Individual Preferences and the Exponential Growth Bias

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Abstract

The exponential growth bias (EGB) refers to individuals' underestimation of the effects of exponential growth and has been shown to affect important financial decisions such as retirement savings. We develop and test a novel experimental design to evaluate the magnitude of the EGB based on multiple price lists. Our design simultaneously elicits the EGB as well as subjects' utility curvatures and time preferences. Allowing for non-linear utility, we structurally estimate the magnitude of the EGB as about half as large as when linear utility is assumed. These results shed light on the relationship between individual preferences and the EGB.

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1 Introduction

Starting with Stango and Zinman (2009), several studies have found evidence for the existence of the exponential growth bias (EGB) in financial decisions using surveys as well as laboratory or field experiments. The EGB implies that individuals underestimate the magnitude of exponential growth and more specifically the effects of compound interest. As many countries are increasingly shifting the responsibility for retirement planning from employers to employees (Benartzi and Thaler, 2007), the EGB affects the effectiveness of policies: individuals who underestimate the final value of their savings might be prone to undersave and run the risk of insufficient retirement earnings (Levy and Tasoff, 2016a; Stango and Zinman, 2009).[1] In this study, we suggest a novel experimental method to evaluate the individual magnitude of the EGB. Moreover, we shed light on the relationship between individual preferences and the EGB. When attempting to estimate the welfare effects of different policy interventions (such as different tax, welfare, or retirement policies) under the presence of the EGB, researchers should be aware of this interplay between individual preferences and the EGB.

Measures of the EGB are usually obtained using survey questions (e.g., Almenberg and Gerdes, 2012; Eisenstein and Hoch, 2007; Stango and Zinman, 2009) or experimental methods (e.g., Goda et al., 2014; Song, 2015). In the former studies, subjects are asked to estimate either the interest rate implied by a stream of payments or the final value of an investment that grows at a constant interest rate over several periods. The robust finding is that the final value is significantly underestimated. In the latter type of studies, a random group of (treated) subjects usually receives some sort of information regarding compound interest which the control group does not obtain. Differences in the observed behavior of the two groups are attributed to the EGB. Treated subjects typically show a higher likelihood to enroll in long-term savings plans and also contribute more to their plans. These studies demonstrate the existence of the EGB and relate the bias to disadvantageous financial decisions based on insufficient financial literacy.

We devise a novel way to elicit the existence and the magnitude of the EGB as well as risk and time preferences with the same incentivized method, which is based on a series of binary choices in multiple price lists (MPLs) for all three parameters of interest. In the main task of the experiment, subjects choose between sooner and later payoffs. The simultaneous assessment of the EGB and

[1]Even though the level of the risk-free interest rate is quite low at the moment, the EGB is still highly relevant for savings behavior. Take for example the expected returns of long-term investments in the stock market and related asset classes, which have essentially the same compounding structure. Another popular explanation of undersaving is quasi-hyperbolic discounting (Laibson, 1997, 1998). However, in our setup, there are no immediate payments, which rules out a role for quasi-hyperbolic discounting, where a separate discount factor β is assumed for instantaneous consumption and a traditional exponential discount factor δ is assumed for longer-term time preferences. We focus on the latter only and leave the addition of quasi-hyperbolic discounting to future work.

individual preferences is aimed at separating the respective influence of the EGB, risk preferences, and time preferences on intertemporal consumption decisions such as retirement savings decisions.

To illustrate why risk and time preferences need to be elicited along with subjects' decisions between sooner and later payoffs, consider two individuals A and B who allocate their wealth for consumption in Periods 1 and 2, which are several units of time apart (e.g., today vs. retirement). Any amount not consumed in Period 1 yields positive (compound) interest until Period 2. Suppose A and B exhibit the EGB to the same extent (which is private information) but differ in their risk preferences: while A's utility function is closer to linear, B's utility function is more concave. As we argue below and as shown in previous research, pointing out the concept of compound interest to both individuals—thereby effectively debiasing them—will have a stronger impact on the Period 1 consumption of A than of B: A will reduce Period 1 consumption to a larger extent than B. Based on this *observed* behavior, one might be tempted to conclude that the EGB of A is stronger, thus ignoring the fact that the stronger change in A's observed behavior is caused by her utility curvature. In sum, a subject making intertemporal decisions will usually not discount the absolute value of a future payoff, but the *utility of consumption using that payoff* instead. With non-linear utility, the value of future payoffs and the utility of consumption using these payoffs will refer to different things. These concerns are relevant for both theory and practice. Policymakers often plan to evaluate policy measures to alleviate the EGB using randomized studies. When utility curvature and time preferences are ignored, evaluations of the magnitude of the EGB could be compromised.[2]

In our study, subjects make incentivized decisions between payoffs in either one or seven months in several MPLs.[3] While the payoffs in one month are always displayed in monetary units, the payoffs in seven months are framed in two different ways. In one condition (Treatment FIN), we explicitly provide final values of monthly compounded interest (expressed in monetary units). In the other condition (Treatment INT), only the *monthly* interest rates used to calculate the final values are given.[4] Both conditions are mathematically equivalent and should, given the correct handling of compound interest, result in identical decisions. In other words, for subjects that do not exhibit the EGB, the switching points reflect their preferences for intertemporal consumption only

[2] Our model equates the timing of the receipt of money with the timing of consumption; this assumption is most likely to be fulfilled by individuals that are cash-constrained.

[3] The use of a front-end delay—receiving the sooner payment in one month instead of an immediate payment—is common in the literature (Andersen et al., 2008). It is used to ensure that the transaction costs for subjects to pick up their payments are identical at all points in time. If subjects were able to pick up their short-term payoffs right after the experiment, this would result in much lower transaction costs for the earlier payment and potentially bias the results.

[4] A scientific calculator was available to all subjects during the entire experiment. Subjects must be aware of a potential calculation problem to use the calculator.

and should be identical in both treatments. Potential deviations can be explained by the inability to compute compound interest: with the EGB, a higher interest rate will be required for indifference in Treatment INT than in Treatment FIN. As a consequence, the switching point in Treatment INT should be higher than in Treatment FIN. This setting allows us to isolate subjects' time preferences *and* the magnitude of the EGB in a similar framework: intertemporal consumption preferences are identified by Treatment FIN, while the magnitude of the EGB is estimated by the deviation of the answer in Treatment INT from the answer in Treatment FIN. The curvatures of individuals' utility functions (proxied by risk preferences) are then elicited in a separate MPL task similar to the one used in Holt and Laury (2002) (HL).

We find that the framing of the payoff information in seven months has a significant effect on intertemporal choices. On average, subjects require a higher interest rate to prefer the future payment in Treatment INT than in Treatment FIN, which is consistent with the EGB. On the individual level, this is the case for almost half (46%) of our subjects. Usage of a scientific calculator does not alleviate the bias. Our setup enables us to correlate subjects' behavior with a wide array of covariates such as age, gender, financial literacy, and cognitive reflection. Interestingly, we find no significant correlations between EGB-consistent behavior and financial literacy as well as cognitive reflection. However, wrongly answering a specific question to (roughly) estimate the final value of a long-term investment is a good predictor of biased behavior in our experiment. We interpret this finding as evidence for the validity of our approach to elicit the EGB.

Our MPL-based setup additionally enables us to perform structural estimations. Importantly, estimates of the EGB's magnitude vary substantially between specifications: when utility curvature is taken into account, the point estimate of the bias parameter is reduced by half compared to when linear utility is assumed. Thus, when using our approach to measure the magnitude of the EGB, it is important to take individual preferences into account. Ignoring the interplay of risk preferences, time preferences, and the EGB is likely to result in biased assessments of the EGB in this setup. For this reason, explicitly or implicitly accounting for individual preferences is of prime importance when investigating the EGB in intertemporal consumption decisions.

The remainder of this paper proceeds as follows. We review the related literature in Section 2 and illustrate the intuition behind our experiment using a simple model in Section 3. The experimental setup is described in Section 4. We present our results along with several robustness checks in Section 5. Section 6 concludes.

2 Related Literature

Our study is related to research on the EGB and to the elicitation of utility parameters. In their seminal EGB study, Stango and Zinman (2009) find that many individuals' inability to account for the impact of compound interest leads to suboptimally low savings and high borrowing. Their analysis is based on the survey approach of Eisenstein and Hoch (2007), who find that individuals anchor on linear growth when estimating compound growth. Almenberg and Gerdes (2012) detect a negative correlation between financial literacy and the EGB. Foltice and Langer (forthcoming) find that teaching a formula to calculate compound growth to subjects might help to develop a grasp of exponential effects. McKenzie and Liersch (2011) discuss experiments with an emphasis on retirement savings and find that merely pointing out of the effects of exponential growth to employees already increases their savings rate. Levy and Tasoff (2016a) conduct incentivized experiments on how the EGB influences the construction of expected budget constraints in life cycle consumption decisions. They find substantial evidence for the EGB, with around one third of their subjects being "fully biased" in the sense that they appear to fully linearize compound growth; moreover, they show that EGB is negatively related to asset accumulation. Levy and Tasoff (2016b) conduct a laboratory experiment and show that compound interest leads biased individuals to increase consumption. Moreover, wealth-neutral income shifts raise biased individuals' consumption. In addition, biased individuals act dynamically inconsistently by updating their consumption plans in the direction of their current balances and individuals make more biased decisions when *shorter* periods of interest are used in the decision problem. Levy and Tasoff (2017) report that individuals tend to be overconfident regarding their ability to correctly account for exponential growth, thereby shedding light on the question of why there has been no market solution to the EGB so far. Based on a sample of US households, Goda et al. (2015) find that the EGB negatively affects retirement savings (in addition to present bias and long-run discount factors); eliminating the EGB has the potential to significantly increase retirement savings. Mackinnon and Wearing (1991) argue that the EGB could be attributed to a lack of feedback concerning the accuracy of estimates. Without explicitly referring to the EGB, Read et al. (2013) observe that intertemporal decisions change depending on whether income is framed as amounts or interest rates. In short, policy interventions may be less effective than expected, and individual traits such as overconfidence can prevent individuals from reducing their bias.

In recent years, the first papers based on field experiments addressing the EGB have become available: Goda et al. (2014) conduct a field experiment with university employees in which they examine how to increase participation in retirement savings plans. Providing a detailed description of how exactly to enroll, additionally displaying the savings likely to be amassed at retirement, and showing the income which is likely to be earned during retirement all increase the likelihood of participation, while the amount of contributions to the savings plan is only higher in the latter treatment that directly shows the future income. Song (2015) conducts a field experiment about the relationship between financial literacy and retirement savings in China. The treated group receives financial education with a special emphasis on compound interest, which is found to increase contributions to retirement savings plans by around 40%.

In sum, the EGB is a very robust finding and some successful debiasing approaches have been suggested. Our experimental design to elicit the EGB is incentive-compatible and uses one common method (binary choices in MPLs) for the elicitation of utility parameters as well as the EGB. This attribute makes it especially convenient to employ in surveys and experiments that already use the MPL method and thus can help researchers avoid potential experimenter demand effects. Eliciting the EGB with a simple survey question about the final value of an investment might potentially provide weak incentives for subjects to answer precisely[5] and produce noisy estimates. Incentive-compatible experiments such as the ones described above offer some relief concerning these aspects; however, our proposed method has the advantage that many experimenters are familiar with the MPL method and might find it convenient to integrate the approach into their studies.[6]

In many applications, the MPL method is mainly utilized to elicit risk preferences from experimental subjects (Hey and Orme, 1994; Holt and Laury, 2002). Coller and Williams (1999) and Harrison et al. (2002) use the MPL method to elicit time preferences. In their analyses, linear utility is assumed, thereby comparing the present value y_t in Period t and the final value $y_{t+\tau}$ in Period $t+\tau$, which is assumed to be exponentially discounted by the time preference parameter δ: $y_{t+\tau}(1+\delta)^{-\tau}$. They find discount rates of around 20% (Coller and Williams, 1999) and 30% (Harrison et al., 2002). Andersen et al. (2008) argue that it is crucial to take utility curvature into account when measuring time preferences. Instead of comparing absolute final values, the *utilities* of the present and final values should be compared, i.e., $u(y_t)$ and $u(y_{t+\tau})(1+\delta)^{-\tau}$. For any non-linear utility function (concave in most cases), estimates will differ from the ones described above. Indeed, Andersen et al. (2008) find large differences between estimates with linear and non-linear utility. While they estimate an implied discount rate of 25% with linear utility, accounting for non-linear (concave) utility

[5]The incentive compatibility of open-ended questions in many domains is questioned by Harrison (1992) and Harrison and Rutström (2008), for example. In their study of discounting behavior, Andersen et al. (2014) explicitly refrain from considering open-ended questions for the elicitation of utility parameters.

[6]The exact structure of the MPL approach is described in Section 4.

lowers the estimate to 10%. They conclude that ignoring utility curvature introduces considerable bias into the elicitation of time preferences.[7]

These studies show that the combined elicitation of utility curvature and time preferences plays an important role to elicit unbiased estimates of implied discount rates. We argue that this logic can be extended to estimations of the EGB. In situations where researchers wish to explore the effects of the EGB from observed intertemporal decisions (as in the example of individuals A and B in Section 1), they are well advised to take utility curvature and time preferences into account. In the next section, we provide a simple intuition for this claim.

3 Model

Depending on the specific parameters of an individual's preferences, the EGB will bias her optimal consumption patterns in different ways. In this section, we provide the theoretical foundation for this claim and demonstrate the added value of simultaneously eliciting risk and time preferences when analyzing the extent to which subjects exhibit the EGB based on intertemporal consumption decisions.

Consider an individual with utility $U = u(c_1) + u(c_2)(1+\delta)^{-\tau}$, where $u(c_i)$ is the piecewise utility from consumption c_i in Period $i \in \{1, 2\}$. To be able to account for biases in the calculation of compound growth, Period 2 is situated $\tau \geq 2$ time units in the future. In line with standard theory, δ is the rate at which the individual discounts future consumption for every time unit up to Period 2.[8] Using ω as the individual's budget in Period 1 and i as the interest rate at which assets grow in each unit of time, we can write $c_2 = (\omega - c_1)(1+i)^{\tau}$. The subject's intertemporal Euler equation for optimal consumption is then

$$u'(c_1) = \frac{(1+i)^{\tau}}{(1+\delta)^{\tau}} u'(c_2). \tag{1}$$

However, subjects exhibiting the EGB will systematically underestimate compound interest.

[7]This issue has been the subject of several studies in recent years. Laury et al. (2012) propose a method to elicit discount rates and utility curvature in a single task: subjects choose between a lottery that will be played out soon against a lottery that will be played out later. Consistent with Andersen et al. (2008), they estimate an annual discount rate of around 12%. Anderhub et al. (2001) ask subjects to price lotteries which are paid out at different points in time. Andreoni and Sprenger (2012) propose the *Convex Time Budget* (CTB) method as an alternative way to elicit discount rates that simultaneously accounts for utility curvature and time preferences. Subjects can divide their budget between sooner and later payoffs. The more they choose to receive later, the higher their total budget becomes. They estimate discount rates of around 30%. However, Harrison et al. (2013) express reservations about the CTB method from an econometric as well as from an economic perspective. Furthermore, using the CTB method, our experimental design would likely become overly complicated. For these reasons, we choose to rely on the conventional MPL method in this study.

[8]We abstract from quasi-hyperbolic discounting to isolate the effects of the EGB in the standard model only.

This will lead them to underestimate their future budget for consumption.[9] Following the model of Stango and Zinman (2009) and starting from the present value y_t of an investment, the final value $y_{t+\tau}$ after τ time units is calculated as

$$y_{t+\tau} = y_t(1+i)^{(1-\theta)\tau}. \tag{2}$$

The parameter θ expresses the extent to which the individual underestimates compound growth.[10] For $\theta = 0$, Equation (2) collapses to the standard expression $y_{t+\tau} = y_t(1+i)^{\tau}$. For $\theta \in (0, 1]$, the estimation of the investment's final value will be biased downwards. Taking this into account, we rewrite $c_2 = (\omega - c_1)(1+i)^{(1-\theta)\tau}$. The intertemporal Euler equation is then

$$u'(c_1) = \frac{(1+i)^{(1-\theta)\tau}}{(1+\delta)^{\tau}} u'(c_2). \tag{3}$$

Importantly, the effect of the EGB in this setting does not only depend on θ, but also on the individual's utility function's curvature and her preferences. For an individual with constant relative risk aversion (CRRA) utility $u(x) = x^{1-\rho}/1-\rho$, Figure 1 depicts the amount of optimal consumption in Period 1 (as a percentage of total wealth ω) for $\tau = 10$ (i.e., Period 2 is situated 10 time units in the future) and two assumed parameter values: $\rho = 0.2$ (left-hand panel) and $\rho = 0.6$ (right-hand panel).[11]

While the first value of ρ ($\rho = 0.2$) represents only slightly risk averse behavior, the second value ($\rho = 0.6$) represents a more risk averse agent. Both figures have in common that rather patient individuals ($\delta \to 0$) consume around half of their wealth or less in the first period, while more impatient individuals (increasing δ) consume more of ω in Period 1. For higher values of δ, consumption in Period 1 converges to 100%. Biased individuals (dashed and dotted lines) have distorted perceptions of the final value of their investment and consume more in Period 1 than the unbiased optimal amount (solid line) would suggest and thus reduce their savings contribution.

Depending on how concave an individual's utility function is, the same value of θ will manifest itself in varyingly large departures from optimal consumption in Period 1. Take for example an individual with $\delta = 0.05$ and $\theta = 0.5$. In the left-hand panel of Figure 1, with $\rho = 0.2$, her

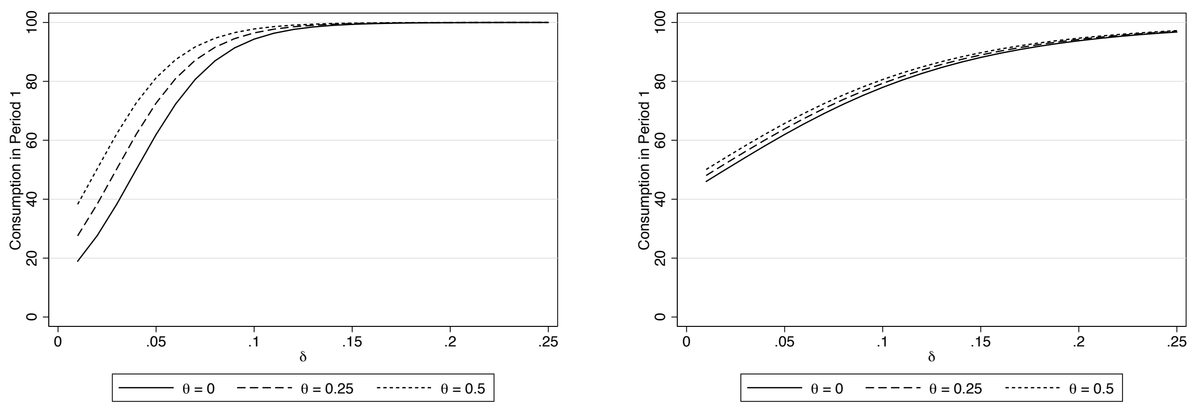
[9] As in Levy and Tasoff (2016a), we assume that the EGB influences the calculation of final values, but not the discounting of future utility.

[10] The precedent for this model is developed in Wagenaar and Sagaria (1975). Stango and Zinman (2009) estimate a median θ of 0.2.

[11] The CRRA specification is commonly used in the literature on the elicitation of risk and time preferences (e.g., Andersen et al., 2008, 2014; Andreoni and Sprenger, 2012). In our robustness tests in Section 5.3.2, we show that our results are not substantially changed for other utility specifications such as constant absolute risk aversion (CARA). Appendix A provides details about the derivation of the optimal consumption depicted in Figure 1.

Figure 1: This figure depicts the utility-maximizing consumption of an individual in Period 1 for varying values of the EGB, $\theta \in \{0, 0.25, 0.5\}$. We assume the CRRA utility function described in the text and show plots for $\rho = 0.2$ in the left-hand panel and $\rho = 0.6$ in the right-hand panel. We further assume $\tau = 10$, $i = 0.05$, and $\omega = 100$.

a) CRRA, $\rho = 0.2$ b) CRRA, $\rho = 0.6$



consumption in the first period will be more than 30% higher than that of a comparable unbiased person with $\theta = 0$. In the right-hand panel of Figure 1, however, with $\rho = 0.6$, the difference between the biased individual ($\theta = 0.5$) and the unbiased individual ($\theta = 0$) will only be around 5 percentage points (pp), which amounts to a relative bias of less than 10%. This difference in consumption deviations between biased and unbiased individuals results solely from the different utility curvatures.[12] If utility curvature is not measured in the experiment, the erroneous conclusion from the observed behavior would be a substantially more pronounced bias with $\rho = 0.2$ than in a situation where $\rho = 0.6$, even though θ is identical in both constellations. Furthermore, the effectiveness of a policy intervention may be reduced.

In addition, for high values of δ, the three curves converge—in this case, the preference for present consumption is so high that no matter what the projection of compound growth is, the individual will always want to consume 100% of her wealth in Period 1. Such discount rates are well in the range of existing estimates: recall from Section 2 that previous studies report discount rates between 0.1 and 0.3. This illustrates a further caveat of attempting to identify the EGB from intertemporal decisions: when individuals are impatient, debiasing them will not lead them to consume less in Period 1. Thus, even though a bias might be present, it will not be possible to identify it from the intertemporal decision alone.

[12] Levy and Tasoff (2016a) show that for utility with an elasticity of intertemporal substitution (EIS) larger than 1, present consumption will be suboptimally high in the presence of the EGB. For the CRRA function we use, EIS $= 1/\rho$. In the cases we consider above, $\rho < 1$ and thus EIS > 1. A more subtle point is that for EIS < 1 (when $\rho > 1$), consumption in Period 1 will be suboptimally *low* in the presence of the EGB. Our structural analyses in Section 5.3 are able to account for this point.

These stylized examples demonstrate the importance of simultaneously estimating the utility parameters ρ and δ when attempting to analyze the role of the EGB in intertemporal consumption decisions. In Section 4, we devise an experimental design based on intertemporal consumption decisions that enables us to disentangle these influences and estimate each of them in an incentivized framework.

4 Experimental Design

In this section, we present an experimental design aimed at eliciting the EGB based on intertemporal consumption decisions.[13] The currency used in the experiment is Currency Units (CU), where CU $1,000$ = EUR 1.

4.1 Multiple Price Lists

Each subject is required to evaluate four MPLs related to intertemporal consumption. The MPL approach to eliciting individual preferences uses lists consisting of several rows with two columns each. Each of the rows represents a trade-off between two monetary payoffs. For example, in an MPL with twelve rows, each subject has to choose between payoffs in the left-hand and right-hand column twelve times. In all of the cases used here, the rows are sorted in ascending order with respect to the attractiveness of the right-hand column. If a subject with monotonic preferences chooses the left-hand column at first and then switches to the right-hand column in a later row, she will stick to that column for the remainder of the list. In this experiment, we consider two types of MPLs. First, there are MPLs in which subjects make decisions between monetary amounts that will be paid out in one month (left-hand column) or seven months (right-hand column) in every row. Second, in an MPL similar to the one used in HL, subjects choose between two risky lotteries in each row.

4.2 Treatments

In the MPLs concerning payments in one or seven months, subjects are confronted with two treatments: FIN (final value) and INT (interest rate). In both treatments, the payment in one month is displayed in monetary units. Within both FIN and INT, the interest rate levels are varied. Subjects are confronted with a *high* interest rate version with increases of 2 pp from one row to the next as well as a *low* (0.5 pp) interest rate version of each list.

[13] The instructions are provided in Appendix B.1. The comprehension questions are reported in Appendix B.3, while the questions about financial literacy, cognitive reflection, and savings behavior are provided in Appendix B.4.

Table 1: This table displays the four MPLs of Treatments FIN and INT.

			Treatment	
			FIN	INT
Interest rate level	High	(steps of 2.0 pp)	L1	L3
	Low	(steps of 0.5 pp)	L2	L4

Treatment FIN This treatment contains two MPLs (L1 and L2). All final values in one month and seven months are displayed in CU amounts. L1 and L2 differ by the implied monthly interest rate level (low and high), i.e., by the relation between the amounts on the left-hand and on the right-hand side. By design, the EGB cannot influence subjects' decisions in this treatment. Treatment FIN thus enables us to elicit the pure time preferences of each subject.

Treatment INT This treatment also contains two MPLs (L3 and L4). The final values in one month are expressed in CU amounts, while the final values in seven months are indicated by the implied *monthly* interest rates (in percent) only (i.e., the monthly interest rate over six months). It is crucial for our setup to use monthly instead of annual interest rates, since with an annual rate, there would be no interest compounding.[14] Similar to treatment FIN, L3 and L4 differ regarding their interest rate levels (low and high).

The combination of treatments and interest rate levels is summarized in Table 1. The exact parameters used for both treatments and interest rate levels are provided in Table 2. Screenshots of all lists are depicted in Appendix B.5. Importantly, the two lists of Treatment FIN are identical to their counterparts in Treatment INT—with the exception of the framing of the right-hand column. While L1 and L3 form an identical pair with 2 pp interest rate steps, L2 and L4 are identical and based on 0.5 pp interest rate steps. To ensure that subjects are not confused by the different types of information displayed on the right-hand side in the two treatments, detailed descriptions can be accessed anytime by clicking on a help button available at the bottom of each MPL screen.

In every row of each list, subjects are faced with the decision to choose between the short-term payment in the left-hand column or the longer-term payment in the right-hand column (i.e., Option A or Option B).[15] At first, a subject will choose Option A as long as the additional payoff from Option B is not high enough to justify the additional waiting time of six months. As soon as

[14]Since the relevance of our experiment crucially depends on subjects' perception of the interest rate as a *monthly* interest rate, the precise definition of the interest rate was explained in detail before starting the treatment (see Appendix B.2); in addition, the definition could be accessed anytime by clicking on a help button at the bottom of a screen. Furthermore, the comprehension questions which needed to be answered before starting the treatment partly referred to the monthly computation of the interest rate (see Appendix B.3).

[15]For simplicity, subjects are not able to indicate indifference.

Table 2: This table describes the MPLs for *Treatment FIN* and *Treatment INT*. *High* and *Low* denote the respective interest rate level. *Option A* (left-hand side of the MPLs), denoted in CU, is paid after 1 month and is identical for both FIN and INT as well as for both interest rate levels. *Option B* (right-hand side of the MPLs) is paid after 7 months. In Treatment FIN, the final value after 6 months of compounded monthly interest (denoted in CU) is presented to the subjects. In Treatment INT, only the respective monthly interest rate between Month 1 and 7 is displayed instead.

Treatment FIN			Treatment INT		
Option A (paid in 1 month)	Option B (paid in 7 months)		Option A (paid in 1 month)	Option B (paid in 7 months)	
High/Low	**L1**: High	**L2**: Low	High/Low	**L3**: High	**L4**: Low
12,000	12,000	12,000	12,000	0%	0.0%
12,000	13,514	12,365	12,000	2%	0.5%
12,000	15,184	12,738	12,000	4%	1.0%
12,000	17,022	13,121	12,000	6%	1.5%
12,000	19,042	13,514	12,000	8%	2.0%
12,000	21,259	13,916	12,000	10%	2.5%
12,000	23,686	14,329	12,000	12%	3.0%
12,000	26,340	14,751	12,000	14%	3.5%
12,000	29,237	15,184	12,000	16%	4.0%
12,000	32,395	15,627	12,000	18%	4.5%
12,000	35,832	16,081	12,000	20%	5.0%
12,000	39,568	16,546	12,000	22%	5.5%

the additional payoff from Option B is high enough to compensate her for postponing consumption, she will switch to this side for the rest of the current list. Since the value of Option B grows larger in each row, a subject with monotonic preferences will stick to it and not switch back to Option A. The row in which the subject first switches to Option B is labeled *switching point*. In the following sections, we compare the switching points in both treatments. For subjects that do not exhibit the EGB, the switching points reflect their time preferences only and should be identical in both treatments. By contrast, potential deviations can be attributed to the inability or unwillingness to compute compound interest or to the use of wrong rules of thumb. With the EGB, a higher interest rate will be required for indifference in Treatment INT than in Treatment FIN. As a consequence, the switching point in Treatment INT should be higher than in Treatment FIN.

To rule out order effects,[16] we vary the order in which the lists are displayed to the subjects. We conduct the experiment in four different versions which are randomly assigned to each subject and use dummies to account for the different versions in our regressions in Section 5.[17]

In addition, subjects are presented with a modified version of the MPL used in HL, consisting of ten rows. This allows us to elicit risk preferences as a proxy for the curvature of subjects' utility

[16] For example, Harrison et al. (2005) comment on the effects of the order in which lists are presented to subjects in HL.

[17] Version 1: {L1,L2 | L3,L4}, Version 2: {L3,L4 | L1,L2}, Version 3: {L2,L1 | L4,L3}, Version 4: {L4,L3 | L2,L1}.

Table 3: This table displays the modified version of the HL MPL used for the elicitation of subjects' utility curvatures. *Option A* and *Option B* describe the left-hand and right-hand column, respectively. p and $1-p$ denote the probability with which the respective amount (denoted in CU) will be paid. *EV(A)* and *EV(B)* are the expected values of the respective option in each row. *Implied range of* ρ describes the implied range in which the implied utility parameter ρ of the CRRA utility function described in Section 3 should lie when the respective row is chosen for the switch from A to B. The last three columns are not shown to subjects.

Option A				Option B				EV(A)	EV(B)	Implied range of ρ		
p	CU	$1-p$	CU	p	CU	$1-p$	CU					
0.1	20,000	0.9	16,000	0.1	38,500	0.9	1,000	16,400	4,750	$-\infty <$	ρ	< -1.71
0.2	20,000	0.8	16,000	0.2	38,500	0.8	1,000	16,800	8,500	$-1.71 <$	ρ	< -0.95
0.3	20,000	0.7	16,000	0.3	38,500	0.7	1,000	17,200	12,250	$-0.95 <$	ρ	< -0.49
0.4	20,000	0.6	16,000	0.4	38,500	0.6	1,000	17,600	16,000	$-0.49 <$	ρ	< -0.15
0.5	20,000	0.5	16,000	0.5	38,500	0.5	1,000	18,000	19,750	$-0.15 <$	ρ	< 0.14
0.6	20,000	0.4	16,000	0.6	38,500	0.4	1,000	18,400	23,500	$0.14 <$	ρ	< 0.41
0.7	20,000	0.3	16,000	0.7	38,500	0.3	1,000	18,800	27,250	$0.41 <$	ρ	< 0.68
0.8	20,000	0.2	16,000	0.8	38,500	0.2	1,000	19,200	31,000	$0.68 <$	ρ	< 0.97
0.9	20,000	0.1	16,000	0.9	38,500	0.1	1,000	19,600	34,750	$0.97 <$	ρ	< 1.37
1.0	20,000	0.0	16,000	1.0	38,500	0.0	1,000	20,000	38,500	$1.37 <$	ρ	$< \infty$

functions.[18] The list uses the same values as in HL, with the exception that the lottery payoffs are denoted in EUR and multiplied by 10 before converting them to CU. These changes are intended to make sure that the payments in this task reflect a similar range of values as those used in the MPLs for FIN and INT described above. The parameters are shown in Table 3. A screenshot of the list is provided in Appendix B.5.

4.3 Incentivization

We offer subjects incentive-compatible compensation. In addition to the show-up fee of EUR 5, each subject receives one payment from one of the four FIN and INT MPLs: after the experiment, one of the four MPLs is randomly selected. Of this MPL, one row is randomly chosen. Subjects then obtain the payoff they have chosen in the selected row. Moreover, a subject receives a payment from her chosen lottery in a randomly determined row of the HL MPL with a probability of 10%.[19] While the show-up fee and the potential payoff from the HL MPL are paid out immediately after the experiment (there is no time delay in the HL MPL), the payoffs in one or seven months are in fact paid out one or seven months after the experiment. We offer our subjects to transfer their delayed payment to their bank account at the respective point in time. However, they also have the choice

[18]By doing so, we assume that risk preferences directly correspond to utility curvature and are thus a suitable proxy for an individual's EIS (e.g., Andersen et al., 2008, 2014).

[19]Paying one out of several lists with equal probability is common practice in comparable experiments, see e.g. Andersen et al. (2008), Tanaka et al. (2010), or Andreoni et al. (2015).

to pick up their payoffs in person at our university offices.[20]

4.4 Background Variables

A main advantage of laboratory experiments is the comparatively high degree of control and the availability of a large set of background variables. For example, in order to make our experiment a conservative test of the EGB, we provide our subjects with access to the standard Windows calculator (set on scientific mode for exponential calculations).[21] We are able to check whether subjects who use the calculator respond differently to the treatments. This could be an important issue, since the mere use of the calculator could indicate whether a subject actually attempts to calculate the final value of the investment or simply guesses.

To assess the validity of our method, we use a question to elicit the EGB similar to the one used in Eisenstein and Hoch (2007) and Song (2015): "Assume you deposit EUR 1,000 in a savings account this year at a constant interest rate of 9% per year. How much money do you have in your account in 30 years if interest is compounded annually?". Subjects can choose one of the following intervals: $x < 5,000$, $5,000 < x < 10,000$, $10,000 < x < 15,000$, and $x > 15,000$. The true final value is EUR 13,268, i.e., the third interval is the correct answer. Moreover, we measure subjects' general financial literacy (for example, with regard to inflation, portfolio diversification, and retirement savings). Furthermore, we ask our subjects basic questions about their savings behavior, for example, what fraction of their monthly net income they usually save. We also conduct the cognitive reflection test (CRT) as described in Frederick (2005) to measure how much a subject focuses on the task at hand. In addition, all subjects are asked to self-assess their risk attitude. At the end of the experiment, subjects are required to provide demographic details such as their gender, age, and field of study in a questionnaire.

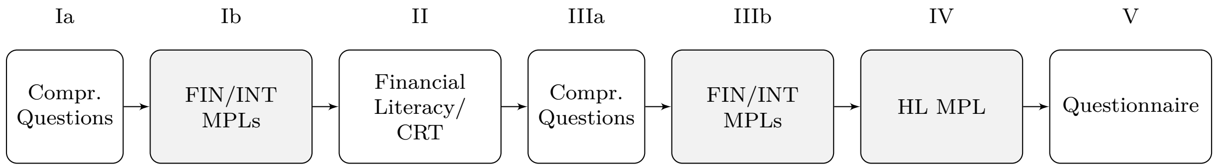
4.5 General Setup

The experiment is programmed using the software z-Tree (Fischbacher, 2007). Subjects are unable to interact or communicate with each other during the experiment. The timeline of the experiment is summarized in Figure 2. Before the experiment can be started, subjects need to answer several

[20] To make this option as convenient as possible, subjects are given a detailed description of where and when to pick up the payment. In each session, around 25% of the subjects decided to collect the payment in person. Only one of these subjects did not pick up the delayed payment.

[21] This approach is similar to Foltice and Langer (forthcoming), who argue that due to the prevalence of smartphones, most individuals have permanent access to calculators. Providing subjects with a calculator thus creates a more realistic environment. Hardware calculators or smartphones are not allowed in the laboratory.

Figure 2: This figure displays the structure of the experiment. The core (incentivized) parts consisting of multiple price lists (MPLs) are shaded in light gray. In Treatment FIN ("final value"), we provide final values of monthly compounded interest. In Treatment INT ("interest rate"), only the monthly interest rates used to calculate the final values are given. CRT represents the cognitive reflection test as suggested by Frederick (2005). HL MPL is an MPL similar to the one used in Holt and Laury (2002).



comprehension questions (Part Ia) correctly to make sure that they understand the task.[22] Part Ib then presents each subject with either two MPLs of FIN or INT (depending on which of the four versions the subject is randomly allocated to). Part II contains the financial literacy and CRT questions. In Parts IIIa and IIIb, the two remaining MPLs of either FIN or INT are displayed. Part IV confronts subjects with the HL MPL. Part V contains the questionnaire, after which the experiment ends and payments are determined.

5 Results

This section describes our dataset and presents the main results. After validating our EGB elicitation method along with various robustness checks, we present and discuss the results obtained by structural estimation.

5.1 Data Description

We use the data of 98 subjects for our analyses, all of which are university students.[23] The average payment per subject is around EUR 23 (including the show-up fee of EUR 5), ranging from EUR 17 to EUR 59.

Table 4 displays descriptive statistics of our subjects.[24] About 50% are female. The mean

[22]In the case of wrong answers, subjects can try again until the correct answer is chosen. The number of incorrect answers given by each subject is recorded and used for the robustness checks in Section 5.2.2.

[23]Of the 115 subjects we conducted the experiment with, we exclude 17 who violate the postulation of monotonic preferences, i.e., that "more money is better than less money". These subjects either perform multiple switches between the left-hand and right-hand column, prefer the right-hand column in the first line of the four FIN and INT MPLs (in which the present and future payoffs are equal), or prefer the left-hand column in the last line of the HL MPL (in which the safe payoff in the right-hand column is higher than that in the left-hand column). This is consistent with other studies such as HL, Andersen et al. (2008), and Montiel Olea and Strzalecki (2014). 13 of these 17 subjects either perform no more than two multiple switches or exhibit violations in the HL MPL only, so we are able to include them in our robustness checks in Section 5.2.2.

[24]Appendix C.1 contains histograms of some of the descriptive statistics.

Table 4: This table contains descriptive statistics of the 98 subjects in our study. *FL score* denotes the financial literacy score and does not include the EGB question, which is reported separately.

	Mean	Median	SD	Min	Max
Female (=1)	0.53	1	0.50	0	1
Age (in years)	24.58	24	3.76	19	41
Economics-related major (=1)	0.29	0	0.45	0	1
FL score	3.10	3	1.52	0	6
EGB question correct (=1)	0.23	0	0.43	0	1
CRT score	1.98	2	1.04	0	3
Calculator used in at least one list (=1)	0.77	1	0.43	0	1
Time for FIN and INT MPLs (in seconds)	266.15	236	147.53	82	878
Monthly savings (in % of net income)	17.58	10	21.56	0	90
Stock experience (=1)	0.24	0	0.43	0	1
Self-assessed risk aversion	4.54	4	2.16	0	10
Observations	98				

(median) age of our subjects is 25 (24) years. 29% of the subjects have their background in an economics-related field of study.[25] The mean (median) financial literacy score, measured on a scale from 0 to 6, indicating the number of correct answers to the questions on financial literacy, equals 3.10 (3). The EGB question is excluded from the financial literacy score and answered correctly by 23% of the subjects; while 23% seems close to the expected result if subjects simply guess (as described above, four response options are offered), we show that correctly answering the question is strongly correlated with our experimental measure of the EGB. The mean (median) CRT score, measured on a scale from 0 to 3, representing the number of correct answers in the CRT, is equal to 1.98 (2). 77% use the calculator at least once in one of the four MPLs in Treatment FIN or INT.[26] The mean (median) time spent on the four MPLs of Treatments FIN and INT is 266 (236) seconds. Subjects indicate that they save a mean (median) percentage of 18% (10%) of their monthly net income. 24% of the subjects have already had experience with stock investments. The mean (median) self-assessed risk attitude, measured on a scale from 0 to 10 (where 10 indicates the strongest preference for taking risks), is 4.54 (4).

5.2 Validity of EGB Elicitation Method

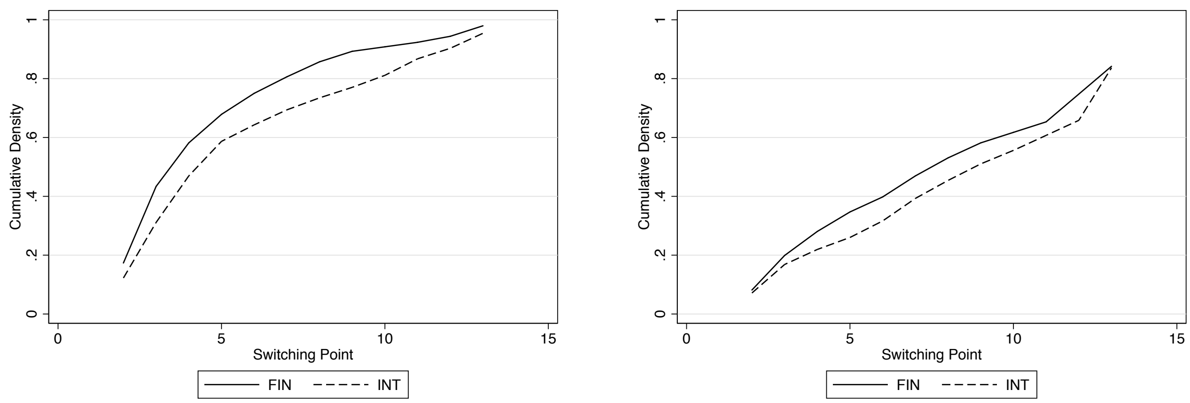
Similar to existing studies using experimental methods, we first investigate the EGB in intertemporal decisions.

[25] This also includes business majors, for example.

[26] Subjects use the calculator more often in Treatment INT than in Treatment FIN. For the low interest rate level, 42% of the subjects use the calculator in INT, while only 20% use the calculator in FIN ($p < 0.01$ using a χ^2-test). For the high interest rate level, 57% of the subjects use the calculator in INT, while only 14% do so in FIN ($p < 0.01$ using a χ^2-test). Also, subjects take more time to evaluate the lists in INT than in FIN: the mean (median) time to finish the task in Treatment INT is 166 (143) seconds, while that for Treatment FIN is 100 (81) seconds. Using a Wilcoxon signed-rank test, these distributions are significantly different ($p < 0.01$). Taken together, these points imply that subjects indeed try to calculate the final values in INT instead of simply guessing.

Figure 3: This figure shows interval midpoints of the cumulative switching point distributions by treatment (FIN/INT) and interest rate level (high/low). The left-hand panel displays the results for the high interest rate level; the right-hand panel contains the results for the low interest rate level.

a) High Interest Rate Level b) Low Interest Rate Level



5.2.1 Main Results

A subject who never switches (i.e., always chooses the left-hand column) is assigned a switching point of 13.[27] Subjects who switch as soon as possible have a switching point of 2.[28] These two cases represent censoring on the left-hand (switching point = 2) and right-hand (switching point = 13) side, which is addressed by using a Tobit model for our regressions.

The cumulative densities of L1 and L3 (high interest rate level) as well as L2 and L4 (low interest rate level) are depicted in Figure 3—the left-hand (right-hand) panel contains the results for the high (low) interest rate level. For both interest rate levels, the distribution of switching points in INT lies to the right of that in FIN, which implies that the switching points in INT are higher than in FIN (as predicted by the EGB).

The mean switching point across FIN and INT is 6.6, i.e., the average subject switches from a payoff in one month to a payoff in seven months between the sixth and seventh row.[29] The average switching point of 5.1 (median: 4) in L1 and L3 (high interest rate level, see Panel a) of Figure 3) is lower than that of 8.1 (median: 8) in L2 and L4 (low interest rate level, see Panel b) of Figure 3), which is statistically significant using a Wilcoxon rank-sum test ($p < 0.01$). This result is plausible and shows that subjects understood the task since the higher interest rates in L1 and L3 induce

[27] As the true switching point could be much higher, this is a conservative assumption.

[28] Recall from above that the present and future payoffs are equal in the first line of the four FIN and INT MPLs and we thus exclude two subjects who prefer the right-hand column in the first line of these lists.

[29] The densities of the switching point distributions in the four FIN and INT MPLs are shown in Appendix C.2. The distributions of the differences in switching points between FIN and INT are shown in Appendix C.3. The average switching point in the HL MPL equals 5.9; the respective density and cumulative distribution are depicted in Appendix C.4.

subjects to switch to the payment in seven months in an earlier row.

In order to estimate the overall effect of Treatment INT compared to Treatment FIN, we compare the switching points in L1 and L2 (FIN) with those in L3 and L4 (INT). While the average switching point in FIN is around 6.2, it is 7.05 in INT. Using a Wilcoxon rank-sum test, the distributions of switching points are significantly different ($p < 0.05$).

For our multivariate analyses, we regress subjects' switching points on an indicator for Treatment FIN or INT and several background variables. Since we observe four switching observations per subject in our treatments, we have 392 observations for our regressions. We use robust standard errors that allow for clustering on the subject level.

Table 5 reports the results of our main specification. We run Tobit regressions on the row in which a subject switches from the payoff in one month to the payoff in seven months (i.e., the switching point).[30] In the baseline specification (Column 1), the switching points in Treatment INT are about 1.3 rows higher than in Treatment FIN; this effect is significant at the 1% level. To control for order effects, we include version dummies in Column 2 and also add session dummies to allow for heterogeneous effects between sessions.[31] The treatment effect remains virtually unchanged. Adding the financial literacy and CRT scores, a gender dummy, age,[32] a dummy denoting an economics-related major subject, a dummy indicating calculator usage, the time spent on all MPLs (measured in minutes), monthly savings as a percentage of net income, and an indicator variable for the interest rate level as further control variables (Column 3) does not alter the estimated treatment effect.[33] We find that the switching point significantly decreases with the high interest rate level, a higher financial literacy score, and correctly answering the EGB elicitation question. In Column 4, we add an interaction term between the treatment dummy and the interest rate level and find that the treatment has a significantly larger effect for the high interest rate level (i.e., steps of 2 pp) than for the low interest rate level (i.e., steps of 0.5 pp). The effect equals almost one additional switching point step for the high interest level ($p < 0.05$). This result is in line with Stango and Zinman (2009), who also find an increasing relationship between the interest rate and the intensity of the EGB. With higher interest rates, the difference between linearized growth and the true (correctly compounded) final value is higher. As a result, there is more room for error and improvement by implementing a policy design. This consistency with the findings of earlier studies supports the validity of our EGB

[30] Appendix C.5 provides tables with similar results of Ordered Logistic and OLS regressions at the same significance levels.

[31] Similar to Andersen et al. (2008), we pool over all subjects.

[32] Adding a quadratic term for age does not alter our results. The coefficient of age^2 is not statistically significant.

[33] The indicator for stock experience is not included here, since three subjects choose not to answer the respective question, which would further reduce the number of observations. Including the variable does not alter our results.

elicitation method. In Column 5, we add interaction terms of the treatment dummy and all further covariates: besides the high interest rate level, the only significant interaction can be observed with respect to the correct answer to the EGB question. While subjects with a correct answer to the EGB question have lower switching points in Treatment FIN compared to subjects with an incorrect answer (as indicated by the negative coefficient on the non-interacted dummy variable representing a correct answer), this difference significantly increases in Treatment INT.

We next investigate the correlates of subjects' individual likelihood to respond to the treatment, i.e., to show behavior consistent with the EGB. Table 6 contains the average marginal effects of a binary Logit regression in which the dependent variable is equal to 1 if a subject exhibits the EGB and 0 otherwise. We define a subject as exhibiting the EGB if the switching point in at least one of the two MPLs in Treatment INT is higher than in the corresponding MPL in Treatment FIN and if no switching point in Treatment FIN is higher than in Treatment INT.[34] By this definition, 45 of 98 subjects (46%) exhibit EGB-consistent behavior. In Column 1, we find that neither gender, major subject, calculator use, time spent, or monthly savings are significantly related to the likelihood of EGB-consistent behavior. We only find a correlation with age: for each additional year of age, the propensity to exhibit EGB-consistent behavior drops by about 2.3 pp. This finding could be explained by older students' higher likelihood to have encountered the concept of compound interest in their studies. In Column 2, we add financial literacy and CRT scores as exogenous variables. Interestingly, neither of these variables is significantly correlated with subjects behaving consistently with the EGB. However, subjects who answer the EGB elicitation question correctly (Column 3) are almost 40 pp less likely to behave in accordance with the EGB prediction. This finding is significant at the 1% level and robust after adding all control variables (Column 4).

Regarding the validity of our EGB elicitation method based on MPLs, the significant influence of the EGB elicitation question used in earlier studies and the consistency of our findings with earlier results lead us to conclude that our method represents a valid measure of EGB-consistent behavior.

5.2.2 Robustness

Table 7 contains various robustness checks of the results presented in Table 5. Besides including subjects who switch more than once and dropping subjects who never switch, we evaluate a number of additional control variables. In all columns, we use the same covariates as in Column 3 of Table 5 and include version dummies as well as session dummies. In Column 1, out of the 17 excluded

[34] Our results are robust to alternative definitions of exhibiting the EGB. For example, if we require a subject to have lower switching points in both MPLs of Treatment FIN (L1/L2) compared to the corresponding MPLs of Treatment INT (L3/L4), our results are virtually unchanged.

Table 5: This table displays the results of Tobit regressions. The dependent variable is the switching point from the left-hand side (paid after one month) to the right-hand side (paid after seven months). The dependent variable can take on values between 2 and 13. Standard errors (reported in parentheses) are clustered on the subject level. ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively.

	(1)	(2)	(3)	(4)	(5)
Treatment INT (=1)	1.3177***	1.3145***	1.3110***	0.8458*	4.2759
	(0.403)	(0.404)	(0.401)	(0.451)	(3.248)
High interest rate level (=1)			-4.8111***	-5.2785***	-5.2343***
			(0.318)	(0.389)	(0.381)
Treatment INT (=1) × High interest rate level (=1)				0.9302**	0.8589**
				(0.384)	(0.379)
Female (=1)			-0.2687	-0.2715	-0.0237
			(1.463)	(1.464)	(1.503)
Treatment INT (=1) × Female (=1)					-0.5006
					(0.836)
Age (in years)			-0.0530	-0.0527	-0.0150
			(0.167)	(0.167)	(0.191)
Treatment INT (=1) × Age (in years)					-0.0749
					(0.117)
Economics-related major (=1)			-0.2199	-0.2210	-0.0483
			(1.438)	(1.438)	(1.479)
Treatment INT (=1) × Economics-related major (=1)					-0.3513
					(0.692)
FL score			-0.8496*	-0.8513*	-0.7617
			(0.452)	(0.452)	(0.473)
Treatment INT (=1) × FL score					-0.1762
					(0.281)
EGB question correct (=1)			-3.9861***	-3.9835***	-2.7423*
			(1.372)	(1.372)	(1.472)
Treatment INT (=1) × EGB question correct (=1)					-2.4292***
					(0.711)
CRT score			-0.4221	-0.4210	-0.4573
			(0.545)	(0.546)	(0.598)
Treatment INT (=1) × CRT score					0.0675
					(0.408)
Calculator used in at least one list (=1)			2.4937	2.4955	2.7349
			(1.577)	(1.577)	(1.680)
Treatment INT (=1) × Calculator used in at least one list (=1)					-0.4790
					(1.145)
Time for FIN and INT MPLs (in minutes)			0.0671	0.0665	0.0540
			(0.233)	(0.233)	(0.246)
Treatment INT (=1) × Time for FIN and INT MPLs (in minutes)					0.0247
					(0.122)
Monthly savings (in % of net income)			-0.0132	-0.0132	-0.0140
			(0.033)	(0.033)	(0.036)
Treatment INT (=1) × Monthly savings (in % of net income)					0.0014
					(0.018)
Constant	5.7405***	6.5622***	12.5288***	12.7592***	11.0406**
	(0.621)	(1.590)	(4.520)	(4.534)	(4.880)
Observations	392	392	392	392	392
Pseudo R^2	0.002	0.004	0.071	0.071	0.073
Log likelihood	-918.90	-917.12	-855.73	-855.42	-853.75
Version dummies	No	Yes	Yes	Yes	Yes
Session dummies	No	Yes	Yes	Yes	Yes

subjects, we consider 13 multiple switchers (MUL) who do not switch more than twice or only

Table 6: This table displays average marginal effects of a binary Logit regression on the propensity of behaving in accordance with the EGB. The dependent variable equals 1 if i.) both switching points in INT are higher than in FIN or ii.) one switching point in INT is higher in FIN while the other one remains constant and zero otherwise. Version and session dummies are included in every regression. Standard errors (reported in parentheses) are clustered on the subject level. ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively.

	(1)	(2)	(3)	(4)
Female (=1)	0.1033	0.0494	-0.0010	-0.0484
	(0.107)	(0.109)	(0.106)	(0.114)
Age (in years)	-0.0234*	-0.0206	-0.0290**	-0.0275**
	(0.013)	(0.013)	(0.012)	(0.012)
Economics-related major (=1)	-0.1011	-0.0587	-0.1012	-0.0674
	(0.107)	(0.104)	(0.106)	(0.102)
Calculator used in at least one list (=1)	0.1006	0.0943	0.1125	0.1077
	(0.143)	(0.147)	(0.133)	(0.138)
Time for FIN and INT MPLs (in minutes)	0.0133	0.0147	-0.0017	-0.0003
	(0.022)	(0.021)	(0.026)	(0.027)
Monthly savings (in % of net income)	-0.0007	-0.0004	-0.0017	-0.0016
	(0.002)	(0.002)	(0.002)	(0.002)
FL score		-0.0420		-0.0455
		(0.032)		(0.034)
CRT score		-0.0473		-0.0187
		(0.046)		(0.047)
EGB question correct (=1)			-0.3912***	-0.3762***
			(0.100)	(0.103)
Observations	98	98	98	98
Pseudo R^2	0.111	0.133	0.193	0.209
Log likelihood	-60.12	-58.63	-54.56	-53.47

violate monotonicity in the HL MPL.[35] We define the location of their first switch as their unique switching point. In sum, we now use 444 observations of 111 subjects. The estimated treatment effect remains highly significant and is even slightly larger than in our baseline analysis.

Even though subjects who never switch decide consistent with theory, we are interested whether the effect holds even without them. In Column 2, we thus only consider observations with a switching point larger than 2 and lower than 13, i.e., we leave out never-switch (NEV) observations. With a value of around 0.7, the coefficient of the treatment dummy is smaller, but still significant at the 1% level. Our results thus seem not to be driven by NEV observations.[36] Note that the number of subjects that always choose the left-hand column (i.e., with a switching point of 13) is higher in INT than in FIN, which is again consistent with the EGB. Similarly, the number of subjects that switch as soon as possible (i.e., with a switching point of 2) is higher in FIN than in INT.

To exclude subjects who might have gone through the experiment without carefully reading the instructions and studying the different MPLs, we next restrict our sample to those subjects who

[35] The answers of four subjects who switch more often do not allow for a meaningful interpretation. Thus, they remain excluded.

[36] A similar point is made by Montiel Olea and Strzalecki (2014), for example.

Table 7: This table displays the results of Tobit regressions as robustness checks. The dependent variable is the switching point from the left-hand side (paid after one month) to the right-hand side (paid after seven months). The dependent variable can take on values between 2 and 13. *MUL* denotes multiple switchers, *NEV* refers to never-switch observations, and *Self-ass. RA* is short for *self-assessed risk aversion*. All control variables of Column 3 in Table 5 as well as version and session dummies are included. Standard errors (reported in parentheses) are clustered on the subject level. ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively.

	(1) MUL incl.	(2) NEV excl.	(3) Time> $p10$	(4) Help	(5) Question	(6) Self-ass. RA
Treatment INT (=1)	1.4397***	0.7031***	1.3250***	1.3032***	1.3218***	1.2992***
	(0.406)	(0.243)	(0.418)	(0.403)	(0.406)	(0.400)
Use of help button in INT (=1)				0.0266		
				(1.349)		
Compr. question wrong (=1)					-1.4094	
					(1.236)	
Self-assessed risk aversion						0.5199*
						(0.266)
Observations	444	228	356	392	392	392
Pseudo R^2	0.052	0.052	0.078	0.050	0.052	0.077
Log likelihood	-986.11	-525.29	-788.18	-874.85	-872.83	-849.55

take more time than the lowest decile ($p10$) to make their choices in the four MPLs[37] and observe no changes to our results (Column 3).

To control for potential heterogeneity in the understanding of the experimental tasks, we add a dummy variable that equals one if a subject clicks on the help button in one or both of the two MPLs in treatment INT (Column 4). The treatment effect remains unchanged.

Along the same line of reasoning, we include a dummy variable that equals one if a subject selects a wrong answer at least once in the comprehension questions before each treatment (Column 5). Again, the treatment effect is virtually unchanged.

We also add the self-assessment of risk preferences in Column 6. Our core results remain unchanged. However, the switching point is about 0.5 rows higher for every additional unit of self-reported risk aversion. Consistent with our reasoning in Section 3, risk preferences seem to affect the observed consumption decisions. Consequently, if risk preferences are not measured and ignored in the analysis, an assessment of the extent of the EGB based on the observed switching point could be biased. This provides a first hint at the relationship between risk preferences (i.e., utility curvature) and intertemporal decisions, which we will further examine in the next section, using structural estimation.

[37] The lowest decile took less than 115 seconds for all four MPLs.

5.3 Preference Heterogeneity and the EGB

As described above, time preferences and utility curvature are additionally elicited at the same time as the EGB. In this section, using structural estimation, we incorporate this data into our analysis. Our main specification builds on the functional form of EGB outlined in Section 3 and assumes a CRRA decision maker. We then test alternative specifications of both the functional form and utility.

5.3.1 Main Results

In our main specification, we assume CRRA utility for our subjects.[38] Inserting Equation (2) into the utility function and allowing for intertemporal discounting, utility in t and $t+\tau$ can be written as

$$u(y_t) = \frac{y_t^{1-\rho}}{1-\rho} \qquad \text{and} \qquad u(y_{t+\tau}) = \frac{\left[y_t(1+i)^{(1-\theta)\tau}\right]^{1-\rho}}{(1+\delta)^{\tau}(1-\rho)}. \tag{4}$$

Similar to Andersen et al. (2008), we estimate the parameters δ, θ, and ρ by maximizing a joint likelihood function for the four FIN and INT MPLs as well as the HL MPL. While the curvature of our subjects' utility functions, determined by ρ, is identified through the HL MPL, δ and θ are identified through subjects' responses to L1 and L3 as well as L2 and L4, respectively. We begin by maximizing the following log-likelihood function for the HL MPL:

$$\ln L^{HL}(\rho; m, \mathbf{X}) = \sum_i \left[\ln(\Phi(\nabla EU) \mid m_i = 1) + \ln(\Phi(-\nabla EU) \mid m_i = -1)\right], \tag{5}$$

where i denotes the row, $m_i = 1$ when the left-hand side of the HL MPL is chosen, and $m_i = -1$ when the right-hand side is chosen. $\mathbf{X}$ represents subject characteristics such as age, gender, etc.[39] The latent index ∇EU is defined as the difference between the expected utility of the left-hand (EU_l) and right-hand column (EU_r) of the HL MPL in every row for different candidate values of ρ: $\nabla EU = EU_l - EU_r$. This index is then linked to the standard cumulative normal distribution function $\Phi(\nabla EU)$ to calculate a likelihood between 0 and 1 to choose the payment in the left-hand column of a list. We apply the same method to the estimation of δ and θ. While we calculate ∇EU for suitable values of ρ in the previous case, we now calculate the latent index for present values ∇PV for candidate values of ρ, δ, and θ: $\nabla PV = PV_l - PV_r$. Similar to Equation (5), we maximize

[38] For simplicity, we abstract from non-zero background consumption.

[39] $\mathbf{X}$ is only relevant for the estimation with covariates (Table 9) and consists of the same control variables as used for the regression in Column 3 of Table 5.

the log-likelihood for MPLs 1 to 4:

$$\ln L^{EGB}(\rho, \delta, \theta; m, \mathbf{X}) = \sum_i \left[\ln(\Phi(\nabla PV) \mid m_i = 1) + \ln(\Phi(-\nabla PV) \mid m_i = -1)\right]. \tag{6}$$

Note that ρ is also included in Equation (6), since we wish to estimate the parameter together with δ and θ. In addition, we allow for stochastic errors in subjects' decisions by modifying the latent indices ∇EU and ∇PV to include the possibility of Fechner errors (Harrison and Rutström, 2008; Hey and Orme, 1994):

$$\nabla EU = \frac{EU_l - EU_r}{\mu} \qquad \text{and} \qquad \nabla PV = \frac{PV_l - PV_r}{\mu}. \tag{7}$$

In this specification, the error term is modeled as normally distributed with mean 0 and a standard deviation of μ (Harrison, 2008).[40] In order to obtain our final estimates, we sum up the respective likelihoods (Andersen et al., 2008):

$$\ln L(\rho, \delta, \theta, \mu; m, \mathbf{X}) = \ln L^{HL} + \ln L^{EGB}. \tag{8}$$

Table 8 contains the estimation results without any further covariates (such as individual subject characteristics). Note that all subjects are included, independent of their actual degree of EGB. As in the regressions of Section 5.2, standard errors are clustered on the subject level. Panel a) assumes linear utility ($\rho = 0$). In this case, the monthly discount factor δ is equal to 0.047 and θ is estimated as 0.516. Both values are significant at the 1 percent level.

When we allow for concave utility, as reported in Panel b), δ decreases to 0.018. Converted to the yearly discount rate, this implies $\delta = 0.74$ in Panel a) and $\delta = 0.24$ in Panel b) of Table 8.[41] This is in line with the claim that estimates of δ are considerably smaller when allowing for non-linear utility (see Section 2). We estimate $\rho = 0.632$, which implies concave utility and is comparable to other estimates in the literature.[42] Importantly, while we estimate $\theta = 0.516$ in Panel a), the estimated magnitude of the EGB parameter decreases to $\theta = 0.259$ in Panel b). This value closely resembles the estimates obtained by Stango and Zinman (2009), where the median value of θ equals 0.2.

Taking non-linear utility into account, we thus estimate the magnitude of the EGB as about

[40] A potential alternative is to use Luce errors (Harrison and Rutström, 2008) instead, which provides us with comparable results for the estimation of θ. However, similar to Andersen et al. (2014), we focus on the specification with Fechner errors.

[41] The implied discount factor on the year level δ_{year} is calculated as $\delta_{year} = (1 + \delta_{month})^{12} - 1$.

[42] Andersen et al. (2008) and Andersen et al. (2014) find $\rho = 0.74$ and $\rho = 0.65$, for example.

Table 8: This table displays the results of structural estimations of Equation (8) with no further covariates. Panel a) reports the results of estimating δ and θ under linear utility, Panel b) allows for concave utility by estimating ρ, while Panel c) additionally considers Fechner errors. The respective log-likelihood (LL) and the *Akaike Information Criterion* (AIC) are reported in brackets for every model. All estimations are performed using the data of 98 subjects. Standard errors (reported in parentheses) are clustered on the subject level. ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively.

Parameter	Estimate	Standard error	Lower 95% CI	Upper 95% CI
a) *Assuming linear utility ($LL = -7,724.02$, $AIC = 15,452.05$)*				
δ	0.047***	0.006	0.036	0.058
θ	0.516***	0.038	0.442	0.591
b) *Allowing for concave utility ($LL = -3,046.35$, $AIC = 6,098.69$)*				
ρ	0.632***	0.034	0.566	0.699
δ	0.018***	0.002	0.013	0.023
θ	0.259***	0.057	0.147	0.371
c) *Allowing for concave utility and Fechner errors ($LL = -3,046.29$, $AIC = 6,100.57$)*				
ρ	0.636***	0.035	0.568	0.704
δ	0.018***	0.002	0.013	0.022
θ	0.260***	0.059	0.145	0.376
μ	0.985***	0.070	0.847	1.123

half as large as when linear utility is assumed. As described in Section 3, reducing θ by about half can imply substantially different intertemporal consumption patterns. This result reveals why it is crucial to measure utility curvature simultaneously with time preferences and the EGB. A comparison of the log-likelihood (LL) as well as the Akaike Information Criterion (AIC) between Panels a) and b) reveals that the model fit improves after allowing for non-linear utility.

As shown in Section 3, a θ of 0.25 implies that an individual with $\rho = 0.2$ and $\delta = 0.05$ consumes about 15% more in the current period than a comparable unbiased individual.

To test the robustness of these results, Panel c) reports estimates when we additionally allow for Fechner errors. In this case, we estimate $\mu = 0.985$. Importantly, compared to Panel b), the estimate for θ is virtually unchanged. The AIC is slightly higher (i.e., worse) than in Panel b), which means that the addition of this degree of freedom is punished more than it contributes to the model fit.[43]

MLE also lends itself to adding covariates to the estimation of each parameter in order to examine heterogeneity. The results of estimating Panel b) of Table 8 with covariates are presented in Table 9.[44] The correlations of the covariates with θ are comparable to those observed in our binary

[43]We rerun the estimations of Table 8 using the sample with multiple switchers as in Column 1 of Table 7. The findings remain qualitatively unchanged: we estimate $\theta = 0.55$ with linear utility and $\theta = 0.3$ with concave utility.

[44]We use this specification since it has the lowest AIC value, i.e., provides the best model fit. Note that after adding covariates, the constant does not represent a point estimate of the mean parameter value as in Table 8 anymore.

Table 9: This table displays the results of structural estimations of ρ, δ, and θ as in Panel b) of Table 8 with covariates added to the estimation. Version dummies are also included (not reported). The LL of the estimated model is $-2,697.86$, the AIC is $5,479.72$. All estimations are performed using the data of 98 subjects. Standard errors (reported in parentheses) are clustered on the subject level. ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively.

Variable	ρ	δ	θ
Constant	0.697	0.027	0.558
	(0.514)	(0.024)	(0.887)
Female (=1)	−0.012	0.000	−0.024
	(0.111)	(0.006)	(0.191)
Age (in years)	0.004	−0.000	−0.006
	(0.014)	(0.001)	(0.030)
Economics-related major (=1)	−0.096	0.003	−0.024
	(0.082)	(0.006)	(0.185)
FL score	−0.001	−0.003	−0.027
	(0.026)	(0.002)	(0.059)
EGB question correct (=1)	−0.310***	−0.001	−0.472***
	(0.092)	(0.006)	(0.127)
CRT score	−0.012	−0.002	0.034
	(0.076)	(0.003)	(0.125)
Calculator used in at least one list (=1)	0.021	0.008	0.034
	(0.129)	(0.008)	(0.224)
Time for FIN and INT MPLs (in minutes)	−0.017	0.001	−0.044*
	(0.013)	(0.001)	(0.026)
Monthly savings (in % of net income)	0.001	−0.000	0.002
	(0.002)	(0.000)	(0.005)

Logit regression in Table 6. While the measures for financial literacy and cognitive reflection do not have a significant influence on θ, we estimate a much smaller θ for subjects that answer the EGB question correctly (Column 3). This change of θ is also consistent with the significant interaction term of the correct answer to the EGB question and Treatment INT in Column 5 of Table 5 and supports the claim that our approach adds to the understanding of the EGB in conjunction with individual preferences.[45]

Moreover, we observe that subjects answering the EGB question correctly exhibit significantly lower values of ρ (Column 1), which is again consistent with Table 5 (Column 5), in which the non-interacted coefficient of the EGB question is marginally significant. Apparently, there is a correlation between ρ and θ. Subjects exhibiting the EGB have significantly higher values of ρ, indicating that estimates of the EGB that ignore utility curvature miss an important influence that determines individual consumption decisions. Independent of the actual drivers of this correlation, the mere existence of a significant relation between different preference parameters strongly calls for a simultaneous assessment of these.

[45] Since the only highly significant covariate is the correct answer to the EGB question, the model estimates the parameters for a representative agent who answered the question correctly and for an agent who did not answer correctly. In this context, a typical disadvantage of the MLE approach is the joint analysis of potentially quite different subjects.

A further observation is that θ decreases when subjects take more time to complete the MPLs (Column 3). This might indicate that subjects exhibiting stronger bias answer intuitively, i.e., without taking more time to compute compound interest or thinking thoroughly about the effects of compounding. Although there is no significant influence of the variable representing the use of a calculator, the (weakly) significant impact of time on θ suggests that some subjects take more time to respond than others, thereby computing future values more accurately.

5.3.2 Alternative Specifications and Robustness

As described above, the analyses in Tables 8 and 9 pool subjects exhibiting the EGB and subjects not exhibiting the EGB. In Table C.3 in Appendix C.6, we repeat the analysis of Table 8 based on the subset of 45 subjects exhibiting the EGB, i.e., subjects whose switching point in at least one of the two MPLs in Treatment INT is higher than in the corresponding MPL in Treatment FIN and for whom no switching point in Treatment FIN is higher than in Treatment INT. As expected, the estimates of θ are higher compared to the full sample of subjects in all specifications. Importantly, the finding that θ declines when allowing for concave utility remains unchanged. While the reduction is smaller than in the full sample in relative terms, θ still declines by almost 20% when allowing for concave instead of linear utility.

The previous analyses are based on the assumption of CRRA utility. To test the robustness of our results, we repeat our estimation based on CARA utility, specified as

$$u(y_t) = -e^{-\gamma y_t}, \tag{9}$$

where $\gamma > 0$ denotes the constant coefficient of risk aversion. Table 10 shows that the decline in θ with concave instead of linear utility is observed with CARA utility, too. As with CRRA utility, the reduction is equal to about 50% in relative terms. We thus conclude that our observations are not driven by the assumption of CRRA utility. Note that our estimates of δ are significantly higher with CARA than with CRRA; however, our conclusions regarding θ are unaffected.

While the specification of utility does not substantially change our results, the functional form of EGB assumed above is only one of several forms discussed in previous research. The functional form described so far is equal to the specification of EGB used in Stango and Zinman (2009). Eisenstein and Hoch (2007), Keren (1983), Timmers and Wagenaar (1977), and Wagenaar and Sagaria (1975)

Table 10: This table displays the results of structural estimations of Equation (8) with no further covariates. In contrast to Table 8, CARA utility as specified in Equation (9) instead of CRRA utility is assumed. Panel a) reports the results of estimating δ and θ under linear utility, Panel b) allows for concave utility by estimating γ, while Panel c) additionally considers Fechner errors. The respective log-likelihood (LL) and the *Akaike Information Criterion* (AIC) are reported in brackets for every model. All estimations are performed using the data of 98 subjects. Standard errors (reported in parentheses) are clustered on the subject level. ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively.

Parameter	Estimate	Standard error	Lower 95% CI	Upper 95% CI
a) *Assuming linear utility* ($LL = -7,724.02$, $AIC = 15,452.05$)				
δ	0.047***	0.006	0.036	0.058
θ	0.516***	0.038	0.442	0.591
b) *Allowing for concave utility* ($LL = -2,958.31$, $AIC = 5,922.61$)				
γ	0.118***	0.006	0.106	0.130
δ	0.044***	0.006	0.033	0.055
θ	0.237***	0.024	0.068	0.382
c) *Allowing for concave utility and Fechner errors* ($LL = -2,863.36$, $AIC = 5,734.72$)				
γ	0.178***	0.010	0.159	0.197
δ	0.041***	0.005	0.031	0.051
θ	0.223***	0.026	0.022	0.391
μ	0.074***	0.005	0.064	0.084

analyze a more flexible form of EGB, which is usually specified as

$$y_{t+\tau} = \alpha y_t (1+i)^{(1-\theta)\tau}, \tag{10}$$

where α represents a factor by which individuals (insufficiently) compensate for the underestimation of exponential growth. To investigate the robustness of our results regarding the functional form of EGB, Table 11 contains the estimation results based on the more flexible functional form and CRRA utility. The first observation is that α is larger than 1 with linear utility and very close to 1 when concave utility is assumed; this suggests that the underestimation of exponential growth is partly corrected for with α in the linear specification and that no such correction is observed with concave utility.[46] Second, as before, we find that the estimates of θ sharply decline when switching from linear to concave utility; in relative terms, the reduction is even higher than in the previous specifications.

Levy and Tasoff (2016a) suggest the following EGB specification, which reflects an individual's

[46]The result that α is close to one suggests that adding α to the functional form of EGB might be of minor importance. Eisenstein and Hoch (2007) obtain estimates for α that are significantly smaller than 1.

perception p of the time-τ value of one CU invested at time t:[47]

$$p(i,t;\alpha) = \prod_{t=0}^{\tau-1}(1+\alpha i) + \sum_{t=0}^{\tau-1}(1-\alpha)i. \tag{11}$$

If $\alpha = 1$, exponential growth is assessed correctly; for $\alpha = 0$, an individual is fully biased and computes linear growth. In contrast to the specifications used above, this specification has the advantage that no bias is predicted for $\tau = 1$, which seems plausible—note that an individual with $\theta > 0$ would incorrectly assess exponential growth over one period according to Equation (2); our experimental setup accounts for this potential issue by employing a monthly interest rate over *six* months. However, when we estimate the model shown in Equation (11), α is equal to 0 in all specifications. The reason is that the differences between the amounts in the rows of our MPLs are so large that even a deviation by one row yields $\alpha = 0$; this is because the MPLs are calibrated to the EGB specification of Stango and Zinman (2009). While the perception of pure linear growth yields $\alpha = 0$ in Equation 11 (i.e., the lower bound of estimating compound growth is linear growth), the underestimation in our main specification of EGB can result in final values lower than those computed with linear growth, which is reflected in the values chosen in the MPLs. We thus leave the application of our experimental approach to this EGB specification to future research.[48]

6 Conclusion

We propose a novel experimental design to evaluate the magnitude of the EGB using the concept of multiple price lists (MPLs). This setup allows us to estimate utility curvature and time preferences as well as the EGB with the same incentivized method. By this means, we are able to examine and account for the relationship between individual risk and time preferences and the EGB.

In agreement with the literature, we find that biased interest compounding significantly influences intertemporal decisions. Based on our observations, 46% of the subjects behave in accordance with the EGB: when the amount of a (safe) payment in seven months is only given by the periodic interest rate instead of the final value, subjects require a relatively higher interest rate to prefer the payment in seven months to that in one month. This result remains robust to variations in the sample

[47] The equation has been modified to account for the fact that the interest rate is the same in each month in our experiment. In the original specification in Levy and Tasoff (2016a), interest rates can be period-specific.

[48] A further alternative specification of EGB, the polynomial model (Jones, 1984), cannot be reasonably applied to our setting. In the polynomial specification, subjects are typically presented with a series of numbers for which they are asked to extrapolate a future value. In Treatment INT of our experiment, subjects are provided with one starting value and an interest rate for each interest rate level only such that the fitting of a polynomial model is not possible. Moreover, future research might explore other utility specifications such as Epstein-Zin preferences (Epstein and Zin, 1989, 1991).

Table 11: This table displays the results of structural estimations of Equation (8) with no further covariates. In contrast to Table 8, the functional form of EGB is modified as shown in Equation (10). Panel a) reports the results of estimating δ, θ, and α under linear utility, Panel b) allows for concave utility by estimating ρ, while Panel c) additionally considers Fechner errors. The respective log-likelihood (LL) and the *Akaike Information Criterion* (AIC) are reported in brackets for every model. All estimations are performed using the data of 98 subjects. Standard errors (reported in parentheses) are clustered on the subject level. ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively.

Parameter	Estimate	Standard error	Lower 95% CI	Upper 95% CI
a) *Assuming linear utility* ($LL = -6,077.53,\ AIC = 12,161.07$)				
δ	0.061***	0.007	0.048	0.074
θ	0.840***	0.013	0.814	0.866
α	1.342***	0.046	1.251	1.433
b) *Allowing for concave utility* ($LL = -3,046.32,\ AIC = 6,100.64$)				
ρ	0.634***	0.037	0.562	0.706
δ	0.018***	0.003	0.013	0.023
θ	0.251***	0.067	0.120	0.382
α	0.994***	0.029	0.938	1.051
c) *Allowing for concave utility and Fechner errors* ($LL = -3,046.27,\ AIC = 6,102.54$)				
ρ	0.637***	0.037	0.565	0.710
δ	0.017***	0.003	0.012	0.023
θ	0.255***	0.069	0.120	0.390
α	0.986***	0.070	0.849	1.123
μ	0.996***	0.028	0.941	1.050

and the control variables. Financial literacy and cognitive reflection are not significantly correlated with subjects' EGB classification. However, correctly answering a question about the final value of a compounded investment strongly predicts EGB-consistent behavior in our experiment, which supports the validity of our method. Structural estimation allows us to estimate more accurately the linkages between the EGB and individual preferences. Importantly, we find that the magnitude of the EGB is measured only half as high when we allow for non-linear utility curvature (compared to linear utility). Consequently, when applying our approach to measure the magnitude of the EGB, it is critical to take individual preferences into account. Ignoring the interplay of risk preferences, time preferences, and the EGB is likely to result in biased measurements of the EGB in this setup. Explicitly or implicitly accounting for individual preferences is important when investigating the EGB in intertemporal consumption decisions or the effect of policy interventions.

The estimates of the EGB parameter obtained in this study are consistent with those reported in previous research and have substantial economic implications on the individual level. Stango and Zinman (2009) demonstrate that within a population with comparable EGB parameters, more biased individuals save less and borrow more than less biased individuals; in addition, they are more likely to favor short-term credit and short-term assets. In sum, this behavior may result in a substantially lower net worth for biased individuals.

Our study offers avenues for potential future research, such as an extension to the case of quasi-hyperbolic discounting or alternative functional forms of the EGB.

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Appendix

A Derivation of Figure 1

Using the CRRA utility function $u(x) = x^{1-\rho}/1-\rho$ and the intuition behind Equation (2) for total utility U, the term to be maximized is

$$U(c_1) = \frac{c_1^{1-\rho}}{1-\rho} + \frac{\left[(\omega - c_1)(1+i)^{(1-\theta)\tau}\right]^{1-\rho}}{(1-\rho)(1+\delta)^{\tau}}.$$

Maximizing with respect to c_1 provides the optimal consumption c_1^* in Period 1:

$$c_1^* = \frac{\omega(1+i)^{(1-\theta)\tau}}{(1+i)^{(1-\theta)\tau} + \left[\frac{(1+i)^{(1-\theta)\tau}}{(1+\delta)^{\tau}}\right]^{1/\rho}}.$$

Assuming a hypothetical parameterization motivated by previous research ($\rho = 0.2$ and $\rho = 0.6$, $\theta \in \{0, 0.25, 0.5\}$, $\tau = 10$, $i = 0.05$, and $\omega = 100$), this expression is used to plot Figure 1.

B Experiment

B.1 Instructions

(Translation of the German original.)

Thank you for participating in this experiment that consists of 5 independent parts. Please do not communicate with the other participants and refrain from using your mobile phone during the experiment. In case you have questions, please ask one of the experimenters. From now on, please follow the instructions given by the experimenters.

Please do not use a personal calculator. If needed, you will have access to the Windows calculator on your computer. The currency in this experiment is *Currency Units* (CU) with an exchange rate of CU 1,000 = EUR 1. The experiment will take about 60 minutes (not including the determination of your payment). If you choose to leave the experiment early, you will not receive any payment. You will receive a *show-up fee* of EUR 5. In addition, after the experiment, you will receive a payment that depends on your decisions during the experiment. There are no time limits in this experiment.

Part 1: Decisions on Delayed Payoffs 1

Note that this part of the experiment is relevant for your payment. In this part, you decide between payoffs which you will receive in either one month or in seven months (from today). You will see two lists after each other with twelve rows of different payoff combinations in each list.

In the left column of each row you see the payment that you would receive in one month. If you choose this option, you will receive this amount in one month (converted to EUR).

In the right column of each row you see information regarding the payment you could alternatively receive in seven months. Before you see the lists, you will find more details on the type of information you receive on a separate page.[49] You will have to correctly answer two comprehension questions to make sure that you are familiar with the displayed type of information. By pressing *Help* at the bottom of each page, you can access this information at any time. If necessary, you can activate the Windows calculator by pressing *Calculator* (marked in red).

In each row, please indicate whether you prefer the payoff in one month on the left or the payoff in seven months on the right. In each list, you have to make 12 decisions—it is not possible to make fewer or no decisions!

Please press *OK* to confirm your entries and proceed to the next page.

Part 2: Questions on Financial Knowledge

Please answer the questions displayed on the screen.

Please press *OK* to confirm your entries and proceed to the next page.

Part 3: Decisions on Delayed Payoffs 2

Note that this part of the experiment is relevant for your payment. You will see two lists after each other with twelve rows of different payoff combinations in each list. The instructions for this part are identical to Part 1.

Part 4: Decisions on Risky Payoffs

Note that this part of the experiment is relevant for your payment. In this part, you decide between risky payoffs (lotteries). You will see one list with ten rows.

In each row, you see two different payoffs (high and low) in each column and the corresponding probabilities with which these would be paid out to you after the experiment. While the payoffs

[49] More details on this information are provided in Appendix B.2.

themselves remain unchanged in each row, the probabilities for the high and the low payoffs vary. In each row, the probability of receiving the high (low) payoffs in the left column is equal to the probability of receiving the high (low) payoffs in the right column. The probability of receiving the high amount increases with each row in this list.

In each row, please indicate whether you prefer the lottery in the left column or in the right column. In each list you have to make ten decisions—it is not possible to make fewer or no decisions!

Please press *OK* to confirm your entries and proceed to the next page.

Part 5: Concluding Questions

In order to finish the experiment, please answer some final questions. Please press OK to finish the experiment after answering these questions. Your data will of course be treated confidentially and will be available to the experimenters in anonymous form only.

After the page *Determination of Your Payment* appears on your screen, please wait for the experimenters to provide you with a passcode that will let you continue. In order to determine the amount of your payment, one of the experimenters will approach you at your booth.

Determination of Your Payment

In addition to the show-up fee of EUR 5, you will receive a payment which depends on your decisions during the experiment. One of your decisions from Part 1 or 3 will be randomly selected and paid out, converted to EUR. In addition, with a probability of 10%, you will receive the payoff of a randomly selected decision from Part 4.

Payment for Parts 1 and 3 Please throw a four-sided die to determine one of the four lists which is relevant for your payment. The number thrown is equal to the relevant list. For example, if the die shows a 3, the third list is relevant for your payment. Thereafter, please throw a twelve-sided die to select the row which determines the amount of your payment. The number thrown is equal to the relevant row. For example, if the die shows a 6, the sixth row is relevant for your payment. Although you make twelve decisions in all four lists, only one decision will determine your payment. Each row is equally likely to be selected.

If you have chosen the payoff in one month in the selected row, you can collect your payment at our offices in one month. Alternatively, we can transfer the amount to your bank account on the same date. If you have chosen the payoff in seven months in the selected row, you can collect your payment at our offices in seven months. Alternatively, we can transfer the amount to your bank account on the same date.

Payment for Part 4 In addition to the show-up fee and the payment from Parts 1 and 3, with a probability of 10% you will receive the payoff of one of your decisions in Part 4 right after the experiment. Please throw a ten-sided die to determine whether you are eligible for a payment from this part. If the die shows a 1, you will receive a payment; if the die shows a number between 2 and 10, you will not receive a payment.

If you are eligible for a payment, please throw a ten-sided die again to select the relevant row. The number thrown equals the row. For example, if the die shows a 3, the third row is relevant for your payment. Each row has the same likelihood of being selected. After that, please throw a ten-sided die again to determine the outcome of the lottery in the relevant row. If the number you throw is smaller than or equal to the likelihood of the high payoff (divided by ten), you will receive that high payoff. If not, you will receive the low payoff. For example, if the likelihood of receiving the high payoff in the relevant row is 30%, you will receive it if you throw a 1, 2 or 3.

Please remain seated until your booth number is called out to collect your payment.

B.2 Definition of Payouts Displayed Before Treatments

(Translation of the German original.)

This section contains the description of the payout information displayed on a separate screen before Treatment FIN and Treatment INT, respectively.

Information Displayed Before Treatment FIN

In each of the following two lists, the *left column* contains the payment that you would receive in *one month*, denoted in currency units.

The *right column* contains the payment that you would receive in *seven months*, denoted in currency units.

Information Displayed Before Treatment INT

In each of the following two lists, the *left column* contains the payment that you would receive in *one month*, denoted in currency units.

The *right column* contains the monthly interest rate, expressed in percent, which applies to the amount in the left column *in each month between Month 1 and Month 7* (i.e., for each of six subsequent months in total). The final value of this calculation constitutes the payment in *seven months*.

B.3 Comprehension Questions

(Translation of the German original.)

This section contains the comprehension questions before Treatment FIN and Treatment INT, respectively, together with the provided answer options (correct answers are **written in bold**). In order to continue with the experiment, each subject had to answer both questions correctly.

Comprehension Questions in Treatment FIN

1. After what period of time will the monetary amounts in the left-hand column of the following two lists be paid out? (**1 month** / 6 months / 7 months)

2. By how many months do the payoff dates in the left-hand column and right-hand column differ? (1 month / **6 months** / 7 months)

Comprehension Questions in Treatment INT

1. In the following two lists, the final value in the right-hand column is always (smaller than / **larger than or equal to** / equal to) the value in the left-hand column.

2. For how many periods/months do you receive interest on the amount in the left-hand column in order to calculate the final value in the right-hand column? (**6 months** / 7 months / 10 months)

B.4 Financial Literacy, Cognitive Reflection, and Savings

(Translation of the German original.)

This section contains the questions on financial literacy, cognitive reflection, and savings behavior asked in the experiment, together with the provided answer options (correct answers, if applicable, are **written in bold**). Subjects did not receive feedback about the accuracy of their answers.

Financial Literacy Questions

Some of these questions are based on Lusardi and Mitchell (2007) and were slightly altered.

1. Imagine that the interest rate on your savings account was 1% per year and inflation was 2% per year. After one year, how much would you be able to buy with the money in this account? (**Less than today** / Exactly the same as today / More than today / Do not know / No response)

2. True or false? Buying a company stock usually provides a safer (less risky) return than a stock mutual fund. (True / **False** / Do not know / No response)

3. What happens to bond prices if the interest rate falls? (**Rise** / Stay the same / Fall / Do not know / No response)

4. Assume you deposit EUR 1,000 in a savings account this year at a constant interest rate of 9% per year. How much money do you have in your account in 30 years if interest is compounded annually? (Less than EUR 5,000 / Between EUR 5,000 and EUR 10,000 / **Between EUR 10,000 and EUR 15,000** / More than EUR 15,000 / Do not know / No response)

5. True or false? Stock prices normally fluctuate more than bond prices. (**True** / False / Do not know / No response)

6. Imagine that a friend inherits EUR 10,000 today and that his brother will inherit EUR 10,000 3 years from now. Who is wealthier because of the inheritance? (**Your friend** / Your friend's brother / Both are equally wealthy / Do not know / No response)

7. How high is the current annual allowance for the so-called *Riester-Rente*[50] per person? (EUR 73 / EUR 125 / **EUR 154** / Do not know / No response)

Cognitive Reflection Test

The questions used for the CRT follow Frederick (2005).

1. A bat and a ball cost EUR 1.10 in total. The bat costs EUR 1.00 more than the ball. How much does the ball cost?

2. If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?

[50] A German version of a 401(k) retirement savings plan.

3. 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?

Questions on Savings and Investments

1. How much of your monthly disposable net income do you save (in %)? (Scale of 0 to 100)

2. Are you currently holding stocks or stock mutual funds or have you ever held stocks or stock mutual funds? (Yes / No / No response)

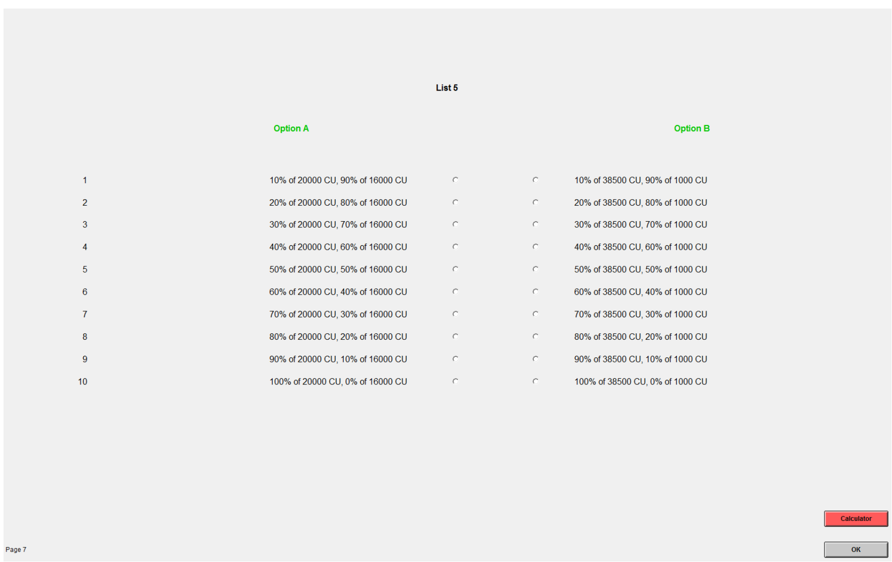
3. In general, would you assess yourself as a person that is willing to take risks or do you try to avoid taking risks? (Scale of 0 to 10; 0 = maximum risk avoidance, 10 = maximum risk taking)

B.5 Screenshots

(Translation of the German original.)

Figure B.1: This figure displays the MPLs used in Treatment FIN and Treatment INT (translated from German). The upper two panels show the MPLs for Treatment FIN, while the lower two panels display the MPLs for Treatment INT. The amounts on the left-hand side of each MPL, denoted in CU, are identical for both treatments and paid after one month. In Treatment FIN, the right-hand side shows the final values after 6 months of monthly compounded interest, while in Treatment INT, the right-hand side shows the respective monthly interest rates only.

Figure B.2: This figure displays the MPL used for the elicitation of the curvature of utility functions (translated from German). Both Option A and B display lotteries, of which each subject has to choose one in each line. All values are denoted in CU.

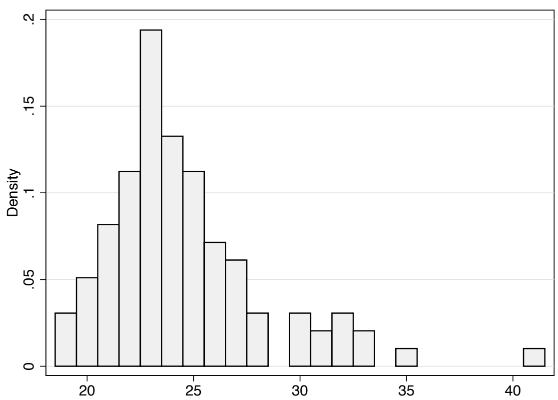


C Descriptive Statistics and Tests of Robustness

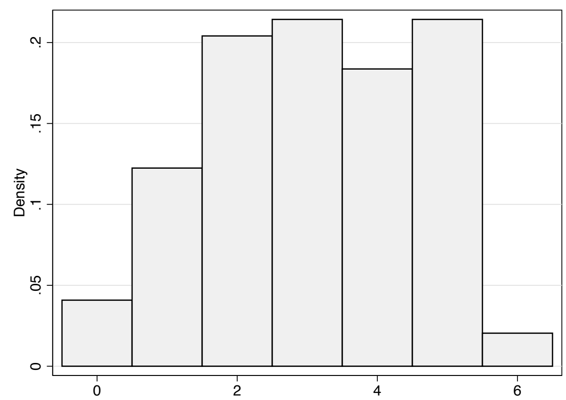
C.1 Descriptive Statistics (Histograms)

Figure C.1: This figure contains the histograms of several variables described in Section 5.1. Top/left: age of subjects, measured in years; top/right: financial literacy score of subjects (the financial literacy score does not include the question concerned with the EGB); middle/left: cognitive reflection test score; middle/right: time for FIN and INT MPLs, measured in seconds; bottom/left: monthly savings, denoted in percent of net income; bottom/right: self-assessed risk attitude, measured on a scale from 0 to 10 (where 10 indicates the strongest preference for taking risks).

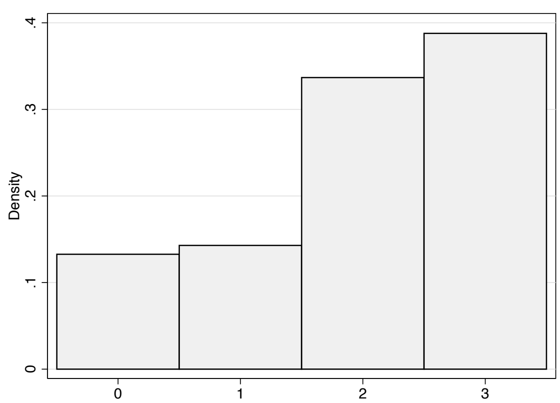
a) Age, Years



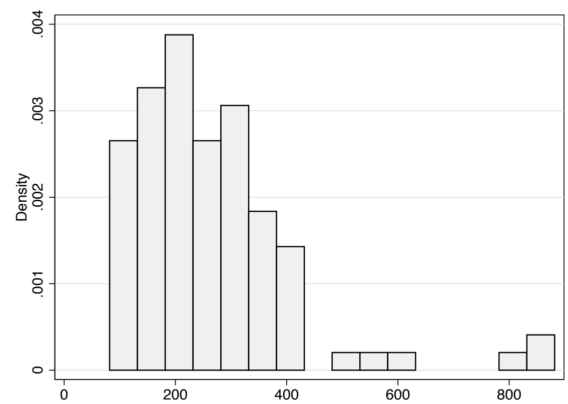
b) Financial Literacy Score (Without EGB)



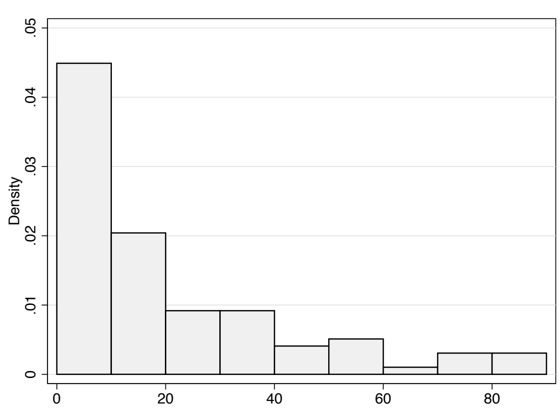
c) Cognitive Reflection Test Score



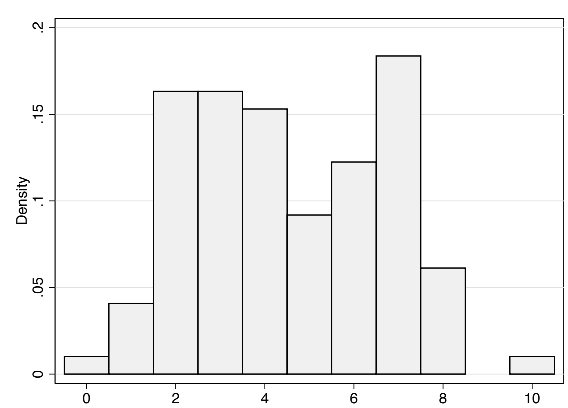
d) Time for FIN and INT MPLs, Seconds



e) Monthly Savings, Percent



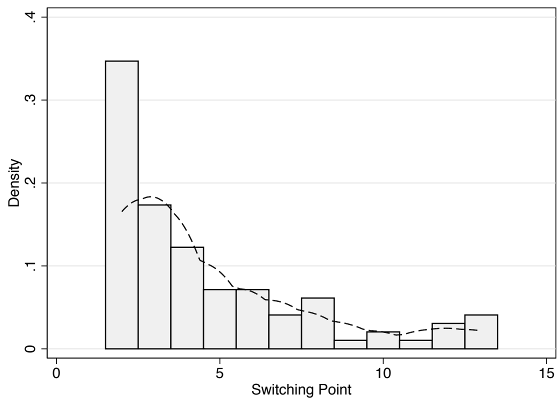
f) Self-Assessed Risk Attitude



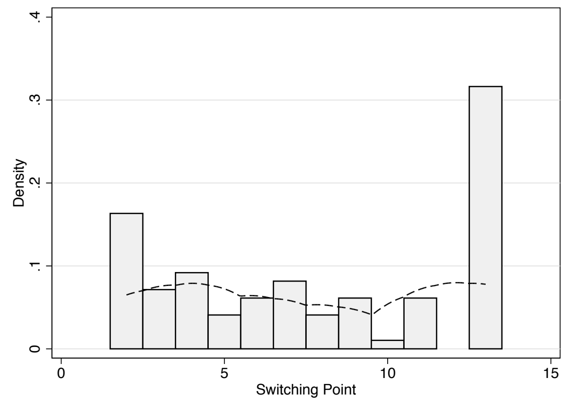
C.2 Switching Points in the FIN and INT Lists

Figure C.2: This figure displays the histograms and kernel densities (Epanechnikov kernel) of the switching points in the MPLs in Treatment FIN and Treatment INT. The upper two panels show the results for the FIN MPLs (left: high interest rate level; right: low interest rate level); the lower two panels contain the results for the INT MPLs (left: high interest rate level; right: low interest rate level).

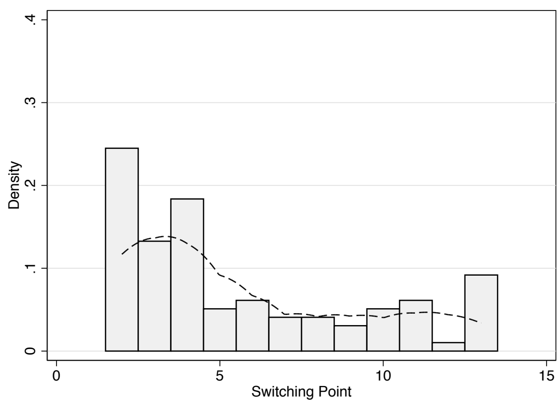
a) L1 (FIN, High)



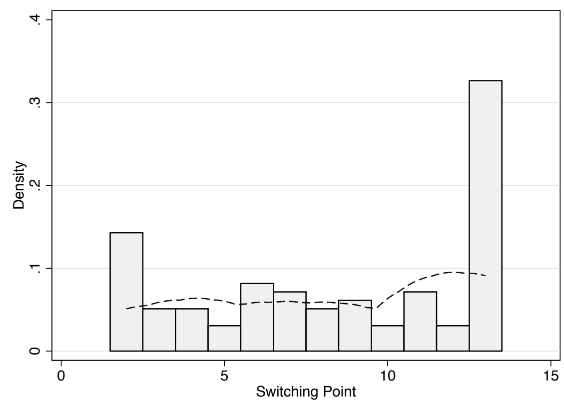
b) L2 (FIN, Low)



c) L3 (INT, High)



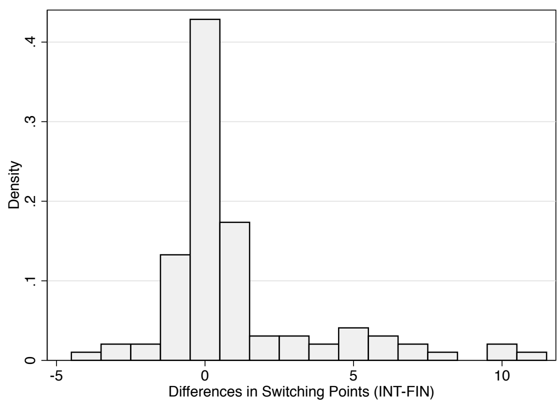
d) L4 (INT, Low)



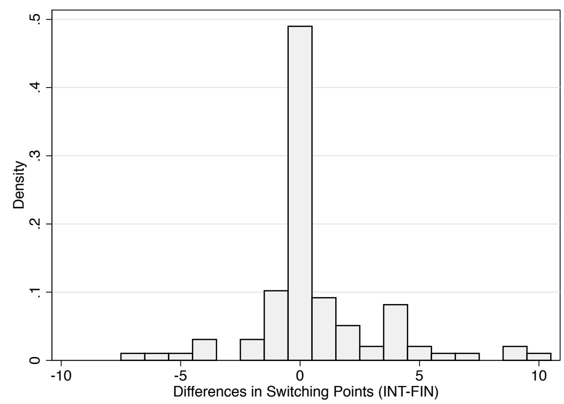
C.3 Differences in Switching Points in the FIN and INT Lists

Figure C.3: This figure displays the histograms of the differences in switching points in the MPLs in Treatment INT and Treatment FIN. The left-hand panel shows the results for the high interest rate level; the right-hand panel contains the results for the low interest rate level.

a) $SP_{INT} - SP_{FIN}$, High

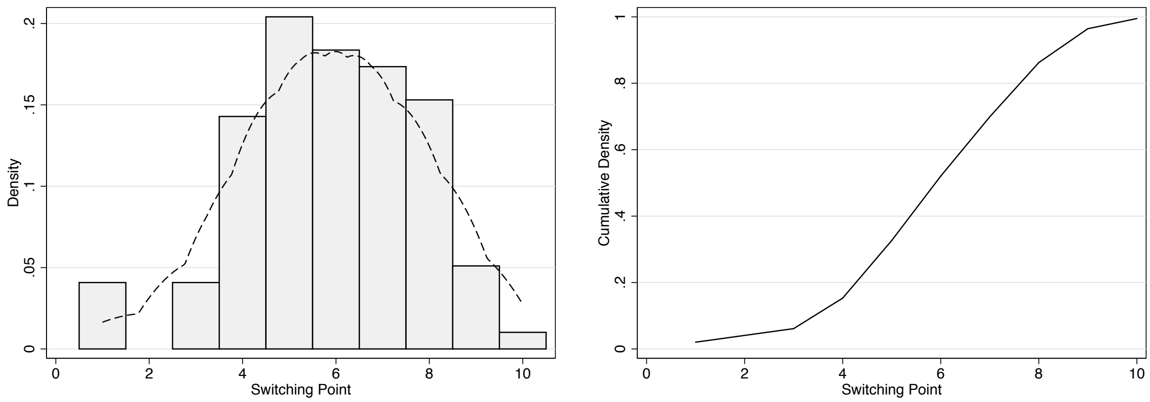


b) $SP_{INT} - SP_{FIN}$, Low



C.4 Switching Points in the Holt/Laury List

Figure C.4: This figure displays the switching points in the HL MPL. The left-hand panel displays a histogram and the kernel density (Epanechnikov kernel) of the switching points, while the right-hand panel shows the cumulative density function.



C.5 Alternative Regression Specifications

Table C.1: This table displays the coefficients of Ordered Logistic regressions. The dependent variable is the switching point from the left-hand side (paid after one month) to the right-hand side (paid after seven months). The dependent variable can take on values between 2 and 13. Standard errors (reported in parentheses) are clustered on the subject level. ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively.

	(1)	(2)	(3)	(4)	(5)
Treatment INT (=1)	0.3598***	0.3579***	0.4358***	0.3092**	0.9044
	(0.097)	(0.099)	(0.126)	(0.140)	(1.126)
High interest rate level (=1)			-1.4720***	-1.5967***	-1.6015***
			(0.147)	(0.164)	(0.167)
Treatment INT (=1) × High interest rate level (=1)				0.2429**	0.2404**
				(0.115)	(0.118)
Female (=1)			-0.1343	-0.1370	-0.1426
			(0.462)	(0.463)	(0.477)
Treatment INT (=1) × Female (=1)					0.0041
					(0.275)
Age (in years)			-0.0231	-0.0232	-0.0201
			(0.059)	(0.059)	(0.071)
Treatment INT (=1) × Age (in years)					-0.0077
					(0.043)
Economics-related major (=1)			-0.1619	-0.1625	-0.1194
			(0.517)	(0.517)	(0.560)
Treatment INT (=1) × Economics-related major (=1)					-0.0959
					(0.244)
FL score			-0.2590*	-0.2605*	-0.2497
			(0.154)	(0.154)	(0.167)
Treatment INT (=1) × FL score					-0.0246
					(0.096)
EGB question correct (=1)			-1.1693***	-1.1707***	-0.8283*
			(0.433)	(0.434)	(0.488)
Treatment INT (=1) × EGB question correct (=1)					-0.6681***
					(0.237)
CRT score			-0.1661	-0.1646	-0.1698
			(0.181)	(0.181)	(0.202)
Treatment INT (=1) × CRT score					0.0090
					(0.132)
Calculator used in at least one list (=1)			0.8950	0.8963	1.0218*
			(0.549)	(0.550)	(0.604)
Treatment INT (=1) × Calculator used in at least one list (=1)					-0.2390
					(0.375)
Time for FIN and INT MPLs (in minutes)			0.0167	0.0163	0.0142
			(0.077)	(0.077)	(0.082)
Treatment INT (=1) × Time for FIN and INT MPLs (in minutes)					0.0049
					(0.037)
Monthly savings (in % of net income)			-0.0078	-0.0078	-0.0080
			(0.012)	(0.012)	(0.014)
Treatment INT (=1) × Monthly savings (in % of net income)					0.0001
					(0.006)
Observations	392	392	392	392	392
Pseudo R^2	0.002	0.004	0.076	0.077	0.078
Version dummies	No	Yes	Yes	Yes	Yes
Session dummies	No	Yes	Yes	Yes	Yes

Table C.2: This table displays the results of OLS regressions. The dependent variable is the switching point from the left-hand side (paid after one month) to the right-hand side (paid after seven months). The dependent variable can take on values between 2 and 13. Standard errors (reported in parentheses) are clustered on the subject level. ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively.

	(1)	(2)	(3)	(4)	(5)
Treatment INT (=1)	0.8469***	0.8469***	0.8469***	0.6327**	2.2246
	(0.246)	(0.248)	(0.251)	(0.280)	(2.034)
High interest rate level (=1)			-3.0306***	-3.2449***	-3.2449***
			(0.235)	(0.277)	(0.280)
Treatment INT (=1) × High interest rate level (=1)				0.4286*	0.4286*
				(0.253)	(0.256)
Female (=1)			-0.2061	-0.2061	-0.2206
			(0.871)	(0.872)	(0.912)
Treatment INT (=1) × Female (=1)					0.0289
					(0.530)
Age (in years)			-0.0073	-0.0073	0.0075
			(0.094)	(0.094)	(0.107)
Treatment INT (=1) × Age (in years)					-0.0296
					(0.072)
Economics-related major (=1)			-0.2837	-0.2837	-0.1893
			(0.879)	(0.880)	(0.930)
Treatment INT (=1) × Economics-related major (=1)					-0.1886
					(0.440)
FL score			-0.4969*	-0.4969*	-0.4180
			(0.272)	(0.273)	(0.291)
Treatment INT (=1) × FL score					-0.1579
					(0.190)
EGB question correct (=1)			-2.3305***	-2.3305***	-1.5766**
			(0.731)	(0.732)	(0.793)
Treatment INT (=1) × EGB question correct (=1)					-1.5078***
					(0.429)
CRT score			-0.3389	-0.3389	-0.3625
			(0.325)	(0.325)	(0.360)
Treatment INT (=1) × CRT score					0.0471
					(0.271)
Calculator used in at least one list (=1)			1.5014	1.5014	1.6413*
			(0.907)	(0.908)	(0.969)
Treatment INT (=1) × Calculator used in at least one list (=1)					-0.2800
					(0.755)
Time for FIN and INT MPLs (in minutes)			-0.0011	-0.0011	-0.0109
			(0.150)	(0.150)	(0.151)
Treatment INT (=1) × Time for FIN and INT MPLs (in minutes)					0.0196
					(0.079)
Monthly savings (in % of net income)			-0.0049	-0.0049	-0.0064
			(0.020)	(0.020)	(0.022)
Treatment INT (=1) × Monthly savings (in % of net income)					0.0030
					(0.011)
Constant	6.1939***	6.7482***	10.1759***	10.2830***	9.4870***
	(0.356)	(0.933)	(2.556)	(2.568)	(2.799)
Observations	392	392	392	392	392
Pseudo R^2	0.010	0.019	0.285	0.286	0.294
Version dummies	No	Yes	Yes	Yes	Yes
Session dummies	No	Yes	Yes	Yes	Yes

C.6 Structural Estimations (Subjects with EGB only)

Table C.3: This table displays the results of structural estimations of Equation (8) with no further covariates. In contrast to Table 8, the analysis is based on the subset of 45 subjects exhibiting the EGB (the switching point in at least one of the two MPLs in Treatment INT is higher than in the corresponding MPL in Treatment FIN and no switching point in Treatment FIN is higher than in Treatment INT). Panel a) reports the results of estimating δ and θ under linear utility, Panel b) allows for concave utility by estimating ρ, while Panel c) additionally considers Fechner errors. The respective log-likelihood (LL) and the *Akaike Information Criterion* (AIC) are reported in brackets for every model. All estimations are performed using the data of 98 subjects. Standard errors (reported in parentheses) are clustered on the subject level. ***, **, and * indicate significance at the 1, 5, and 10 percent level, respectively.

Parameter	Estimate	Standard error	Lower 95% CI	Upper 95% CI
a) *Assuming linear utility* ($LL = -1,897.54,\ AIC = 3,799.08$)				
δ	0.036***	0.006	0.025	0.048
θ	0.667***	0.035	0.600	0.735
b) *Allowing for concave utility* ($LL = -1,261.49,\ AIC = 2,528.98$)				
ρ	0.458***	0.069	0.323	0.594
δ	0.023***	0.003	0.017	0.029
θ	0.542***	0.055	0.433	0.650
c) *Allowing for concave utility and Fechner errors* ($LL = -1,250.46,\ AIC = 2,508.91$)				
ρ	0.555***	0.061	0.435	0.675
δ	0.018***	0.003	0.013	0.024
θ	0.556***	0.054	0.450	0.663
μ	0.730***	0.080	0.573	0.887