RATIONALITY & COMPETITION
CRC TRR 190

Measuring Preferences Over Intertemporal Profiles

Chen Sun (HU Berlin)

Discussion Paper No. 386

February 13, 2023

Collaborative Research Center Transregio 190 | www.rationality-and-competition.de
Ludwig-Maximilians-Universität München | Humboldt-Universität zu Berlin
Spokesperson: Prof. Georg Weizsäcker, Ph.D., Humboldt University Berlin, 10117 Berlin, Germany
info@rationality-and-competition.de

Measuring Preferences Over Intertemporal Profiles

Chen Sun*

February 7, 2023

Abstract

Growing evidence indicates that utility over time is different from utility under risk. Hence, measuring intertemporal preferences (discounting and utility) exclusively from intertemporal choices is desirable. We develop a simple method for measuring intertemporal preferences. The method is parameter-free in both discounting and utility, and it allows a wider range of models to be measured than preceding methods. It is easy to implement, clear to subjects, incentive compatible, and does not require more measurements than existing methods if identical assumptions are imposed. In an experiment, we illustrate how the method can be used to test recent models with unconventional assumptions non-parametrically.

Keywords: measuring time preferences, intertemporal profile, parameter-free
JEL-code: C91, D12, D91

* Humboldt-Universität zu Berlin (e-mail: chen.sun@hu-berlin.de). I am indebted to my PhD supervisors Jan Potters and Gijs van de Kuilen for their invaluable guidance and support. I am also grateful for the helpful discussions with Arthur van Soest, and the insightful comments of Mohammed Abdellaoui, Aurélien Baillon, Jan Boone, Elena Cettolin, Patricio Dalton, Eric van Damme, Eleonora Freddi, Reyer Gerlagh, Binglin Gong, Yiming Liu, Bin Miao, Peter Moffat, Wieland Müller, Jens Prüfer, Kirsten Rohde, David Schindler, Sebastian Schweighofer-Kodritsch, Maroš Servátka, Stefan Trautmann, Bert Willems, Yilong Xu, Yuxin Yao, Songfa Zhong and participants at the Tilburg Economics Workshop and Mini-Series, the job talk at Humboldt University of Berlin, the 2020 EEA Annual Congress, and the 2021 ESA Global Meeting. I thank the Dutch Research Council (NWO) and the German Science Foundation (Deutsche Forschungsgemeinschaft through the project CRC TRR 190) for their financial support.

Many economic decisions require people to choose between intertemporal profiles. An *intertemporal profile* is a sequence of outcomes that occur at different time points (e.g., 20 euros today *and* 20 euros in a month is a two-outcome profile). For instance, individuals who select pension plans are choosing among income profiles over their lifetime, and students who make their plans to write a term paper are choosing among effort profiles over a term.

Most methods of measuring intertemporal preferences use choices between *single dated outcomes* (i.e., profiles with only one non-zero outcome, such as 20 euros in a month, as opposed to *mixed profiles*, which have more than one non-zero outcome). With these methods, even a simple discounting model with one discount rate and one utility curvature parameter cannot be identified, unless utility is assumed to be linear. However, evidence shows that utility is nonlinear for both monetary and non-monetary outcomes (Abdellaoui, Attema, and Bleichrodt 2010; Andreoni and Sprenger 2012; Abdellaoui et al. 2013; Miao and Zhong 2015; Cheung 2020; and Sun and Potters 2022 for monetary outcomes; Augenblick, Niederle, and Sprenger 2015 for both monetary and non-monetary outcomes). Nonlinear utility implies that corner choices are not always preferred to interior ones.

One way to measure intertemporal preferences allowing non-linear utility is to measure utility through risky choices and then to use those utilities to measure discount rates (Andersen et al. 2008; Takeuchi 2011). This elicitation method has become controversial because recent evidence showed that utility over time is different from utility under risk: The utility curvatures in the two domains are uncorrelated at the individual level (Andreoni and Sprenger 2012), quantitatively different (Abdellaoui et al. 2013; Miao and Zhong 2015; Cheung 2020), and change with stake in opposite directions (Sun and Potters 2022).[1] Therefore, it is desirable to measure intertemporal preferences, including discount rates and utilities, exclusively from intertemporal choices.

In this paper, we introduce a new method for measuring intertemporal preferences in the domain of time. The basic idea is to measure indifference curves in the space of intertemporal profiles using ordered choice lists (akin to Holt and Laury 2002). The method is parameter-free in both utility and discounting, and hence requires no knowledge of functional forms. Most importantly, the method imposes weak restrictions on preferences to be measured. Hence, it allows measurements of a wider range of models, including those

[1] Epper, Fehr-Duda, and Bruhin (2011) corrected for probability weighting when they estimated the utility curvature using risky choices. Whether the correction makes the utility under risk congruent to the utility over time is an interesting empirical question to be addressed. Although this question is important and deserves further study, we focus on measuring utility in the domain of time, which circumvents the question.

with non-stationary period utility functions (Benhabib, Bisin and Schotter 2010), magnitude-dependent discount functions (Noor 2011, and Noor and Takeoka 2022), magnitude-dependent utility curvature (Fudenburg and Levine 2006), and additively non-separable utility functions (Holden and Quiggin 2017). Moreover, the method is easy to implement, clear to subjects, and incentive compatible. Compared with previous methods (Abdellaoui et al. 2010, Andreoni and Sprenger 2012, Abdellaoui et al. 2013, Attema et al. 2016, and Cheung 2020), our method has *all* of the aforementioned advantages. Thus, the method is especially suitable for testing models without concerns about misspecification. Moreover, it does not require more measurements than preceding methods if identical assumptions are made. Therefore, it is also suitable for applied studies where simple measures of utility and discounting are desired.

We implement the method using monetary rewards in an experiment. We first examine the validity of the method by comparing our measured preferences with earlier findings. Then we illustrate how the method can be used to test models non-parametrically. Our test does not rely on strong structural assumptions of specific models, such as additive separability or linear utility; rather, it depends only on models' qualitative predictions on meaningful characteristics. In particular, we test the magnitude effect on the marginal rate of substitution (MRS) on the diagonal, which is a main prediction of Noor and Takeoka (2022), the magnitude effect on the utility curvature as implied by Holden and Quiggin (2017), and the local non-convexity around the sooner corner, which is one of the main predictions of an adapted version of Benhabib et al. (2010).

The measured preferences are consistent with previous studies: The median subject has positive discounting and concave utilities, and larger outcomes are discounted less than smaller outcomes. In addition, our results provide evidence for the magnitude effect on the utility curvature and non-convexity around the sooner corner: Utilities of larger outcomes are less concave, and people have a preference for pure sooner rewards. We find no statistical evidence for increasing marginal rates of substitution. All the results are non-parametric and hence are not generated by specific parametric assumptions. They verify the meaningful characteristics of the unconventional models, which cannot be tested with existing non-parametric methods.

I. Background

An *intertemporal profile* $(z_1, \ldots, z_T) \in \mathbb{R}_T^+ \equiv [0, +\infty)^T$ yields outcome z_i at time t_i for each $i \leq T$. We examine preferences $\succcurlyeq$ over intertemporal profiles in $\mathbb{R}_T^+$. $\sim$ denotes indifference and $\succ$ denotes a strict preference as usual.

Our measurement method uses ordered choice lists, where each choice problem consists of two options that only differ in two outcomes.[2] For instance, a choice list consists of 30 choice problems, each of which consists of two options that only differ in their outcomes at t_i and t_j, where $i, j \leq T$; outcomes at all other time points are the same between the two options and across choice problems. As a result, for ease of presentation, we focus on the varying outcomes and denote them by $(x, y) \in \mathbb{R}_2^+ \equiv [0, +\infty)^2$, where x denotes the outcome at time point t_s (i.e., the *sooner reward*), y denotes the outcome at time point $t_l = t_s + \tau$ (i.e., the *later reward*), and τ is the *delay*. We call $(x, 0)$ where $x > 0$ a *pure sooner reward*, $(0, y)$ where $y > 0$ a *pure later reward*, and (x, y) where $x > 0$ and $y > 0$ a *mixed profile*. A profile (x, y) is *on the diagonal* if $x = y$.

We restrict our attention to preferences that are represented by a utility function, $U(x, y)$, which is continuous, strictly increasing, and differentiable at the *sooner corner* $[0, +\infty) \times \{0\}$ and in the remaining part of the space $[0, +\infty) \times (0, +\infty)$, respectively. By allowing the preference to be discontinuous or non-monotonic between the sooner corner and the interior, we accommodate the fixed-cost-of-waiting model by Benhabib et al. (2010). Among all models, a popular one is the *classic discounting model*, which consists of a stationary period utility function and a magnitude-independent discount function. In the space of two-outcome profiles, it can be expressed as

(1) $$U(x, y) = u(x) + D(t_s, t_l)u(y).$$

where $D(t, t')$ is a discount function indicating the discount factor from t to t'.

The *marginal rate* of *substitution* of the later reward for the sooner reward at profile (x, y) is

(2) $$MRS_{yx}(x, y) = \frac{U_2'(x, y)}{U_1'(x, y)}.$$

The MRS at profile (x, y) measures how much sooner reward a decision-maker is willing to give up to obtain one unit of later reward, which reflects the decision-maker's local

[2] Ordered choice lists with more than two outcomes might be useful for investigating sequence effects such as the preference for increasing sequences (Kahneman et al. 1993, and Loewenstein and Prelec 1993) or a holistic model of intertemporal choices (Baucells and Cillo 2020).

patience at the profile: They are locally more patient if they have a larger MRS. In a classic discounting model, any MRS on the diagonal reduces to the discount factor, $D(t_s, t_l)$.

The *elasticity of intertemporal substitution* (EIS) at a profile (x, y) is the percentage change in income ratio as a response to MRS percentage change given the utility level at (x, y), which can formally be expressed as

$$\varepsilon(x,y) \equiv \frac{1}{\frac{\partial}{\partial Q}\ln\frac{U_2'\big(x(Q,u),y(Q,u)\big)}{U_1'\big(x(Q,u),y(Q,u)\big)}}, \tag{3}$$

where $Q \equiv \ln\left(\frac{x}{y}\right)$ and $u = U(x, y)$. Here, Q is the log-income ratio, and $\frac{U_1'}{U_2'}$ is the MRS, which is equal to the return rate when utility is optimized. EIS measures the sensitivity of quantity ratios to relative price: The larger the EIS, the more sensitive the choices are to changes in return rates.

Suppose (x_0, y_0) is a profile in $\mathbb{R}_2^+$, which is sufficiently distant from the origin, and L is a ray in $\mathbb{R}_2^+$ from the origin with the income ratio $\frac{x}{y} = \lambda \in [0, +\infty]$. By continuity and strict monotonicity, there must be a profile $(x_1, y_1) \in L$ such that $(x_0, y_0) \sim (x_1, y_1)$. The *average rate of substitution* (ARS) of the later reward for the sooner reward between the profile (x, y) and the ray L is

$$ARS_{yx}(x_0, y_0, \lambda) = -\frac{x_1 - x_0}{y_1 - y_0}. \tag{4}$$

The ARS reflects the patience revealed from choices between (x_0, y_0) and profiles on L. The decision-maker is more patient if she has a larger ARS.

Suppose $(x_0, 0) \sim (0, y_1)$. The *monetary discount factor* implied by this indifference relation is

$$\delta^m \equiv \frac{x_0}{y_1}.$$

There is a *magnitude effect on the monetary discount factor* if $(0, ky_1) \succ (kx_0, 0)$ where $k > 1$.

II. Measurement Method

A. Core Procedure

The core component of the method is a procedure that measures indifference curves for each pair of time periods using ordered choice lists. Indifference curves represent preferences in a parameter-free way. They can also be converted into utilities, e.g., by setting the utility of a profile to be the per-period outcome of an equally good profile on the diagonal. If a parametric model is assumed, indifference curves can also be used to estimate parameters.

For measuring one indifference curve, a few indifference relations are elicited between one pre-determined profile and a few profiles with pre-determined income ratios. Figure 1 illustrates how an indifference curve is measured. The indifference curve through the pre-determined profile (x_0, y_0) is measured by eliciting the indifference relations between (x_0, y_0) and each of (x_1, y_1), (x_2, y_2), … , (x_J, y_J), where $\lambda_j = \frac{x_j}{y_j}, j = 1, \dots, J$ are pre-determined by the experimenter and satisfy $0 \leq \lambda_1 < \lambda_2 < \cdots < \lambda_J \leq \infty$. By connecting all those equally good profiles, an indifference curve is obtained. The pre-determined profile can be on the diagonal or a pure sooner/later reward or any other profile, depending on the purpose of the measurement.

To elicit each of the indifference relations, a choice list is used. In one choice list, M binary choice problems are presented. One of the options in all those problems is fixed at (x_0, y_0). The other option moves along the line towards the origin, i.e., it changes from (x_j^1, y_j^1) to (x_j^M, y_j^M), where $\frac{x_j^1}{y_j^1} = \cdots = \frac{x_j^M}{y_j^M} = \lambda_j$ and either $x_j^1 > x_j^2 > \cdots > x_j^M$ or $y_j^1 > y_j^2 > \cdots > y_j^M$ holds. Because the varying option worsens as the subject moves down the list, the indifference relation can be identified by looking at the switch point. Figure 2(a) shows an example of a choice list. The RIGHT option is fixed at a profile on the diagonal, (€20, €20), whereas the LEFT option changes from (€0, €60) to (€0, €20), all of which have an income ratio of zero.

B. Parameter-free Measures of Intertemporal Preferences

By applying the procedure above, we obtain a parameter-free measure of an intertemporal preference over a pair of time periods. The number of required indifference relations and indifference curves depends on desired precision.

If $T > 2$, we can obtain a measure of the intertemporal preference over the T periods by changing outcomes in two periods at a time. For example, if $T = 3$, we can use a choice list with varying outcomes only at $t_s = 1$ and $t_l = 2$ to obtain $(z_1^0, z_2^0, z_3^0) \sim (z_1^1, 0, z_3^0) \sim (0, z_2^2, z_3^0)$, after which another list with varying outcomes only at $t_s = 2$ and $t_l = 3$ can be used to obtain $(z_1^0, z_2^0, z_3^0) \sim (z_1^0, 0, z_3^3)$. In this way, indifference surfaces can be obtained, which represent the preference, and can be converted into utilities.

Another way to measure intertemporal preferences is to measure some local properties of the preference, such as MRS and EIS, at different profiles. If $\ln\lambda_j = \ln\frac{x_0}{y_0} - \Delta$, $\ln\lambda_{j+1} = \ln\frac{x_0}{y_0} + \Delta$, where $\Delta > 0$ is small, and $(x_0, y_0) \sim (x_j, y_j) \sim (x_{j+1}, y_{j+1})$, the MRS at (x_0, y_0) can be approximated by taking the geometric average of the $ARS_{yx}(x_0, y_0, \lambda_j)$ and $ARS_{yx}(x_0, y_0, \lambda_{j+1})$, and the EIS at (x_0, y_0) can be approximated as

$$\varepsilon(x_0, y_0) = \frac{\ln\lambda_{j+1} - \ln\lambda_j}{\ln ARS_{yx}(x_0, y_0, \lambda_{j+1}) - \ln ARS_{yx}(x_0, y_0, \lambda_j)}$$

where the denominator is approximately the percentage change of the return rate and the numerator is approximately the percentage change of the income ratio. When λ_j and λ_{j+1} are fixed, we can also use the ratio $ARS_{yx}(x_0, y_0, \lambda_{j+1})/ARS_{yx}(x_0, y_0, \lambda_j)$ as a simple measure of the convexity of the indifference curve at (x_0, y_0). MRSs and EISs at various profiles characterize the underlying preference and can be used to test models.

C. Parameter-free Measures and Tests of Discount Functions

If a model with a discount function is assumed, i.e., $U(x, y) = u(x) + D(t_s, t_l)u(y)$, where $u(\cdot)$ is a stationary period utility function and $D(t, t')$ is a discount function indicating the discount factor from t to t', we obtain a parametric or non-parametric estimate of the discount rate $D(t_s, t_l)$ for each pair of time periods. Then, by varying the time periods, we can estimate the entire two-argument discount function. One application is to *test the additivity* of discount rates (Read 2001, Read and Roelofsma 2003, and Dohmen et al. 2022 found *sub-additivity*), i.e., to test whether $D(t_1, t_3) = D(t_1, t_2)D(t_2, t_3)$ holds. Once discount rates are additive, we can define a classic one-argument discount function $D(t)$, which is only dependent on the time of the discounted outcome t. Then, it is possible to *test models of discounting*, such as exponential or hyperbolic discounting. If additivity is assumed a priori, we do not need to include all possible pairs of time periods but, rather, only a chain of time periods, as $((t_1, t_2), (t_2. t_3), \dots)$. In all cases, we can always increase the precision simply by including more pairs of time periods.

D. Parametric Model Estimation

The measured indifference curves can, of course, be used for parametric estimation. The required number of measurements is dependent on the number of parameters required to obtain estimates. For example, if we assume a classic discounting model over two periods with linear period utility function, i.e., $U(x, y) = x + \delta y$, then we only need to measure one indifference relation, e.g., $(0. y_0) \sim (x_1, 0)$, as in Coller and Williams (1999). If a classic discounting model with a one-parameter period utility function is assumed, e.g., $U(x, y) = x^\alpha + \delta y^\alpha$, we only need to measure one indifference curve with at least two indifference relations, e.g., $(x_0, y_0) \sim (0, y_1)$ and $(x_0, y_0) \sim (x_2, 0)$.

E. Comparison with Proceeding Methods

Some proceeding methods also measure intertemporal preferences (discount rate or utility or both) purely in the time domain. Abdellaoui et al. (2010), assuming a classic discounting model, used a chained method to measure period utility function in a parameter-free way. The Convex Time Budget (CTB) method developed by Andreoni and Sprenger (2012) elicits choice functions from linear budgets and can be used to measure any quasi-concave intertemporal utility function parametrically. Abdellaoui et al. (2013) measured a classic discounting model parametrically using non-linear least square regressions. Attema et al. (2016), also assuming a classic discounting model, measured the discount function non-parametrically without any knowledge of utility function. Cheung (2020) used an ordered choice list to measure utility non-parametrically and discounting parametrically. Our method is similar with Cheung (2020) in that we both used ordered choice lists where each option is a two-outcome profile. The main difference is that he varied payment dates while we varied outcomes, which makes our measures parameter-free also in discounting.

Compared with these methods, our method has a number of advantages. First, our measurement is parameter-free in utilities. Hence, the underlying utility function(s) can be revealed without a commitment to a parametric family of utility functions.

Second, our measurements are independent of time horizon effects. This implies that researchers do not need to assume exponential discounting or any other discount function to obtain estimates of discount rates. Rather, the measured discount rates can be used to reveal the shape of the discount function or to test models of time horizon effects (e.g., hyperbolic discounting, sub-additivity, etc.)

Third, our method is incentive compatible. Incentivization is useful, especially for experiments on intertemporal choices, because hypothetical experiments reported a higher discount rate than real stake ones (Coller and Willams 1999). Incentive compatibility can be easily implemented given that all stimuli in the choice lists are pre-determined.

Fourth, as we use ordered choice lists with only two varying components (i.e., the two outcomes of the LEFT option) and the components change monotonically across rows, the method is easy to implement and clear to subjects. Subjects can easily understand why telling the truth is optimal to them rather than have to trust the experimenter.

Most importantly, our method requires extremely weak assumptions on the preference to be measured. It only requires the preference to be represented by a continuous and monotonic utility function. Hence, it can be used to measure a variety of models, including those with unconventional assumptions, such as a magnitude-dependent discount function (Noor 2011, and Noor and Takeoka 2022), magnitude-dependent utility curvature (Fudenburg and Levine 2006), non-stationary period utility functions and non-convexity (Benhabib et al. 2010), or a non-separable utility function (Holden and Quiggin 2017).

Proceeding methods share some of the aforementioned advantages, while our method has *all* of them. This makes it especially suitable for *testing theories* of intertemporal choices without any concerns about misspecification.

The flexibility of our method does not make it more costly. It is not surprising that a parameter-free measurement requires more questions than a typical parametric estimation; however, as long as identical parametric assumptions are made, our method does not require more questions than existing methods. Hence, our method is also suitable for *applied studies* where simple measures of utility and discounting are needed. For instance, if a classic discounting model with a discount rate and a one-parameter utility function is assumed, as in many applications, researchers only need two choice lists. Because choice lists are ordered and computerized programs force subjects to present at most one switch point, those are essentially two decisions. If, based on that, the utility function is assumed to be linear, then one single choice list can identify the discount rate, and, in this case, the single-reward choice list by Coller and Willams (1999) can be seen as a special case of our method.

III. Experiment

We applied our method to measure preferences over two-outcome intertemporal profiles of monetary rewards. The aim is to show that a) the method can be easily implemented, b) the measured preferences are consistent with the findings of previous experiments, and c) various non-standard models can be measured or tested in a parameter-free way.

A. *Theoretical Background*

Existing evidence shows that an average person i) is indifferent between a smaller sooner reward and a larger later reward (see Frederick et al. 2002 for a review), ii) presents the magnitude effect over single dated outcomes, i.e., $(x,0)\sim(0,y) \Rightarrow (0,ky) \succ (kx,0)$ if $k > 1$ (see Andersen et al. 2013 for a review), iii) has a strict concave period utility function, and iv) has a discount factor less than one when utility curvature is controlled. Most existing models predict these characteristics. Accordingly, our first goal is to examine whether our measured preferences also display them.

Our second goal is to test a few recent models that either cannot be tested by previous methods or can only be tested parametrically. Those models in their original versions are made tractable by imposing strong structural assumptions, such as additive separability, linear utility, or a specific utility function. A parametric test that relies on these assumptions might reject a model not because its main economic meaning is absent in the data but because these structural assumptions are not satisfied.

In light of this, we take a different route. We test models' qualitative predictions on meaningful characteristics of choices. This is similar in spirit with Kerschbamer's (2015) test of models on distributional preferences. The idea is to test models in terms of the characteristics with important economic meanings, ensuring that the test is unaffected by specific assumptions that are made mainly for technical convenience.

We choose three models. The first model is the generalized discounted utility model by Noor and Takeoka (2022). The model assumes that the discount factor is a function of the discounted outcome. Formally, in the space of two-outcome profiles, the overall utility is

$$U(x,y) = D_{u(x)}(t_s)u(x) + D_{u(y)}(t_l)u(y)$$

where the period utility function $u(\cdot)$ is increasing and the discount function $D_{u(x)}(\cdot)$ is decreasing in time delay. The main hypothesis is magnitude-decreasing impatience, i.e., $D_{u(x)}(\cdot)$ is increasing in $u(x)$. With this hypothesis and some other assumptions, the model explains a number of empirical findings such as magnitude effect, preference reversal, and preference for increasing sequences. In our experiment, we test a major prediction of the model: *MRS on the diagonal is increasing in the stake*. This qualitative prediction does not rely on parametric assumptions of the utility and the discount functions and has not yet been tested.

The second model is the mental zooming theory by Holden and Quiggin (2017). Preference is represented by a time non-separable overall utility function as:

$$U(x, y) = u\big(x + k(x + y)^{\beta}\big) + \delta u\big(y + k(x + y)^{\beta}\big)$$

where $u(\cdot)$ is a homogeneous utility function and $k(x + y)^{\beta}$ is background consumption, with $k, \beta > 0$.[3] The idea is that people integrate experimental rewards with more background consumption/wealth if the choice problem involves a longer period or a higher stake. If the background consumption grows proportionally to reward size ($\beta = 1$), choices will be homothetical. If the background consumption grows faster ($\beta > 1$; slower [$\beta < 1$]) than the stake, the EIS on the diagonal will be increasing (decreasing) in stake, suggesting that utility will be relatively less (more) concave.

In our experiment, we measure *utility curvature on the diagonal* for two different stakes to investigate how it *changes with stake*. Different from Holden and Quiggin (2017), who measured utility curvature from risky choices, we measure it purely in the time domain.

The third model is the fixed-cost-of-waiting model by Benhabib et al. (2010). It explains diminishing impatience and magnitude effect on monetary discount rates by a fixed cost of waiting. When this model is adapted for choices between two-outcome profiles assuming that a fixed cost is incurred whenever the later reward is non-zero, it predicts that any indifference curve jumps downward at the sooner corner. The intuition is that people have a preference for pure sooner rewards. They therefore appear to be disproportionately impatient when one of the options is to have all money on the sooner date. Formally, the overall utility function is

$$U(x, y) = u(x, y) - C \cdot 1(y > 0)$$

where $u(x, y)$ is a continuous, monotonic, and quasi-concave utility function and $C > 0$ is the fixed cost incurred whenever the decision-maker must wait for a non-zero later reward.

If the fixed cost is sufficiently large relative to the rewards, when we use our method to measure the preference, we should observe that an indifference curve fails to be convex around the sooner corner due to the downward jump. We therefore tested the model by examining the *non-convexity at the sooner corner*.

Furthermore, if the utility function $u(x, y)$ is homogeneous (as assumed in many empirical studies, including Benhabib et al. 2010), we should observe that the effect of the fixed cost on the local non-convexity decreases with the stake; when outcomes are scaled up, the measured indifference curve bends less backward and can even look convex. The intuition is that a fixed cost is less salient when outcomes are larger.

[3] In their original experiment, Holden and Quiggin (2017) used a single-reward task, and the background consumption in the original model was only affected by the later reward y. Because we allow mixed profiles in our measurement, we assume that the background consumption relies on the total amount of rewards, i.e., $x + y$.

We tested all the three predictions above in a parameter-free way; no knowledge of discounting or utility was used in the measurement. This is not possible with existing measurement methods because they require additive separability and stationary period utility functions. The CTB method by Andreoni and Sprenger (2012) can be used to measure the models of Noor and Takeoka (2022) and Holden and Quiggin (2017) parametrically if functional forms are known. However, the local non-convexity of Benhabib et al. (2010) implies that one can only identify the convex hull of an indifference curve using the CTB method. In this respect, our method has advantages both in applicability and in being parameter-free.

B. Design

We implemented our measurement method in a real-stake experiment. Specifically, we measured subjects' preferences over intertemporal profiles consisting of two monetary rewards: received in $t_1 = 1$ day and received in $t_2 = 141$ days.

For each subject, we elicited two indifference curves in the space of two-outcome profiles: through (€20, €20) and through (€80, €80). For each indifference curve, we used choice lists to elicit the indifference relations between a profile on the diagonal and another profile whose income ratio is among the following four values: 0, $\frac{1}{2}$, 2, or ∞. Hence, the following eight indifference relations were elicited from each subject:

$$(0, y_{1,L}) \sim (20,20), (x_{2,L}, 2x_{2,L}) \sim (20,20), (2y_{3,L}, y_{3,L}) \sim (20,20), (x_{4,L}, 0) \sim (20,20),$$
$$(0, y_{1,H}) \sim (80,80), (x_{2,H}, 2x_{2,H}) \sim (80,80), (2y_{3,H}, y_{3,H}) \sim (80,80), (x_{4,H}, 0) \sim (80,80).$$

Figure 3 presents those indifference relations in the (x, y) space: OA, OB, OC, and OD for the lower stake and O'A', O'B', O'C', and O'D' for the higher stake. These indifference relations imply eight ARSs, denoted by $r_{j,k}$, where $j = 1,2,3,4, k = L, H$.

Each indifference relation was elicited by a 30-row choice list. In the last row, the LEFT option was dominated by the RIGHT option. Moving up the list, the LEFT option became increasingly attractive. In the first row, choosing the RIGHT option implied an ARS either less than 0.5 (if the LEFT options had a larger later outcome) or greater than 2 (if the LEFT options had a larger sooner outcome), which is very unlikely. Figure 4 displays the 240 choice problems in the (x, y) space. Each choice problem is represented by a line segment, of which the two endpoints stand for the two options. We present the full tables of stimuli in Appendix A.

In principle, subjects were required to make 30 choices in each list. However, we explicitly pointed out that, in each list, the RIGHT option was fixed and the LEFT worsened moving down the list. Therefore, once a subject chose LEFT in a row, they would also prefer LEFT to RIGHT in all preceding rows, and the program would automatically select LEFT in those rows. Similarly, if a subject chose RIGHT in a row, all rows below would automatically turn into RIGHT. Figure 2(b) displays how the computer program would proceed if a subject chose an option in a row. By imposing such a mechanism, we ruled out the possibility of multiple switching and substantially reduced subjects' thinking cost and the experiment duration.

The order of the eight lists was randomized in two independent dimensions: from the sooner corner to the later corner or vice versa, and the lower stake first or the higher stake first. Subjects could switch between lists at any moment, regardless of whether they had finished the current list. Choices were automatically stored when subjects switched to another list, and thus they could easily make comparisons across lists if desired.

The experimental payments had two components. First, all subjects received a €3 *participation fee* on each of the two dates, t_1 and t_2. Second, each subject had 10% chance to receive *earnings depending on choices*, which were determined by a random incentive scheme with both between-subject (by a 10-sided die) and within-subject randomization (by computer program).

For a real-stake experiment on intertemporal choices, it is important to equalize the transaction costs as well as the credibility of payments across periods. For this purpose, we followed the protocol of Andreoni and Sprenger (2012) and provided an equal amount of participation fees on both payment dates, with the participation fees and earnings depending on choices both delivered by bank transfer. Thus, the payment tools were the same for the two payments, and subjects received money twice regardless of their choices. The survey by Sun and Potters (2022) shows that bank transfer is as good as cash in terms of liquidity to students at Tilburg University. Therefore, subjects had reasons to believe that they would receive payments on time and that the money could be used immediately. Moreover, we provided each subject with a payment reminder card, which recorded the payment amounts and dates as well as the contact information of the experimenter. This further increased payment credibility.

The experiment was conducted at the CentERlab, Tilburg University, September 2017.[4] Overall, 114 university students participated in one of the eight sessions. One session took an hour on average. At the start of each session, the experimenter read the instructions aloud in front of all subjects. Then, the subjects made choices in a zTree program (Fischbacher 2007). Twelve subjects got the earnings depending on decisions, the average of which was €82.46. The overall average earning was €14.68.

C. Results

All 114 subjects completed 240 choices. Two subjects never switched in any list, and their choices are not consistent across lists. Five other subjects chose a dominated option at least once. We thus rule out their choices.

Among the remaining 107 subjects, 24 of them (22%) always behave as if they maximize the total amount without discounting. These subjects behave as if they fully integrate experimental rewards with their lifelong wealth. Because they present no magnitude effect or non-convexity at the sooner corner, we focus on the remaining 83 subjects throughout this section. None of our tests are affected by the exclusion of those total-amount maximizers.

Given the often-observed heterogeneity in preferences, we did not "force" all subjects to have the same preference and estimate the "representative" preference. Instead, we performed within-subject comparisons so that all our tests take heterogeneity of preferences into account.[5]

In all our tests, we treated censored observations (i.e., with no switching) as extreme values (i.e., zero or infinity ARS), which is the more conservative way to perform the tests. Because only a small fraction of choices are censored (5%) and the signed rank test only relies on the rank, we expect censoring to have limited effects on our results.

1. Comparability with Previous Studies

We first tested whether people are indifferent between a smaller pure sooner reward and a larger pure later reward, i.e., whether the monetary discount factor is less than one.[6] Formally, this can be expressed as

[4] All payment dates were workdays, which guaranteed the punctual arrival of payments via bank transfer.

[5] We performed sign tests and Wilcoxon signed-rank tests. The sign test has the advantage of allowing heterogeneity in the size of the effect being tested. The Wilcoxon signed-rank test takes size of effects into account and has an advantage in power. The results of the two tests are always consistent in our study, suggesting robustness of our findings.

[6] In a statistical test, noise is taken into account. Thereby, strictly speaking, we tested whether the monetary discount factor is more likely to be less than one than it is to be greater than one. Similar arguments apply to all other tests in this paper.

(5) $$\hat{\delta}_k^m \equiv \left(\frac{x_{4,k}}{y_{1,k}}\right)^{\frac{365}{140}} < 1, \qquad k = L, H.$$

Columns 1 and 2 of Table 1 show the monetary discount factors for the lower and higher stakes, respectively. The medians are less than one, confirming that subjects exhibit impatience in choices between single dated outcomes.

The average annual monetary discount rate for the entire sample is 25% for the stake of €40 and 19% for the stake of €160 with a delay of 20 weeks. This can be compared with 30% for the stake of CHF 60 (about €40) in Epper, Fehr-Duda, and Bruhin (2011) where the delay was four months. The small gap is possibly caused by sub-additivity: The measured discount rate is decreasing in delay (Read 2001; Dohmen et al. 2022).

The second stylized fact is the magnitude effect over single dated outcomes: People have a larger monetary discount factor for higher stakes. Formally, this can be expressed as

(6) $$\hat{\delta}_L^m < \hat{\delta}_H^m.$$

Column 3 of Table 1 shows the results of the test. The monetary discount factor is greater for the higher stake than it is for the lower stake for the majority. Thus, the magnitude effect on the monetary discount rate is significant, which is consistent with previous evidence.

Experiments using intertemporal profiles have found that the interior part of an indifference curve is convex (Cheung 2020) and the entire indifference curve is on average convex (Andreoni and Sprenger 2012; Sun and Potters 2022). We thus tested whether this is true for our dataset. Columns 1-4 of Table 2 show the tests on convexity. The first two columns concern the convexity of the lower-stake indifference curve. Column 1 presents the ratio between the two ARSs in the interior, which is a measure of convexity in the interior. Given that the ratio is on average greater than one, the interior part of the lower-stake indifference curve is convex. Column 2 presents the ratio of the two ARSs between the profile on the diagonal and the two corners, which is a measure of average convexity for the entire indifference curve. Because the ratio is greater than one, the lower-stake indifference curve is on average convex. These results are consistent with previous findings. The next two columns show the higher-stake case. The indifference curve in the interior is still more likely to be convex, but no evidence shows that the entire curve on average is convex. The difference between the interior and the overall curve can be explained by the effect of non-convexity at the sooner corner (see Section III.C.2).

Andreoni and Sprenger (2012), in their parametric estimation with a classic discounting model, obtained a discount factor less than one after controlling for the utility curvature.

Because the discount factor in a classic discounting model corresponds to the MRS on the diagonal, we examine whether the MRS on the diagonal is on average less than one. Columns 1 and 2 of Table 3 display the estimates of MRSs on the diagonal at the two stakes. The majority have a MRS less than one for both stakes, which is consistent with the previous finding.

One concern about the measurement method is that the specific design with varying outcomes might have induced some subjects to use the heuristic of choosing the option with the largest total amount, though their true preferences are not total-amount maximization. Those subjects are mixed with subjects who have a true preference with (almost) zero discounting and linear utility. In comparing the fraction of (true or induced) total outcome maximizers in our sample with those from earlier studies, it is found that 22% (22/107) of our subjects were total outcome maximizers compared to 23% (22/95) in the Double Multiple Price List results and 20% (19/97) in the CTB results of Andreoni and Sprenger (2012). This suggests that our method does not induce more heuristic-users than existing methods.

The fact that all the results replicate the stylized facts found in the literature confirms the validity of our measurement method.

2. Parameter-free Tests of Models with Unconventional Assumptions

We first tested whether the indifference curve was less convex for higher stakes. We took the ratio of the two ARSs in the interior as a measure of the convexity. Thus, the convexity is smaller for the higher stake than for the lower stake if

$$\frac{r_{3,L}}{r_{2,L}} > \frac{r_{3,H}}{r_{2,H}}. \tag{7}$$

Column 5 of Table 2 presents the results of the test of the magnitude effect on utility curvature. The ratio between the measures of convexity is less than one for the majority, implying that the indifference curve is less convex for the higher stake. The intuition is that people feel that money is more fungible when the stake is higher. The finding supports the mental zooming theory of Holden and Quiggin (2017) with the background consumption growing faster than the stake (i.e., $\beta > 1$).

We then tested whether the MRS on the diagonal was larger for higher stakes. We took the geometric mean of the two ARSs in the interior as a local linear approximation of the MRS. Formally, the MRS on the diagonal is larger for the higher stake than for the lower stake if

(8) $$\sqrt{r_{2,L}r_{3,L}} < \sqrt{r_{2,H}r_{3,H}}.$$

Column 3 of Table 3 presents the results of the test. More subjects presented a MRS on the diagonal increasing in stake compared with subjects who presented a MRS on the diagonal decreasing in stake. However, the difference is insignificant.[7] Therefore, we fail to find statistical evidence for increasing MRS on the diagonal.

Nevertheless, seven subjects have a left-censored MRS on the diagonal for the lower stake and an uncensored MRS for the higher stake. They are extremely impatient when the stake is lower but are patient when the stake is higher. In contrast, we do not find any right-censored MRS on the diagonal. The asymmetry in extreme MRS changes is consistent with the axiom of magnitude-decreasing impatience by Noor and Takeoka (2022). The existence of extreme subjects suggests that there is substantial heterogeneity in how discounting changes with stake.

The results on the two channels of the magnitude effect imply that the magnitude of outcomes affects choices mainly through the perceived fungibility of rewards across periods. In other words, when the magnitude is larger, people care more about the discounted sum of amounts and less about income smoothing. On the other hand, there is no evidence showing that the general patience is increasing in stake, though heterogeneity seems to exist.

Lastly, we tested whether indifference curves are non-convex near the sooner corner by examining whether the ARS to the sooner corner is less than that it is in the interior. Formally, the non-convexity exists if

(9) $$r_{4,L} < r_{3,L} \text{ or } r_{4,H} < r_{3,H}$$

We performed individual-level tests on the ratios of the two ARSs to check whether they are different from one. Table 4 shows the results of the tests. For the lower stake, most subjects have a smaller ARS to the sooner corner than in the interior, which implies non-convexity. For the higher stake, the difference between the two ARSs is still significant but smaller. This is consistent with the fixed-cost-of-waiting model by Benhabib et al. (2010) because a fixed cost of waiting implies that the additional disutility of a mixed profile relative to a pure sooner reward is less pronounced for higher stakes, and thus people exhibit less extra impatience when a pure sooner reward is available.

Our results provide evidence for the meaningful characteristics of Holden and Quiggin (2017) and Benhabib et al. (2010). We also find a pattern consistent with the prediction of

[7] We performed power analysis for the sign test. With the alternative hypothesis that the probability for the ratio of MRS being greater for the higher stake is 0.7, the rejection rate is 89%. Thus, our test is not underpowered.

Noor and Takeoka (2022), though it is statistically insignificant. The tests of the three unconventional models are made possible by the weak requirement of our measurement method on model assumptions. In the meantime, our parameter-free measurement ensures that the findings are robust against model misspecification.

IV. Conclusion

We developed a simple method for measuring intertemporal preferences purely in the time domain. The method requires weak assumptions on the preferences to be measured, and hence it can be used to measure a variety of models. It is parameter-free in both utility and discounting, easy to implement, clear to subjects, and incentive compatible.

Researchers can decide how to use this method based on their purposes. Applied economists who seek a simple way to measure the discount rate while controlling for the utility curvature can measure two indifference relations and perform parametric estimation. Controlling for the utility curvature might be especially attractive while non-monetary outcomes (e.g., food, real effort, and pains) are being examined or when utility curvature and discounting have different economic meanings and correlate with different behaviors. In an experiment, we illustrated that the method can also be used for theoretical purposes: One can test model predictions in a parameter-free way. For applied purposes, the method is as efficient as existing methods; for model testing, it is sufficiently flexible so that a wider range of models can be measured without a commitment to a parametric family of intertemporal utility functions.

REFERENCES

Abdellaoui, M., Attema, A. E., & Bleichrodt, H. (2010). Intertemporal Tradeoffs for Gains and Losses: An Experimental Measurement of Discounted Utility. *Economic Journal, 120*(545), pp. 845-866.

Abdellaoui, M., Bleichrodt, H., l'Haridon, O., & Paraschiv, C. (2013). Is There One Unifying Concept of Utility? An Experimental Comparison of Utility Under Risk and Utility Over Time. *Management Science, 59*(9), pp. 2153–2169.

Andersen, S., Harrison, G. W., Lau, M. I., & Rutström, E. E. (2008). Eliciting Risk and Time Preferences. *Econometrica, 76*(3), pp. 583-618.

Andreoni, J., & Sprenger, C. (2012). Estimating Time Preferences from Convex Budgets. *American Economic Review, 102*(7), pp. 3333-3356.

Attema, A. E., Bleichrodt, H., Gao, Y., Huang, Z., & Wakker, P. P. (2016). Measuring Discounting without Measuring Utility. *American Economic Review, 106*(6), pp. 1476-1494.

Augenblick, N., Niederle, M., & Sprenger, C. (2015). Working over Time: Dynamic Inconsistency in Real Effort Tasks. *The Quarterly Journal of Economics, 130*(3), pp. 1067-1115.

Baucells, M., & Cillo, A. (2020). Predicting the Discount Rate of Multiple Future Payouts. *SSRN Working Paper 3575208*.

Benhabib, J., Bisin, A., & Schotter, A. (2010). Present-Bias, Quasi-Hyperbolic Discounting, and Fixed Costs. *Games and Economic Behavior, 69*(2), pp. 205-223.

Cheung, S. L. (2020). Eliciting Utility Curvature in Time Preference. *Experimental Economics, 23*, pp. 493-525.

Coller, M., & Williams, M. (1999). Eliciting Individual Discount Rates. *Experimental Economics, 2*(2), pp. 107-127.

Dohmen, T., Falk, A., Huffman, D., & Sunde, U. (2022). The Pervasiveness and Robustness of Nonadditivity in Intertemporal Choice. *Working Paper 2022-06-04*.

Epper, T., Fehr-Duda, H., & Bruhin, A. (2011). Viewing the Future Through a Warped Lens: Why Uncertainty Generates Hyperbolic Discounting. *Journal of Risk and Uncertainty, 43*, pp. 169-203.

Fischbacher, U. (2007). z-Tree: Zurich Toolbox for Ready-Made Economic Experiments. *Experimental Economics, 10*(2), 171-178.

Frederick, S., Loewenstein, G., & O'Donoghue, T. (2002). Time Discounting and Time Preference: A Critical Review. *Journal of Economic Literature, 40*(2), pp. 351-401.

Fudenberg, D., & Levine, D. K. (2006). A Dual-Self Model of Impulse Control. *American Economic Review, 96*(5), pp. 1449-1476.

Holden, S. T., & Quiggin, J. (2017). Bounded Awareness and Anomalies in Intertemporal Choice: Zooming in Google Earth as Both Metaphor and Model. *Journal of Risk and Uncertainty, 54*(1), pp. 15-35.

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

Kahneman, D., Fredrickson, B. L., Schreiber, C. A., & Redelmeier, D. A. (1993). When More Pain Is Preferred to Less: Adding a Better End. *Psychological Science, 4*(6), pp. 401-405.

Kerschbamer, R. (2015). The Geometry of Distributional Preferences and a Non-Parametric Identification Approach: The Equality Equivalence Test. *European Economic Review, 76*(May), pp. 85-103.

Loewenstein, G. F., & Prelec, D. (1993). Preferences for Sequences of Outcomes. *Psychological Review, 100*(1), pp. 91-108.

Miao, B., & Zhong, S. (2015). Comment on “Risk Preferences Are Not Time Preferences”: Separating Risk and Time Preference. *American Economic Review, 105*(7), pp. 2272-2286.

Noor, J. (2011). Intertemporal Choice and the Magnitude Effect. *Games and Economic Behavior, 72*(1), pp. 255-270.

Noor, J., & Takeoka, N. (2022). Optimal Discounting. *Econometrica, 90*(2), pp. 585-623.

Read, D. (2001). Is Time-Discounting Hyperbolic or Subadditive? *Journal of Risk and Uncertainty, 23*(1), pp. 5-32.

Read, D., & Roelofsma, P. H. (2003). Subadditive versus Hyperbolic Discounting: A Comparison of Choice and Matching. *Organizational Behavior and Human Decision Processes, 91*(2), pp. 140-153.

Sun, C., & Potters, J. (2022). Magnitude Effect in Intertemporal Allocation Tasks. *Experimental Economics, 25*, pp. 593-623.

Takeuchi, K. (2011). Non-Parametric Test of Time Consistency: Present Bias and Future Bias. *Games and Economic Behavior, 71*(2), pp. 456-478.

TABLES

Table 1. Monetary Discount Factors Over Single Dated Outcomes

	Monetary discount factor		Ratio between the two stakes	
	(1)	(2)		(3)
	Lower stake: $\hat{\delta}_L^m = \left(\frac{x_{4,L}}{y_{1,L}}\right)^{\frac{365}{140}}$	Higher stake: $\hat{\delta}_H^m = \left(\frac{x_{4,H}}{y_{1,H}}\right)^{\frac{365}{140}}$		$\frac{\hat{\delta}_H^m}{\hat{\delta}_L^m}$
Median	0.803	0.894	Median	1.022
$\#\left(\hat{\delta}_k^m < 1\right)$	65	55	$\#\left(\frac{\hat{\delta}_H^m}{\hat{\delta}_L^m} > 1\right)$	45
$\#\left(\hat{\delta}_k^m = 1\right)$	15	25	$\#\left(\frac{\hat{\delta}_H^m}{\hat{\delta}_L^m} = 1\right)$	14
$\#\left(\hat{\delta}_k^m > 1\right)$	3	3	$\#\left(\frac{\hat{\delta}_H^m}{\hat{\delta}_L^m} < 1\right)$	21
Sign test	p = 0.000***	p = 0.000***	Sign test	p = 0.004***
Wilcoxon signed-rank test	p = 0.000***	p = 0.000***	Wilcoxon signed-rank test	p = 0.000***

Notes: Two-sided sign tests and Wilcoxon signed-rank tests on the logarithm of the monetary discount factors for the lower stake and for the higher stake, respectively, and on the ratio between them. The null hypothesis is that the monetary discount factor is equal to one (Columns 1-2) and that the monetary discount factors are equal for the two stakes (Column 3). Censored observations are treated as extreme values (zero or infinity ARS), and indeterminate forms are dropped (only relevant for Column 3). ***, **, and * indicate significance at the 1% level, 5% level, and 10% level, respectively.

Table 2. Convexity of Indifference Curves in the Interior and Overall

	Ratios of two ARSs as measures of convexity					Ratio between the two stakes
	Lower stake		Higher stake			
	(1)	(2)	(3)	(4)		(5)
	Interior: $\frac{\hat{r}_{3,L}}{\hat{r}_{2,L}}$	Overall: $\frac{\hat{r}_{4,L}}{\hat{r}_{1,L}}$	Interior: $\frac{\hat{r}_{3,H}}{\hat{r}_{2,H}}$	Overall: $\frac{\hat{r}_{4,H}}{\hat{r}_{1,H}}$		Interior: $\frac{\hat{r}_{3,H}}{\hat{r}_{2,H}}\frac{\hat{r}_{2,L}}{\hat{r}_{3,L}}$
Median	1.043	1.043	1.000	1.000	Median	0.959
$\#\left(\frac{\hat{r}_{j_2,k}}{\hat{r}_{j_1,k}} > 1\right)$	48	42	40	32	$\#\left(\frac{\hat{r}_{3,H}}{\hat{r}_{2,H}}\frac{\hat{r}_{2,L}}{\hat{r}_{3,L}} < 1\right)$	43
$\#\left(\frac{\hat{r}_{j_2,k}}{\hat{r}_{j_1,k}} = 1\right)$	21	24	23	27	$\#\left(\frac{\hat{r}_{3,H}}{\hat{r}_{2,H}}\frac{\hat{r}_{2,L}}{\hat{r}_{3,L}} = 1\right)$	17
$\#\left(\frac{\hat{r}_{j_2,k}}{\hat{r}_{j_1,k}} < 1\right)$	14	17	20	24	$\#\left(\frac{\hat{r}_{3,H}}{\hat{r}_{2,H}}\frac{\hat{r}_{2,L}}{\hat{r}_{3,L}} > 1\right)$	23
Sign test	0.000***	0.002***	0.013**	0.350	Sign test	0.019**
Wilcoxon signed-rank test	0.000***	0.008***	0.034**	0.534	Wilcoxon signed-rank test	0.010**

Notes: Columns 1 and 3 present ratios of two ARSs in the interior as a measure of convexity in the interior. Columns 2 and 4 present ratios of two ARSs between a profile on the diagonal and the two corners as a measure of average convexity of the entire indifference curve. The indifference curve is convex if the ratio is greater than one. Two-sided sign tests and Wilcoxon signed-rank tests on the logarithm of the measures. The null hypothesis is that the measurement of convexity is equal to one, meaning that the indifference curve is linear. Column 5 presents the ratio of the measures of convexity between the two stakes. Censored observations are treated as extreme values (zero or infinity ARS). ***, **, and * indicate significance at the 1% level, 5% level, and 10% level, respectively.

Table 3. MRS on the diagonal

	MRS on the diagonal		Ratio between the two stakes	
	(1)	(2)		(3)
	Lower stake: $\hat{\delta}_L = \left(\sqrt{\hat{r}_{2,L}\hat{r}_{3,L}}\right)^{\frac{365}{140}}$	Higher stake: $\hat{\delta}_H = \left(\sqrt{\hat{r}_{2,H}\hat{r}_{3,H}}\right)^{\frac{365}{140}}$		$\frac{\hat{\delta}_H}{\hat{\delta}_L}$
Median	0.896	0.947	Median	1.000
$\#\left(\hat{\delta}_k < 1\right)$	48	51	$\#\left(\frac{\hat{\delta}_H}{\hat{\delta}_L} > 1\right)$	36
$\#\left(\hat{\delta}_k = 1\right)$	29	23	$\#\left(\frac{\hat{\delta}_H}{\hat{\delta}_L} = 1\right)$	22
$\#\left(\hat{\delta}_k > 1\right)$	6	9	$\#\left(\frac{\hat{\delta}_H}{\hat{\delta}_L} < 1\right)$	24
Sign test	p = 0.000***	p = 0.000***	Sign test	p = 0.155
Wilcoxon signed-rank test	p = 0.000***	p = 0.000***	Wilcoxon signed-rank test	p = 0.134

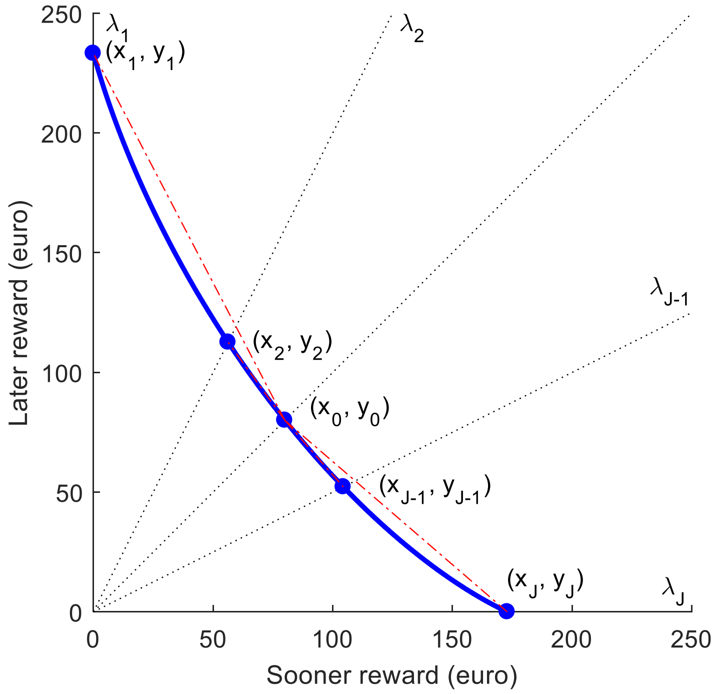
Notes: Two-sided sign tests and Wilcoxon signed-rank tests on the logarithm of the MRSs on the diagonal for the lower stake and for the higher stake, respectively, and on the ratio between them. The MRSs on the diagonal are estimated as the geometric mean of the ARSs in the interior. The null hypothesis is that the MRS on the diagonal is equal to one (Columns 1-2) and that the ratio is equal to one (Column 3). Censored observations are treated as extreme values (zero or infinity ARS), and indeterminate form is dropped (only relevant for Column 3). ***, **, and * indicate significance at the 1% level, 5% level, and 10% level, respectively.

Table 4. The Non-convexity near the Sooner Corner

Ratios of ARS to the sooner corner to that in the interior	Lower stake: $\frac{\hat{r}_{4,L}}{\hat{r}_{3,L}}$	Higher stake: $\frac{\hat{r}_{4,H}}{\hat{r}_{3,H}}$
Median	0.959	1.000
$\#\left(\frac{\hat{r}_{4,k}}{\hat{r}_{3,k}} < 1\right)$	43	35
$\#\left(\frac{\hat{r}_{4,k}}{\hat{r}_{3,k}} = 1\right)$	25	27
$\#\left(\frac{\hat{r}_{4,k}}{\hat{r}_{3,k}} > 1\right)$	15	20
Sign test	0.000***	0.058*
Wilcoxon signed-rank test	0.000***	0.039**

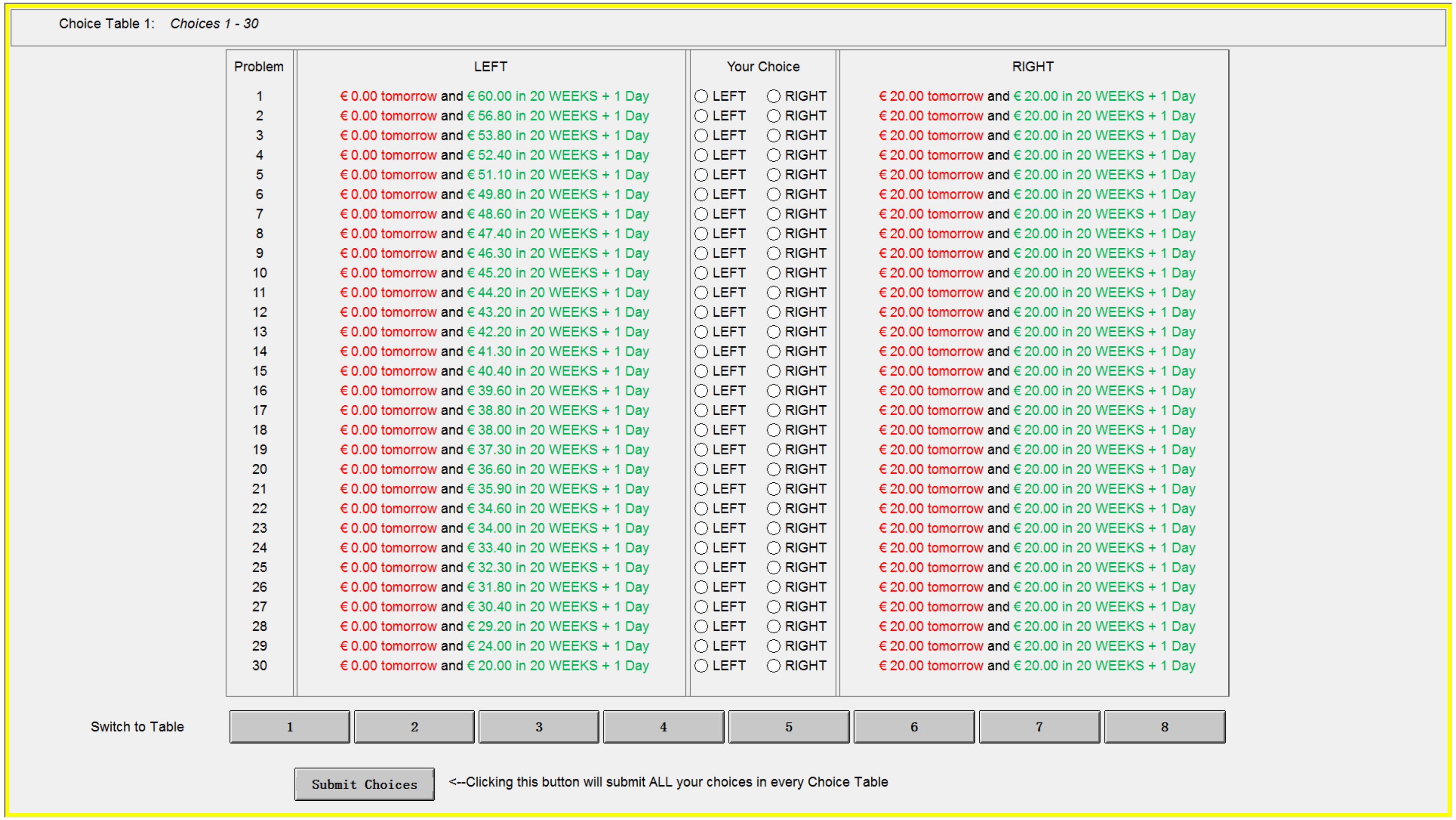
Notes: Two-sided sign tests and Wilcoxon signed-rank tests on the logarithm of the ratio of the ARSs in the interior to that to the sooner corner. The null hypothesis is that the ratio is equal to one. Non-convexity exists if the ratio is less than one. Censored observations are treated as extreme values (zero or infinity ARS), and indeterminate forms are dropped. ***, **, and * indicate significance at the 1% level, 5% level, and 10% level, respectively.

FIGURES



Note: To measure J indifference relations between a pre-determined profile (x_0, y_0) and a ray through the origin with a pre-determined income ratio $\lambda_j \in [0, \infty]$. An indifference curve is obtained by connecting the $J + 1$ equally good profiles.

Figure 1. Measuring an Indifference Curve in the Space of Two-outcome Intertemporal Profiles



Choice Table 1: *Choices 1 - 30*

Problem	LEFT	Your Choice		RIGHT
1	€ 0.00 tomorrow and € 60.00 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
2	€ 0.00 tomorrow and € 56.80 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
3	€ 0.00 tomorrow and € 53.80 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
4	€ 0.00 tomorrow and € 52.40 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
5	€ 0.00 tomorrow and € 51.10 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
6	€ 0.00 tomorrow and € 49.80 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
7	€ 0.00 tomorrow and € 48.60 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
8	€ 0.00 tomorrow and € 47.40 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
9	€ 0.00 tomorrow and € 46.30 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
10	€ 0.00 tomorrow and € 45.20 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
11	€ 0.00 tomorrow and € 44.20 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
12	€ 0.00 tomorrow and € 43.20 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
13	€ 0.00 tomorrow and € 42.20 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
14	€ 0.00 tomorrow and € 41.30 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
15	€ 0.00 tomorrow and € 40.40 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
16	€ 0.00 tomorrow and € 39.60 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
17	€ 0.00 tomorrow and € 38.80 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
18	€ 0.00 tomorrow and € 38.00 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
19	€ 0.00 tomorrow and € 37.30 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
20	€ 0.00 tomorrow and € 36.60 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
21	€ 0.00 tomorrow and € 35.90 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
22	€ 0.00 tomorrow and € 34.60 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
23	€ 0.00 tomorrow and € 34.00 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
24	€ 0.00 tomorrow and € 33.40 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
25	€ 0.00 tomorrow and € 32.30 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
26	€ 0.00 tomorrow and € 31.80 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
27	€ 0.00 tomorrow and € 30.40 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
28	€ 0.00 tomorrow and € 29.20 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
29	€ 0.00 tomorrow and € 24.00 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
30	€ 0.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day	○ LEFT	○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day

Switch to Table | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8

Submit Choices <--Clicking this button will submit ALL your choices in every Choice Table

(a) Before any option is chosen

Choice Table 1: *Choices 1 - 30*

Problem	LEFT	Your Choice	RIGHT
1	€ 0.00 tomorrow and € 60.00 in 20 WEEKS + 1 Day	◉ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
2	€ 0.00 tomorrow and € 56.80 in 20 WEEKS + 1 Day	◉ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
3	€ 0.00 tomorrow and € 53.80 in 20 WEEKS + 1 Day	◉ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
4	€ 0.00 tomorrow and € 52.40 in 20 WEEKS + 1 Day	◉ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
5	€ 0.00 tomorrow and € 51.10 in 20 WEEKS + 1 Day	◉ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
6	€ 0.00 tomorrow and € 49.80 in 20 WEEKS + 1 Day	◉ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
7	€ 0.00 tomorrow and € 48.60 in 20 WEEKS + 1 Day	◉ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
8	€ 0.00 tomorrow and € 47.40 in 20 WEEKS + 1 Day	◉ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
9	€ 0.00 tomorrow and € 46.30 in 20 WEEKS + 1 Day	◉ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
10	€ 0.00 tomorrow and € 45.20 in 20 WEEKS + 1 Day	◉ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
11	€ 0.00 tomorrow and € 44.20 in 20 WEEKS + 1 Day	○ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
12	€ 0.00 tomorrow and € 43.20 in 20 WEEKS + 1 Day	○ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
13	€ 0.00 tomorrow and € 42.20 in 20 WEEKS + 1 Day	○ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
14	€ 0.00 tomorrow and € 41.30 in 20 WEEKS + 1 Day	○ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
15	€ 0.00 tomorrow and € 40.40 in 20 WEEKS + 1 Day	○ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
16	€ 0.00 tomorrow and € 39.60 in 20 WEEKS + 1 Day	○ LEFT ○ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
17	€ 0.00 tomorrow and € 38.80 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
18	€ 0.00 tomorrow and € 38.00 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
19	€ 0.00 tomorrow and € 37.30 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
20	€ 0.00 tomorrow and € 36.60 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
21	€ 0.00 tomorrow and € 35.90 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
22	€ 0.00 tomorrow and € 34.60 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
23	€ 0.00 tomorrow and € 34.00 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
24	€ 0.00 tomorrow and € 33.40 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
25	€ 0.00 tomorrow and € 32.30 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
26	€ 0.00 tomorrow and € 31.80 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
27	€ 0.00 tomorrow and € 30.40 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
28	€ 0.00 tomorrow and € 29.20 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
29	€ 0.00 tomorrow and € 24.00 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day
30	€ 0.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day	○ LEFT ◉ RIGHT	€ 20.00 tomorrow and € 20.00 in 20 WEEKS + 1 Day

Switch to Table [1] [2] [3] [4] [5] [6] [7] [8]

[Submit Choices] <--Clicking this button will submit ALL your choices in every Choice Table

(b) After LEFT is chosen for Choice Problem 10 and RIGHT is chosen for Choice Problem 17

Figure 2. The Choice Table Before and After Some Options are Chosen

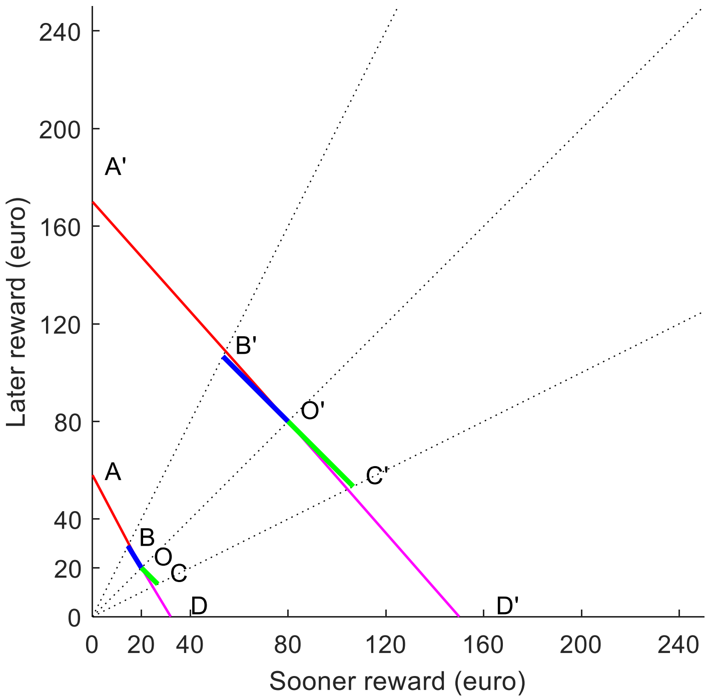


Figure 3. The Eight Indifference Relations Measured in the Experiment

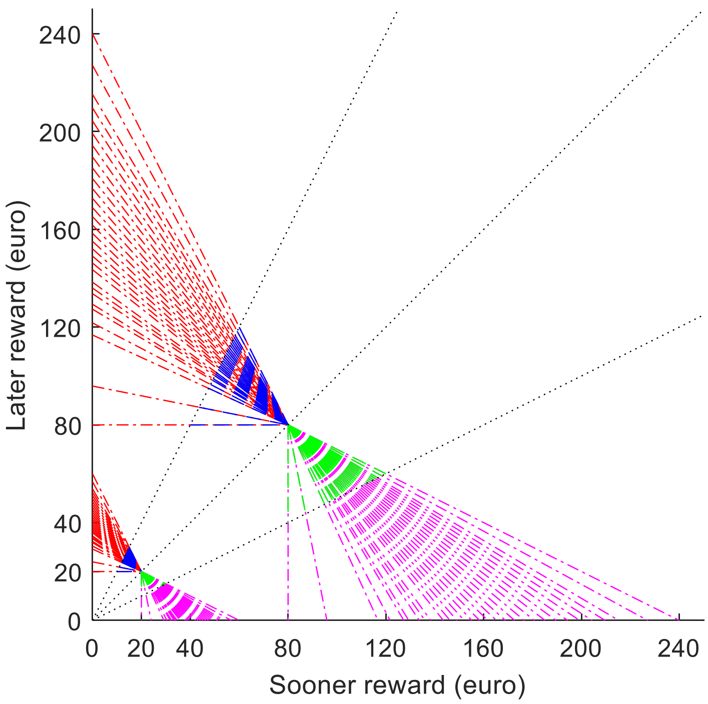


Figure 4. Binary Choice Problems Used in the Experiment

Appendix A. Stimuli Used in the Choice Lists

Choice list 1: to the later corner, for the lower stake

Problem	LEFT Tomorrow (euro)	LEFT 20 WEEKS + 1 Day (euro)	RIGHT Tomorrow (euro)	RIGHT 20 WEEKS + 1 Day (euro)	ARS implied by a switching
1	0.00	60.00	20.00	20.00	≤0.50
2	0.00	56.80	20.00	20.00	0.52
3	0.00	53.80	20.00	20.00	0.57
4	0.00	52.40	20.00	20.00	0.60
5	0.00	51.10	20.00	20.00	0.63
6	0.00	49.80	20.00	20.00	0.66
7	0.00	48.60	20.00	20.00	0.69
8	0.00	47.40	20.00	20.00	0.71
9	0.00	46.30	20.00	20.00	0.75
10	0.00	45.20	20.00	20.00	0.78
11	0.00	44.20	20.00	20.00	0.81
12	0.00	43.20	20.00	20.00	0.85
13	0.00	42.20	20.00	20.00	0.88
14	0.00	41.30	20.00	20.00	0.92
15	0.00	40.40	20.00	20.00	0.96
16	0.00	39.60	20.00	20.00	1.00
17	0.00	38.80	20.00	20.00	1.04
18	0.00	38.00	20.00	20.00	1.09
19	0.00	37.30	20.00	20.00	1.13
20	0.00	36.60	20.00	20.00	1.18
21	0.00	35.90	20.00	20.00	1.23
22	0.00	34.60	20.00	20.00	1.31
23	0.00	34.00	20.00	20.00	1.40
24	0.00	33.40	20.00	20.00	1.46
25	0.00	32.30	20.00	20.00	1.55
26	0.00	31.80	20.00	20.00	1.66
27	0.00	30.40	20.00	20.00	1.80
28	0.00	29.20	20.00	20.00	2.04
29	0.00	24.00	20.00	20.00	3.31
30	0.00	20.00	20.00	20.00	≥5.00

Choice list 2: to the interior where the later outcome is larger, for the lower stake

Problem	LEFT Tomorrow (euro)	LEFT 20 WEEKS + 1 Day (euro)	RIGHT Tomorrow (euro)	RIGHT 20 WEEKS + 1 Day (euro)	ARS implied by a switching
1	15.00	30.00	20.00	20.00	≤0.50
2	14.80	29.60	20.00	20.00	0.52
3	14.60	29.20	20.00	20.00	0.57
4	14.50	29.00	20.00	20.00	0.60
5	14.40	28.80	20.00	20.00	0.63
6	14.30	28.60	20.00	20.00	0.66
7	14.20	28.40	20.00	20.00	0.69
8	14.10	28.20	20.00	20.00	0.71
9	14.00	28.00	20.00	20.00	0.75
10	13.90	27.80	20.00	20.00	0.78
11	13.80	27.60	20.00	20.00	0.81
12	13.70	27.40	20.00	20.00	0.85
13	13.60	27.20	20.00	20.00	0.88
14	13.50	27.00	20.00	20.00	0.92
15	13.40	26.80	20.00	20.00	0.96
16	13.30	26.60	20.00	20.00	1.00
17	13.20	26.40	20.00	20.00	1.04
18	13.10	26.20	20.00	20.00	1.09
19	13.00	26.00	20.00	20.00	1.13
20	12.90	25.80	20.00	20.00	1.18
21	12.80	25.60	20.00	20.00	1.23
22	12.70	25.40	20.00	20.00	1.31
23	12.60	25.20	20.00	20.00	1.40
24	12.50	25.00	20.00	20.00	1.46
25	12.40	24.80	20.00	20.00	1.55
26	12.30	24.60	20.00	20.00	1.66
27	12.10	24.20	20.00	20.00	1.80
28	11.90	23.80	20.00	20.00	2.04
29	10.90	21.80	20.00	20.00	3.31
30	10.00	20.00	20.00	20.00	≥5.00

Choice list 3: to the interior where the sooner outcome is larger, for the lower stake

Problem	LEFT		RIGHT		ARS implied by a switching
	Tomorrow (euro)	20 WEEKS + 1 Day (euro)	Tomorrow (euro)	20 WEEKS + 1 Day (euro)	
1	30.00	15.00	20.00	20.00	≥2.00
2	29.60	14.80	20.00	20.00	1.92
3	29.20	14.60	20.00	20.00	1.76
4	29.00	14.50	20.00	20.00	1.66
5	28.80	14.40	20.00	20.00	1.59
6	28.60	14.30	20.00	20.00	1.52
7	28.40	14.20	20.00	20.00	1.46
8	28.20	14.10	20.00	20.00	1.40
9	28.00	14.00	20.00	20.00	1.34
10	27.80	13.90	20.00	20.00	1.29
11	27.60	13.80	20.00	20.00	1.23
12	27.40	13.70	20.00	20.00	1.18
13	27.20	13.60	20.00	20.00	1.13
14	27.00	13.50	20.00	20.00	1.09
15	26.80	13.40	20.00	20.00	1.04
16	26.60	13.30	20.00	20.00	1.00
17	26.40	13.20	20.00	20.00	0.96
18	26.20	13.10	20.00	20.00	0.92
19	26.00	13.00	20.00	20.00	0.88
20	25.80	12.90	20.00	20.00	0.85
21	25.60	12.80	20.00	20.00	0.81
22	25.40	12.70	20.00	20.00	0.76
23	25.20	12.60	20.00	20.00	0.71
24	25.00	12.50	20.00	20.00	0.69
25	24.80	12.40	20.00	20.00	0.64
26	24.60	12.30	20.00	20.00	0.60
27	24.20	12.10	20.00	20.00	0.56
28	23.80	11.90	20.00	20.00	0.49
29	21.80	10.90	20.00	20.00	0.30
30	20.00	10.00	20.00	20.00	≤0.20

Choice list 4: to the sooner corner, for the lower stake

Problem	LEFT Tomorrow (euro)	LEFT 20 WEEKS + 1 Day (euro)	RIGHT Tomorrow (euro)	RIGHT 20 WEEKS + 1 Day (euro)	ARS implied by a switching
1	60.00	0.00	20.00	20.00	≥2.00
2	56.80	0.00	20.00	20.00	1.92
3	53.80	0.00	20.00	20.00	1.76
4	52.40	0.00	20.00	20.00	1.66
5	51.10	0.00	20.00	20.00	1.59
6	49.80	0.00	20.00	20.00	1.52
7	48.60	0.00	20.00	20.00	1.46
8	47.40	0.00	20.00	20.00	1.40
9	46.30	0.00	20.00	20.00	1.34
10	45.20	0.00	20.00	20.00	1.29
11	44.20	0.00	20.00	20.00	1.23
12	43.20	0.00	20.00	20.00	1.18
13	42.20	0.00	20.00	20.00	1.13
14	41.30	0.00	20.00	20.00	1.09
15	40.40	0.00	20.00	20.00	1.04
16	39.60	0.00	20.00	20.00	1.00
17	38.80	0.00	20.00	20.00	0.96
18	38.00	0.00	20.00	20.00	0.92
19	37.30	0.00	20.00	20.00	0.88
20	36.60	0.00	20.00	20.00	0.85
21	35.90	0.00	20.00	20.00	0.81
22	34.60	0.00	20.00	20.00	0.76
23	34.00	0.00	20.00	20.00	0.71
24	33.40	0.00	20.00	20.00	0.69
25	32.30	0.00	20.00	20.00	0.64
26	31.80	0.00	20.00	20.00	0.60
27	30.40	0.00	20.00	20.00	0.56
28	29.20	0.00	20.00	20.00	0.49
29	24.00	0.00	20.00	20.00	0.30
30	20.00	0.00	20.00	20.00	≤0.20

Choice list 5: to the later corner, for the higher stake

Problem	LEFT		RIGHT		ARS implied by a switching
	Tomorrow (euro)	20 WEEKS + 1 Day (euro)	Tomorrow (euro)	20 WEEKS + 1 Day (euro)	
1	0.00	240.00	80.00	80.00	≤0.50
2	0.00	227.20	80.00	80.00	0.52
3	0.00	215.20	80.00	80.00	0.57
4	0.00	209.60	80.00	80.00	0.60
5	0.00	204.40	80.00	80.00	0.63
6	0.00	199.20	80.00	80.00	0.66
7	0.00	194.40	80.00	80.00	0.69
8	0.00	189.60	80.00	80.00	0.71
9	0.00	185.20	80.00	80.00	0.75
10	0.00	180.80	80.00	80.00	0.78
11	0.00	176.80	80.00	80.00	0.81
12	0.00	172.80	80.00	80.00	0.85
13	0.00	168.80	80.00	80.00	0.88
14	0.00	165.20	80.00	80.00	0.92
15	0.00	161.60	80.00	80.00	0.96
16	0.00	158.40	80.00	80.00	1.00
17	0.00	155.20	80.00	80.00	1.04
18	0.00	152.00	80.00	80.00	1.09
19	0.00	149.20	80.00	80.00	1.13
20	0.00	146.40	80.00	80.00	1.18
21	0.00	143.60	80.00	80.00	1.23
22	0.00	138.40	80.00	80.00	1.31
23	0.00	136.00	80.00	80.00	1.40
24	0.00	133.60	80.00	80.00	1.46
25	0.00	129.20	80.00	80.00	1.55
26	0.00	127.20	80.00	80.00	1.66
27	0.00	121.60	80.00	80.00	1.80
28	0.00	116.80	80.00	80.00	2.04
29	0.00	96.00	80.00	80.00	3.31
30	0.00	80.00	80.00	80.00	≥5.00

Choice list 6: to the interior where the later outcome is larger, for the higher stake

Problem	LEFT Tomorrow (euro)	LEFT 20 WEEKS + 1 Day (euro)	RIGHT Tomorrow (euro)	RIGHT 20 WEEKS + 1 Day (euro)	ARS implied by a switching
1	60.00	120.00	80.00	80.00	≤0.50
2	59.20	118.40	80.00	80.00	0.52
3	58.40	116.80	80.00	80.00	0.57
4	58.00	116.00	80.00	80.00	0.60
5	57.60	115.20	80.00	80.00	0.63
6	57.20	114.40	80.00	80.00	0.66
7	56.80	113.60	80.00	80.00	0.69
8	56.40	112.80	80.00	80.00	0.71
9	56.00	112.00	80.00	80.00	0.75
10	55.60	111.20	80.00	80.00	0.78
11	55.20	110.40	80.00	80.00	0.81
12	54.80	109.60	80.00	80.00	0.85
13	54.40	108.80	80.00	80.00	0.88
14	54.00	108.00	80.00	80.00	0.92
15	53.60	107.20	80.00	80.00	0.96
16	53.20	106.40	80.00	80.00	1.00
17	52.80	105.60	80.00	80.00	1.04
18	52.40	104.80	80.00	80.00	1.09
19	52.00	104.00	80.00	80.00	1.13
20	51.60	103.20	80.00	80.00	1.18
21	51.20	102.40	80.00	80.00	1.23
22	50.80	101.60	80.00	80.00	1.31
23	50.40	100.80	80.00	80.00	1.40
24	50.00	100.00	80.00	80.00	1.46
25	49.60	99.20	80.00	80.00	1.55
26	49.20	98.40	80.00	80.00	1.66
27	48.40	96.80	80.00	80.00	1.80
28	47.60	95.20	80.00	80.00	2.04
29	43.60	87.20	80.00	80.00	3.31
30	40.00	80.00	80.00	80.00	≥5.00

Choice list 7: to the interior where the sooner outcome is larger, for the higher stake

Problem	LEFT		RIGHT		ARS implied by a switching
	Tomorrow (euro)	20 WEEKS + 1 Day (euro)	Tomorrow (euro)	20 WEEKS + 1 Day (euro)	
1	120.00	60.00	80.00	80.00	≥2.00
2	118.40	59.20	80.00	80.00	1.92
3	116.80	58.40	80.00	80.00	1.76
4	116.00	58.00	80.00	80.00	1.66
5	115.20	57.60	80.00	80.00	1.59
6	114.40	57.20	80.00	80.00	1.52
7	113.60	56.80	80.00	80.00	1.46
8	112.80	56.40	80.00	80.00	1.40
9	112.00	56.00	80.00	80.00	1.34
10	111.20	55.60	80.00	80.00	1.29
11	110.40	55.20	80.00	80.00	1.23
12	109.60	54.80	80.00	80.00	1.18
13	108.80	54.40	80.00	80.00	1.13
14	108.00	54.00	80.00	80.00	1.09
15	107.20	53.60	80.00	80.00	1.04
16	106.40	53.20	80.00	80.00	1.00
17	105.60	52.80	80.00	80.00	0.96
18	104.80	52.40	80.00	80.00	0.92
19	104.00	52.00	80.00	80.00	0.88
20	103.20	51.60	80.00	80.00	0.85
21	102.40	51.20	80.00	80.00	0.81
22	101.60	50.80	80.00	80.00	0.76
23	100.80	50.40	80.00	80.00	0.71
24	100.00	50.00	80.00	80.00	0.69
25	99.20	49.60	80.00	80.00	0.64
26	98.40	49.20	80.00	80.00	0.60
27	96.80	48.40	80.00	80.00	0.56
28	95.20	47.60	80.00	80.00	0.49
29	87.20	43.60	80.00	80.00	0.30
30	80.00	40.00	80.00	80.00	≤0.20

Choice list 8: to the sooner corner, for the higher stake

Problem	LEFT option		RIGHT option		ARS implied by a switching
	Tomorrow (euro)	20 WEEKS + 1 Day (euro)	Tomorrow (euro)	20 WEEKS + 1 Day (euro)	
1	240.00	0.00	80.00	80.00	≥2.00
2	227.20	0.00	80.00	80.00	1.92
3	215.20	0.00	80.00	80.00	1.76
4	209.60	0.00	80.00	80.00	1.66
5	204.40	0.00	80.00	80.00	1.59
6	199.20	0.00	80.00	80.00	1.52
7	194.40	0.00	80.00	80.00	1.46
8	189.60	0.00	80.00	80.00	1.40
9	185.20	0.00	80.00	80.00	1.34
10	180.80	0.00	80.00	80.00	1.29
11	176.80	0.00	80.00	80.00	1.23
12	172.80	0.00	80.00	80.00	1.18
13	168.80	0.00	80.00	80.00	1.13
14	165.20	0.00	80.00	80.00	1.09
15	161.60	0.00	80.00	80.00	1.04
16	158.40	0.00	80.00	80.00	1.00
17	155.20	0.00	80.00	80.00	0.96
18	152.00	0.00	80.00	80.00	0.92
19	149.20	0.00	80.00	80.00	0.88
20	146.40	0.00	80.00	80.00	0.85
21	143.60	0.00	80.00	80.00	0.81
22	138.40	0.00	80.00	80.00	0.76
23	136.00	0.00	80.00	80.00	0.71
24	133.60	0.00	80.00	80.00	0.69
25	129.20	0.00	80.00	80.00	0.64
26	127.20	0.00	80.00	80.00	0.60
27	121.60	0.00	80.00	80.00	0.56
28	116.80	0.00	80.00	80.00	0.49
29	96.00	0.00	80.00	80.00	0.30
30	80.00	0.00	80.00	80.00	≤0.20

Appendix B. Instructions

Eligibility to Participate

Welcome to this experiment! Before we begin, I need to remind you of the eligibility for this study.

Since your earnings from this experiment will be paid by bank transfer, you MUST have a Euro Payment bank account on your name, which will continue to be valid for at least five months, and you must inform us about your international bank account number (IBAN) during the experiment.

If you do not meet the criterion above, please inform us now.

General Instructions

We will now go over the instructions together. The instructions are simple and if you follow them carefully, you might earn a significant amount of money, which will be paid to you by bank transfer.

We ask you not to communicate with other participants during the experiment. If you have a question, please raise your hand. A monitor will come to you to answer your question in private.

In this experiment, you are asked to make some choices. After you make all choices, we request you to finish a short questionnaire.

Earnings

Your earnings in this experiment will consist of two parts.

First, for completing the experiment (including the questionnaire), you will receive a €6 participation fee regardless of your choices. You will receive the participation fee in two equally sized payment of €3 each, which will arrive in your bank account on two different dates: tomorrow and 20 weeks from tomorrow.

In addition to the participation fee, you can also receive earnings depending on your choices. The chance to receive earnings depending on your choices is 10%. Soon each of you will get one lottery card, on which you can see your Lottery Number. The Lottery Number is between 0 and 9. At the end of the experiment, we will invite one of you to throw a ten-sided die to determine the Lucky Number. If the Lucky Number is equal to your Lottery Number, you will receive the earnings depending on your choices, plus the participation fee; otherwise you will only receive the participation fee.

Recall that you will make multiple choices. If your Lucky Number is the same as your Lottery Number, we will randomly select one of your choices as the choice-that-counts, to determine your earnings depending on choices. All choices are equally likely to be selected, so you should consider each choice carefully.

Choices

You will be asked to make a series of choices, which will be displayed in eight Choice Tables. Each row of the Choice Table concerns a separate choice problem.

For each choice problem, you are asked to choose between two options, labelled LEFT and RIGHT. Each option yields money on two different dates. The first date is tomorrow, and the second date is 20 weeks from tomorrow.

Below is a sample Choice Table with ten choice problems. It is not a table that you will actually encounter during the experiment, but merely illustrates the format.

Choice Table 1: *Choice 1-10*

No.	LEFT			Your Choice		RIGHT		
1	€ 25.00 tomorrow	and	€ 50.00 in 20 weeks + 1 day	○	○	€ 30.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day
2	€ 23.50 tomorrow	and	€ 47.00 in 20 weeks + 1 day	○	○	€ 30.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day
3	€ 22.00 tomorrow	and	€ 44.00 in 20 weeks + 1 day	○	○	€ 30.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day
4	€ 21.10 tomorrow	and	€ 42.20 in 20 weeks + 1 day	○	○	€ 30.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day
5	€ 20.10 tomorrow	and	€ 40.20 in 20 weeks + 1 day	○	○	€ 30.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day
6	€ 19.50 tomorrow	and	€ 39.00 in 20 weeks + 1 day	○	○	€ 30.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day
7	€ 19.00 tomorrow	and	€ 38.00 in 20 weeks + 1 day	○	○	€ 30.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day
8	€ 18.40 tomorrow	and	€ 36.80 in 20 weeks + 1 day	○	○	€ 30.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day
9	€ 17.00 tomorrow	and	€ 34.00 in 20 weeks + 1 day	○	○	€ 30.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day
10	€ 15.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day	○	○	€ 30.00 tomorrow	and	€ 30.00 in 20 weeks + 1 day

Switch to Table	1	2	3	4	5	6	7	8

Submit Choices ←Clicking this button will submit ALL your choices in every table

As you can see in the sample Choice Table, the first row concerns a choice between the following two options: LEFT earns you €25 tomorrow PLUS €50 in 20 weeks + 1 day, while RIGHT earns you €30 tomorrow PLUS €30 in 20 weeks + 1 day. You need to select LEFT or RIGHT by clicking the corresponding radio button.

You need to make a choice for each row. Note that RIGHT is fixed in a Choice Table, while LEFT gets worse as you move down the Choice Table, because both payments of LEFT are decreasing. Thereby, if you prefer LEFT to RIGHT in one row, you should also prefer LEFT to RIGHT in all rows above. Similarly, if you prefer RIGHT to LEFT in a row, you should also prefer RIGHT to LEFT in all rows below. In order to make your choice easier, whenever you click the radio button of LEFT in one row, the program automatically makes all your choices in the preceding rows into LEFT. Similarly, whenever you click on the radio button of RIGHT in one row, the program automatically makes all your choices in the rows below into RIGHT.

The figure below displays what happens if you click LEFT for Problem 3 and RIGHT for Problem 8. Doing so determines your choices for Problems 1-3 and Problems 8-10. To complete the Choice Table, you would still need to determine your choices for Problems 4-7.

Choice Table 1: *Choice 1-10*

No.	LEFT	Your Choice		RIGHT
1	**€ 25.00 tomorrow and € 50.00 in 20 WEEKS + 1 Day**	◉	○	€ 30.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day
2	**€ 23.50 tomorrow and € 47.00 in 20 WEEKS + 1 Day**	◉	○	€ 30.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day
3	**€ 22.00 tomorrow and € 44.00 in 20 WEEKS + 1 Day**	◉	○	€ 30.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day
4	€ 21.10 tomorrow and € 42.20 in 20 WEEKS + 1 Day	○	○	€ 30.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day
5	€ 20.10 tomorrow and € 40.20 in 20 WEEKS + 1 Day	○	○	€ 30.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day
6	€ 19.50 tomorrow and € 39.00 in 20 WEEKS + 1 Day	○	○	€ 30.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day
7	€ 19.00 tomorrow and € 38.00 in 20 WEEKS + 1 Day	○	○	€ 30.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day
8	€ 18.40 tomorrow and € 36.80 in 20 WEEKS + 1 Day	○	◉	**€ 30.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day**
9	€ 17.00 tomorrow and € 34.00 in 20 WEEKS + 1 Day	○	◉	**€ 30.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day**
10	€ 15.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day	○	◉	**€ 30.00 tomorrow and € 30.00 in 20 WEEKS + 1 Day**

Switch to Table	1	2	3	4	5	6	7	8

Submit Choices ←Clicking this button will submit ALL your choices in every table

Remember there are eight Choice Tables in total. When you want to switch to another Choice Table, you can press the button with the number of the target Choice Table depicted below each table. You can revise your choices as much as you like, within and across Choice Tables. Once you are satisfied with all of your choices, you can click on the "Submit Choices" button to submit ALL your choices in the eight Choice Tables.

Please be informed that we need to wait for all participants finishing their choices before we can proceed. Thereby we appreciate your patience if you submit your choices earlier.

Now let's make a brief summary of the experiment:

- You make choices in eight Choice Tables. For each choice problem (which takes a row in one Choice Table), you select either LEFT or RIGHT.
- You will always earn €3 tomorrow PLUS €3 in 20 weeks + 1 day as a participation fee. They will arrive in your bank account on the corresponding dates.
- If your Lottery Number is equal to the Lucky Number (which will be determined at the end of the experiment), one of your choices will be realized. The money in that choice will be added to the participation fee.

That is the end of the instructions. If you have a question, please do not hesitate to raise your hand.