |
| | | NTP | 0.197 | 0.238 | 0.269 | 0.671 | | |
| .375 | K | DR: Initial | 0.344 | 0.341 | 0.326 | 0.128 | 0.414 | 0.928 |
| | | DR: Final | 0.352 | 0.352 | 0.264 | 0.303 | | |
| | | NTP | 0.328 | 0.360 | 0.313 | 0.662 | | |
| | U | DR: Initial | 0.300 | 0.347 | 0.390 | 0.260 | 0.008 | 0.660 |
| | | DR: Final | 0.335 | 0.371 | 0.375 | 0.882 | | |
| | | NTP | 0.280 | 0.330 | 0.320 | 0.181 | | |
| .500 | K | DR: Initial | 0.419 | 0.410 | 0.282 | 0.000 | 0.116 | 0.864 |
| | | DR: Final | 0.473 | 0.426 | 0.315 | 0.001 | | |
| | | NTP | 0.435 | 0.425 | 0.329 | 0.036 | | |
| | U | DR: Initial | 0.339 | 0.361 | 0.286 | 0.000 | 0.014 | 0.986 |
| | | DR: Final | 0.381 | 0.385 | 0.271 | 0.000 | | |
| | | NTP | 0.418 | 0.374 | 0.271 | 0.000 | | |
| .625 | K | DR: Initial | 0.582 | 0.533 | 0.408 | 0.001 | 0.037 | 0.670 |
| | | DR: Final | 0.600 | 0.564 | 0.324 | 0.016 | | |
| | | NTP | 0.599 | 0.541 | 0.318 | 0.031 | | |
| | U | DR: Initial | 0.500 | 0.487 | 0.332 | 0.000 | 0.104 | 0.580 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | DR: Final | 0.511 | 0.505 | 0.381 | 0.000 | | |
| | | NTP | 0.483 | 0.473 | 0.299 | 0.000 | | |
| .750 | K | DR: Initial | 0.696 | 0.634 | 0.357 | 0.000 | 0.020 | 0.775 |
| | | DR: Final | 0.739 | 0.670 | 0.322 | 0.001 | | |
| | | NTP | 0.723 | 0.671 | 0.263 | 0.034 | | |
| | U | DR: Initial | 0.622 | 0.583 | 0.380 | 0.000 | 0.083 | 0.414 |
| | | DR: Final | 0.661 | 0.606 | 0.355 | 0.000 | | |
| | | NTP | 0.604 | 0.571 | 0.360 | 0.000 | | |
| .875 | K | DR: Initial | 0.855 | 0.796 | 0.251 | 0.000 | 0.051 | 0.240 |
| | | DR: Final | 0.880 | 0.815 | 0.231 | 0.002 | | |
| | | NTP | 0.817 | 0.768 | 0.178 | 0.010 | | |
| | U | DR: Initial | 0.800 | 0.707 | 0.307 | 0.000 | 0.045 | 0.528 |
| | | DR: Final | 0.824 | 0.728 | 0.327 | 0.000 | | |
| | | NTP | 0.756 | 0.698 | 0.449 | 0.000 | | |

### 3.5 Estimated probability weighting functions and value functions

Table 5 shows that final decisions on unknown urns were more optimistic than initial decisions. This pattern is also reflected in estimated parameters of probability weighting functions, see Table 6 for the Prelec's $\alpha$-$\beta$ parameterization and Table 7 for the simple intercept-slope parameterization. In both cases the only significant difference is that there is less pessimism (lower $\beta$/$b$) in final than in initial decisions on unknown urns.

Table 6. Estimated parameters for the Prelec (1998) probability weighting functions and the value function

| | | **Median** | | | **Wilcoxon test: Initial=Final** | | | **Mann-Whitney: DR-Final=NTP** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Urn** | **treatment** | $\rho$ | $\alpha$ | $\beta$ | $\rho$ | $\alpha$ | $\beta$ | $\rho$ | $\alpha$ | $\beta$ |
| K | DR: Initial | 1.142 | 0.916 | 1.064 | 0.515 | 0.336 | 0.118 | 0.607 | 0.079 | 0.847 |
| | DR: Final | 1.082 | 0.948 | 1.025 | | | | | | |
| | NTP | 1.094 | 0.803 | 1.054 | | | | | | |
| U | DR: Initial | 1.158 | 0.826 | 1.258 | 0.075 | 0.581 | 0.002 | 0.592 | 0.222 | 0.751 |
| | DR: Final | 1.142 | 0.806 | 1.210 | | | | | | |
| | NTP | 1.199 | 0.653 | 1.148 | | | | | | |

Table 7. Estimated parameters of linear probability weighting functions

| | | Median | | Wilcoxon test: Initial=Final | | Mann-Whitney: DR-Final=NTP | |
|---|---|---|---|---|---|---|---|
| **urn** | **treatment** | ***a*** | ***b*** | ***a*** | ***b*** | ***a*** | ***b*** |
| K | DR: Initial | 0.140 | 0.501 | 0.314 | 0.117 | 0.475 | 0.714 |
| | DR: Final | 0.130 | 0.011 | | | | |
| | NTP | 0.156 | 0.048 | | | | |
| U | DR: Initial | 0.208 | 0.169 | 0.799 | 0.009 | 0.410 | 0.751 |
| | DR: Final | 0.239 | 0.130 | | | | |
| | NTP | 0.387 | 0.092 | | | | |

The median estimated probability weighting functions by treatment are represented graphically in Figure(s) 2 and 3.

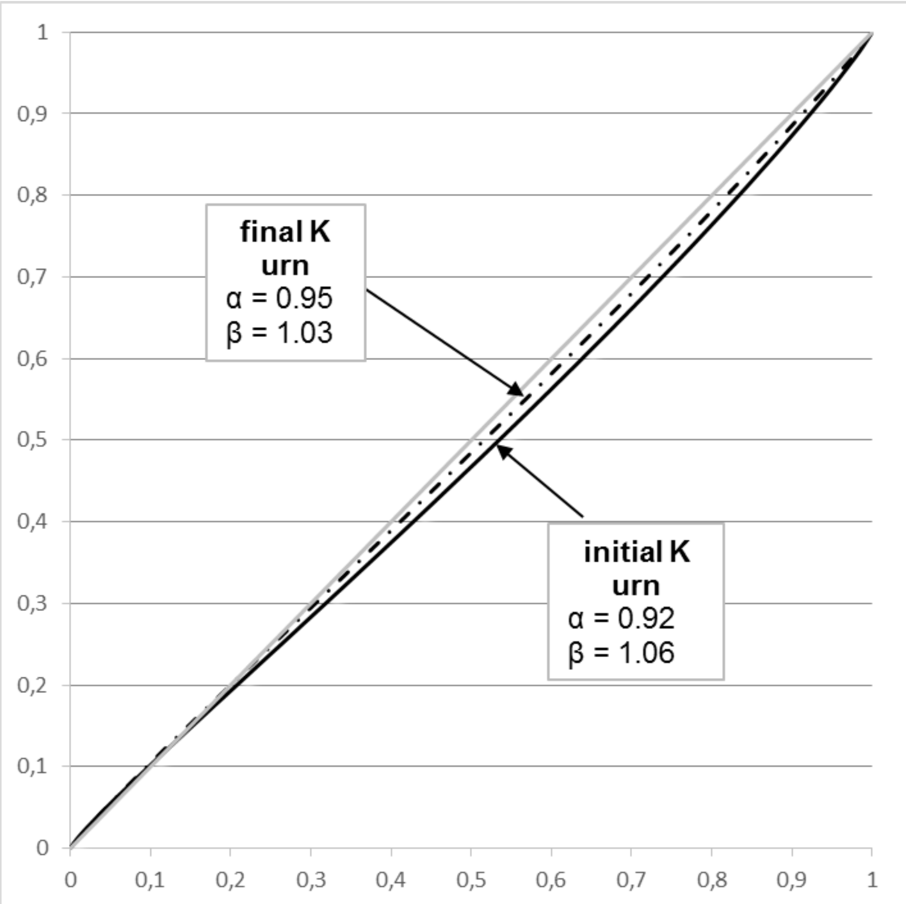


Fig. 2. Median individual probability weighting functions: known urns

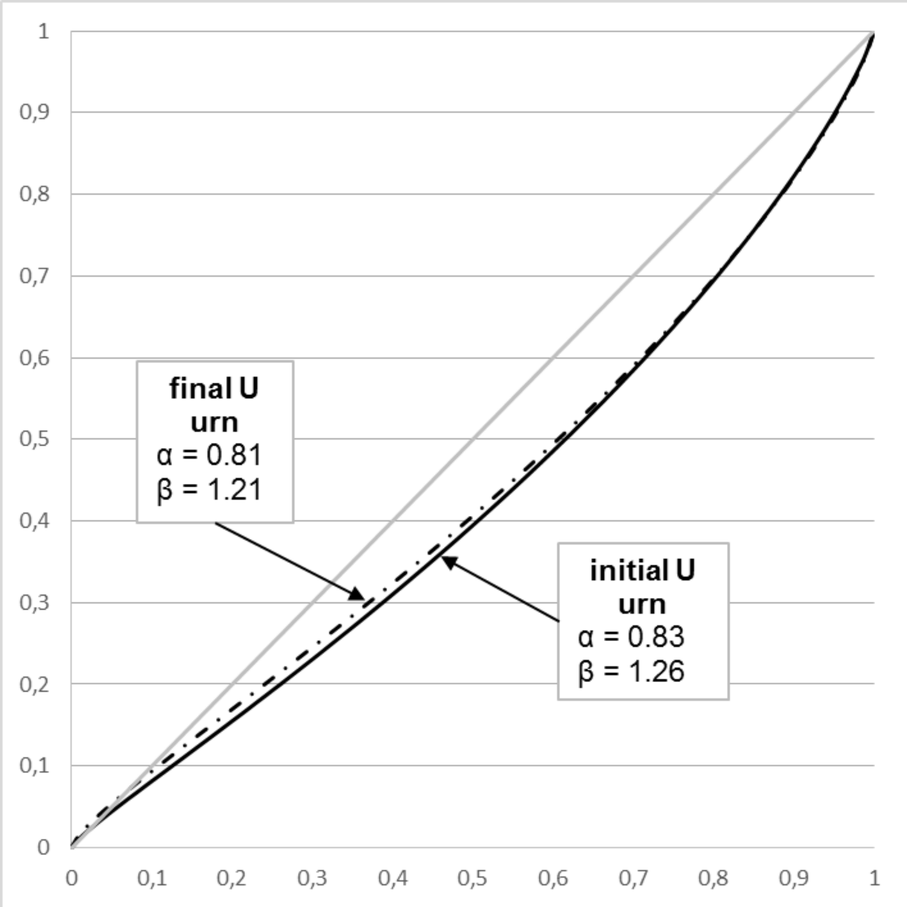

Fig. 3. Median individual probability weighting functions: unknown urns

As can be seen, in the case of known urns, median participant is close to the correct probability weighting, while she is markedly pessimistic in the case of unknown urns. In both cases, differences between final and initial decisions are subtle, generally involving less pessimism in the latter case.

### 3.6 The link with the Cognitive Reflection Test

While participants' demographic characteristics had little bearing on observed behavior, the scores on the Cognitive Reflection Test (CRT) turned out to be strongly correlated with choices. Specifically those with low score on the CRT tended to provide higher CEs. This tendency was highly significant initial and final choices in all conditions. No link with the number or direction of changes, nor decision times was found.

## 4. CONCLUSION

In this paper we used a novel method of identifying within-subject changes in decisions under risk and uncertainty after additional deliberation. While data shows substantial heterogeneity (as is typical in similar tasks), the following general patterns can be clearly observed. First, most participants are quite consistent in their choices in that they do not make many (large) changes. Second, however, a non-trivial minority of choices do get updated. Third, most of these choices involve reporting a higher certainty equivalent of the random lottery (more risk acceptance). Fourth, this pattern is stronger in the case of "unknown" urns (involving ambiguous chances of success). Fifth, the pattern does not seem to apply to a specific probability range only. The main shift involves the change in the "pessimism" coefficient b/β. While median choices (be it initial or final) for known urns are nearly consistent with normatively correct probability weighting function (i.e. identity function), initial choices under ambiguity are very pessimistic. Additional deliberation pushes them towards rationality.

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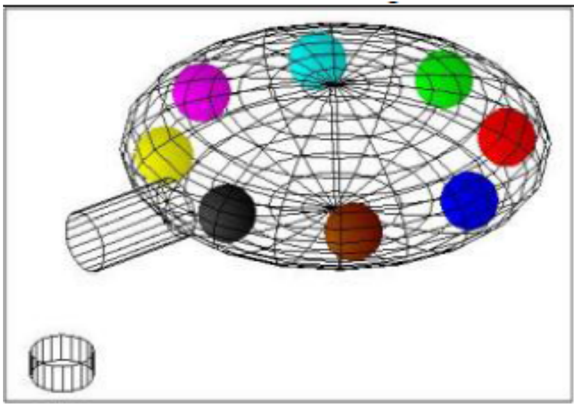
**Appendix A: Experimental Instructions (DR condition)**

Thank you for participating in this experiment! Just for being here on time you will earn 5 PLN. You can keep this amount regardless of the outcome of the experiment. Any further payoff will depend on how much you earn during the experiment, in accordance with the procedure specified in these instructions.

**INSTRUCTIONS**

In today's experiment you will make several decisions over a number of rounds. In each round will see an urn with eight balls. The balls may have different colours: black, blue, green, yellow, pink, red, brown and turquoise.



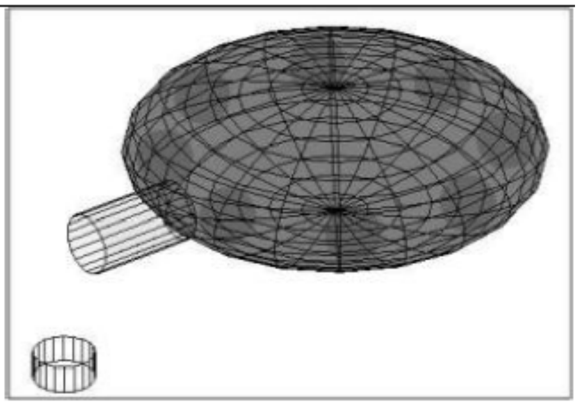


Fig. 1a. TRANSPARENT URN
In an urn like this you can see one ball in each of the eight colours

Fig. 1b. OPAQUE URN
With an urn like that you cannot know how many balls of each colour are inside

Figure 1 shows two kinds of urns that you can face. **Figure 1a. shows a transparent urn**. It will always contain exactly eight balls, with one ball in each of eight colours. This means that **the probability of selecting each colour is the same. The opaque urn shown in Figure 1b**. also has exactly eight balls. However, you cannot see the colours of the balls in this urn. **This means that you cannot know exactly how many balls of each colour are there.** It may happen that some of these colours are missing, while others will show up more than once. You will not know the exact composition of the urn. The probabilities of selecting different colours cannot be known and may be different for different colours.

We are interested in finding out how much each of a number of lotteries represented by urns is worth to you. You will be asked to make two decisions: an initial decision and a final decision in each of 34 rounds (including two trial rounds). In each of them you will have to indicate how much a lottery is presently worth to you. You will be asked to type in this amount in the dedicated field on the screen, as illustrated in Figure 2. Please note the possible payoffs and the number of balls resulting in each possible outcome. Both the higher and lower amount that may result from the lottery an the number of balls resulting in these outcomes will vary across decision tasks. Because your final monetary payoff will depend on these decisions, you should carefully analyse these aspects of the choices you make. Figure 2 shows an example of a decision task involving a transparent urn. At the top you can see how much time is left till the end of the round, which round it is and which phase of the run. Below you can see a transparent or opaque urn and information on how many colours are associated with winning each specific amount. Below you can see the question “How much is this lottery worth to you?”, prompting an answer to be typed in and confirmed.

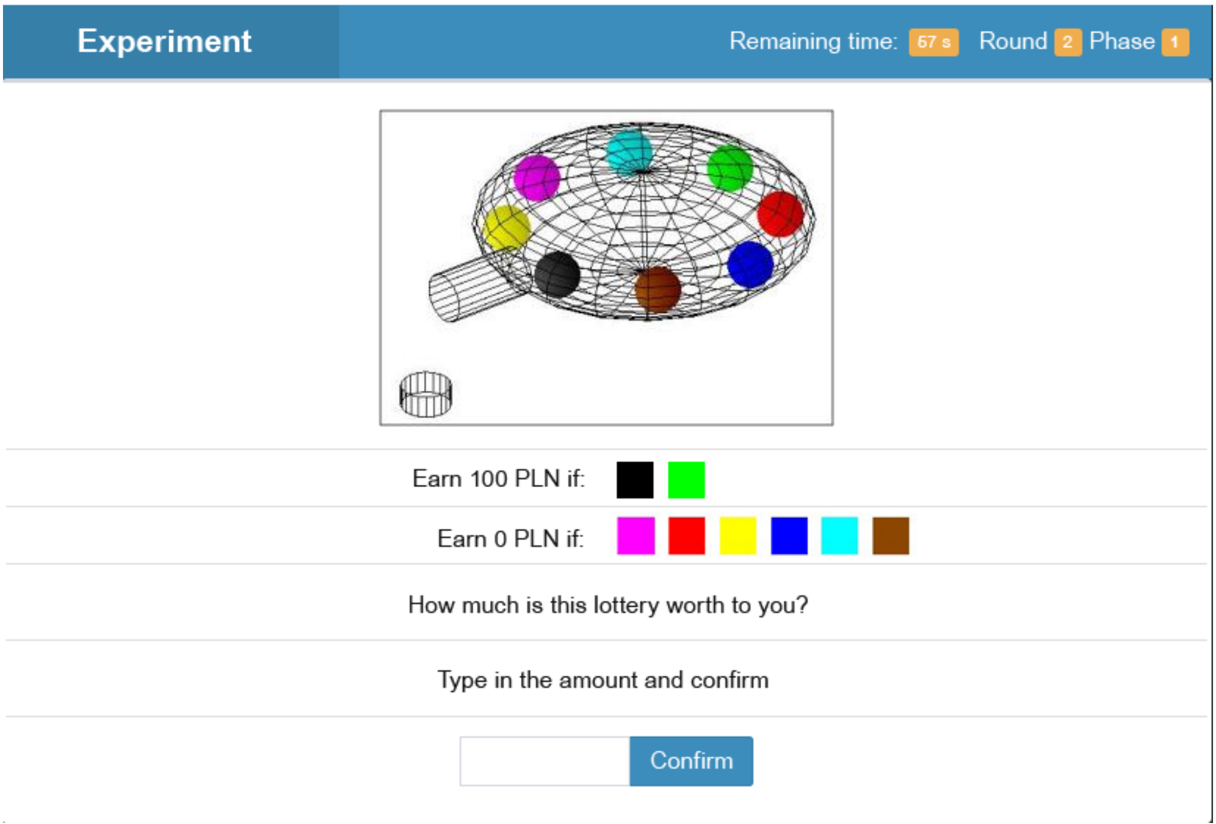



Fig. 2: An example of a decision task.

NOTE: unlike in most experiments in our Laboratory, TIME will play a very important role in today’s experiment. Each round will last up to 60 seconds and within this time you will have to make two decisions: initial and final. Ideally, you would like to keep indicating, at any moment of the round, what you currently consider to the best choice. Try to EVALUATE THE LOTTERY AS FAST AS YOU CAN AND ENTER YOUR INITIAL DECISION by typing in the amount and clicking “confirm” or pressing the Enter button. Then go back to the description of the lottery and think again. IF YOU CHANGE YOUR MIND, CHANGE YOUR CHOICE ON THE SCREEN ACCORDINGLY. Type in a new amount and click “confirm” or press Enter. You can also leave your initial choice unchanged: IF YOU COME TO A CONCLUSION THAT THE INITIALLY TYPED IN AMOUNT IS OPTIMAL, RE-TYPE IT ONCE MORE and click “confirm” or press Enter. Upon confirming the final decision you will be prompted to move to the next round by clicking the “next round” button.

To encourage possibly quick but at the same time careful consideration we will use the following method to determine your payoffs. At the end of the experiment the computer will not only randomly choose one round to determine your payoffs, but also a SPECIFIC SECOND of this round. The choice that was indicated by you at this specific second in this round will be implemented. If the computer chooses a second, in which you had not managed to choose any option yet, one of the options will be chosen randomly. Typically, it will be less profitable for you than have your own, conscious choices implemented. It means that it is best to make your initial decision very quickly (but not too quickly, it would effectively be random again in such a case), whereas if you realize that the initial choice was not optimal, to type in and confirm the modified amount.

We always randomly pick one of the 60 seconds, no matter how long the round actually lasted. If we pick on the of the seconds after your final decisions, this decision will be implemented.

Example

In round 9, a participant was evaluating a lottery represented by a transparent urn (with known probabilities). It involved winning 100 PLN with probability 4/8 and 40 PLN otherwise (thus also with probability 4/8). The participant initially assessed that the lottery is worth 60 PLN to her. She typed in this amount and confirmed it in the 10th second of the round. She knew, however, that the initial decision may not be optimal and that the payoff may be determined by the decision made at some later second of the round. She thus looked at the lottery again and realized that it is worth more to her than she initially thought. She thus eventually changed the decision (in the 44th second of the round), by typing in a new amount, 72 PLN and clicking "confirm", thereby ending the round.

Let us now assume that at the end of the experiment the computer randomly picked round 9. Simultaneously, a specific second of this round (1-60) is selected. Let us assume for example, that the 15th second is selected. Thus the initial decision, confirmed in the 10th second, is implemented. We thus understand that the decision maker evaluated the lottery at 60 PLN.

The computer randomly picks a number from the range between the lowest and the highest payoff in the lottery (here: 40-1000) this number can be interpreted as the amount offered to the participant instead of the lottery. If this amount is higher than the signalled value of the lottery, she will receive this amount. If it is lower – she will receive the lottery. Assume for example that the amount of 48 PLN is selected. The participant likes the lottery (evaluated at 60 PLN) better than this amount. Thus the lottery will be played: the participant will get 100 with probability 4/8 and 40 PLN otherwise. By contrast, if the randomly picked number was higher than her evaluation of the lottery (equal to 60 PLN), for example equal to 70 PLN, the participant will receive this amount instead of running the lottery.

If a later second of the round is picked, one by which the participant has managed to confirm her final decision, for example the 47th second of the round, this final decision will be implemented. For example, if the randomly picked sure amount offered instead of the lottery is 70 PLN as before, this time it will be lower than the participant's evaluation of this lottery (72 PLN). This time, instead of getting 70 PLN for sure, the participant will play the lottery.

By contrast, if one of the first 9 seconds (in which no choice was made yet) is picked, the computer will randomly pick the lottery or the randomly picked amount being offered instead of the lottery.

Even if the mechanism described above seems complicated, its consequences are simple: it is in your best interest to make a quick initial decision and modify your decision as soon as you come to a conclusion that the initial decision was not optimal. If you strengthen your belief that it was indeed optimal, you can re-type it and confirm to move on to the subsequent round.

**Appendix B: Cognitive Reflection Test**

Question 1: A bat and a ball cost 110 PLN in total. The bat costs 100 more than the ball.

How much does the ball cost? (correct answer: 5. intuitive: 10).

Question 2: In a lake. there is a patch of lily pads. Every day. the patch doubles in size. If it takes 48 days for the patch to cover the entire lake. how long would it take for the patch to cover half of the lake? (correct answer: 47. intuitive: 24).

Question 3: If it takes 5 machines 5 minutes to make 5 widgets. how long would it take 100 machines to make 100 widgets? (correct answer: 5. intuitive: 100).

**Appendix C: Supplementary tables**

**Table C1. Wilcoxon tests for equality of final vs. initial Certainty Equivalents in DR**

| **Round** | *z* | ***p*** |
|---|---|---|
| 1 | -0.42 | 0.675 |
| 2 | -0.272 | 0.786 |
| 3 | -1.736 | 0.083 |
| 4 | -.829 | 0.407 |
| 5 | -2.270 | 0.023 |
| 6 | -2.810 | 0.005 |
| 7 | -2.633 | 0.008 |
| 8 | -1.219 | 0.223 |
| 9 | -1.094 | 0.274 |
| 10 | -.515 | 0.607 |
| 11 | -1.819 | 0.069 |
| 12 | -.789 | 0.430 |
| 13 | -2.824 | 0.005 |
| 14 | -2.096 | 0.036 |
| 15 | -.818 | 0.413 |
| 16 | -.804 | 0.421 |

| **Round** | *z* | ***p*** |
|---|---|---|
| 17 | -2.302 | 0.021 |
| 18 | -1.793 | 0.073 |
| 19 | -2.058 | 0.040 |
| 20 | -3.051 | 0.002 |
| 21 | -2.852 | 0.004 |
| 22 | -2.120 | 0.034 |
| 23 | -1.453 | 0.146 |
| 24 | -2.609 | 0.009 |
| 25 | -1.313 | 0.189 |
| 26 | -1.309 | 0.191 |
| 27 | -.473 | 0.636 |
| 28 | -2.277 | 0.023 |
| 29 | -.874 | 0.382 |
| 30 | -3.018 | 0.003 |
| 31 | -2.172 | 0.030 |
| 32 | -2.707 | 0.007 |

**Table C2. Mann Whitney U tests for equality of final Certainty Equivalents: DR vs. NTP**

| **ROUND** | *z* | ***p*** |
|---|---|---|
| 1 | -0.506 | 0.613 |
| 2 | -0.078 | 0.938 |
| 3 | -0.245 | 0.806 |
| 4 | -0.072 | 0.943 |
| 5 | -0.388 | 0.698 |
| 6 | -0.048 | 0.962 |
| 7 | -0.953 | 0.341 |
| 8 | -1.705 | 0.088 |
| 9 | -0.683 | 0.494 |
| 10 | -0.678 | 0.498 |
| 11 | -1.615 | 0.106 |
| 12 | -0.250 | 0.803 |
| 13 | -0.245 | 0.807 |
| 14 | -0.906 | 0.365 |
| 15 | -1.542 | 0.123 |
| 16 | -1.449 | 0.147 |

| **ROUND** | *z* | ***p*** |
|---|---|---|
| 17 | -1.725 | 0.084 |
| 18 | -1.677 | 0.094 |
| 19 | -1.875 | 0.061 |
| 20 | -2.143 | 0.032 |
| 21 | -1.796 | 0.072 |
| 22 | -1.912 | 0.056 |
| 23 | -1.962 | 0.050 |
| 24 | -1.551 | 0.121 |
| 25 | -1.445 | 0.149 |
| 26 | -1.013 | 0.311 |
| 27 | -1.512 | 0.130 |
| 28 | -0.041 | 0.967 |
| 29 | -1.801 | 0.072 |
| 30 | -1.181 | 0.238 |
| 31 | -0.861 | 0.389 |
| 32 | -0.077 | 0.939 |

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