ECONSTOR
Make Your Publications Visible.

A Service of
ZBW
Leibniz-Informationszentrum Wirtschaft
Leibniz Information Centre for Economics

Oberrauch, Luis; Kaiser, Tim

Working Paper

Financial literacy and intertemporal arbitrage

DIW Discussion Papers, No. 1912

Provided in Cooperation with:
German Institute for Economic Research (DIW Berlin)

Suggested Citation: Oberrauch, Luis; Kaiser, Tim (2020) : Financial literacy and intertemporal arbitrage, DIW Discussion Papers, No. 1912, Deutsches Institut für Wirtschaftsforschung (DIW), Berlin

This Version is available at:
https://hdl.handle.net/10419/226824

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.

WWW.ECONSTOR.EU

Mitglied der Leibniz-Gemeinschaft

DIW BERLIN

1912

Discussion Papers

Deutsches Institut für Wirtschaftsforschung 2020

Financial Literacy and Intertemporal Arbitrage

Luis Oberrauch and Tim Kaiser

Opinions expressed in this paper are those of the author(s) and do not necessarily reflect views of the institute.

IMPRESSUM

© DIW Berlin, 2020

DIW Berlin
German Institute for Economic Research
Mohrenstr. 58
10117 Berlin

Tel. +49 (30) 897 89-0
Fax +49 (30) 897 89-200
http://www.diw.de

ISSN electronic edition 1619-4535

Papers can be downloaded free of charge from the DIW Berlin website:
http://www.diw.de/discussionpapers

Discussion Papers of DIW Berlin are indexed in RePEc and SSRN:
http://ideas.repec.org/s/diw/diwwpp.html
http://www.ssrn.com/link/DIW-Berlin-German-Inst-Econ-Res.html

Financial Literacy and Intertemporal Arbitrage

Luis Oberrauch and Tim Kaiser

Abstract

We study the role of financial literacy for inter-temporal decision-making using an adapted version of the Convex Time Budget Protocol (Andreoni and Sprenger 2012). While we find no evidence of dynamically inconsistent preferences in the aggregate, we document substantial heterogeneity in choice-patterns and estimated parameters at the individual-level: We find that subjects with higher levels of financial literacy are more likely to make patient inter-temporal choices, to allocate the entire budget to a single payment-date, allocate the entire budget to corner choices as interest rates increase, and to show individual discount factors which are in line with extra-experimental market rates. At the same time, financial literacy is uncorrelated with choice consistency and estimated individual error parameters. These results serve as suggestive evidence for inter-temporal arbitrage among financially literate respondents, thereby revealing a potential confound in time-preference elicitation tasks relying on time-dated monetary rewards.

JEL Codes: G53, D15, D91

Keywords: Intertemporal choice, financial literacy, narrow bracketing, arbitrage

November 2020

Acknowledgements: We appreciate comments from Carly Urban, Lukas Menkhoff, and Miguel Luzuriaga, as well as seminar participants in Hamburg, Landau, and Vienna. We thank Ngoc Anh Nguyen for research assistance.

Funding: This work was funded by the *Joachim Herz Foundation.*

Declarations of interest: none

Luis Oberrauch, Research Associate, University of Koblenz-Landau, D-76829 Landau, Germany; oberrauch@uni-landau.de

Tim Kaiser (corresponding author), Junior Professor of Economics and Economic Education, University of Koblenz-Landau and German Institute for Economic Research (DIW Berlin), D-76829 Landau, Germany (ORCiD: https://orcid.org/0000-0001-7942-6693); kaiser@uni-landau.de

Financial Literacy and Intertemporal Arbitrage

1 Introduction

Many of the most important decisions in life are inter-temporal. From saving for old age, investment decisions in education, to the choice of diet and healthy lifestyle. Most of these decisions involve a form of delaying gratification through consumption or leisure in order to gain utility at a later point in time. Thus, understanding the foundations underlying inter-temporal decisions is necessarily important. A large literature in economics has documented empirical evidence that suggests a) that individual time-preference parameters are predictive of field behaviors and many important long-run outcomes (e.g., Shoda et al., 1990; Meier and Sprenger, 2010, 2012; Sutter et al., 2013; Golsteyn et al., 2014), and b) that many individuals violate assumptions of standard exponential discounted utility models, instead exhibiting dynamically time-inconsistent preferences (i.e., present bias) (Imai et al., 2019).

In this literature, economists typically rely on incentivized experiments involving time-dated monetary rewards in order to elicit respondent's deep preference parameters (see Frederick et al., 2002; Cohen et al., 2016; Imai et al., 2019 for reviews of the literature). Unfortunately, such experiments come with several threats to internal validity that have been well documented over the years: In addition to concerns of trust in payment reliability and the problem of differential transaction costs across payment dates (cf. Andersen et al., 2008; Andreoni and Sprenger 2012a; 2012b) subjects' experimental choices will only reveal their individual discount factors when they are either extremely liquidity (credit) constrained or bracket choices narrowly (Rabin and Weizsäcker, 2009), i.e., not considering extra-experimental borrowing and saving opportunities. Violations of the former assumption are common in developed economies where liquidity is not a binding constraint for most individuals, thus the internal validity of the experiment relies on the assumption that individuals bracket their choices narrowly.

Recent literature has shown, however, that the assumption of narrow bracketing may be violated in certain instances and that time-preference elicitation using time-dated monetary rewards may suffer from the confounding factor of respondents engaging in intertemporal arbitrage (see Augenblick et al., 2015; Lührmann et al., 2018). The main argument behind intertemporal arbitrage is the following (cf. Augenblick et al., 2015, p.1068): When respondents do not bracket their choices narrowly, they may consider extra-experimental market rates for credit and savings. A subject who has access to credit at a lower cost than the gross interest rate within the experiment would be better off delaying the payment to a later date and financing

immediate consumption through the external credit market. Similarly, when a subject has access to a savings-vehicle that yields higher returns than the gross interest rate offered within the experiment, taking the sooner payment and utilizing the extra experimental savings opportunities will be optimal. Both of these budget constraints dominate the budget constraint offered within the experiment. When respondents engage in this type of intertemporal arbitrage, the elicited parameters will be uninformative of individual preferences but only reflect external credit and savings-market rates.

Such an argument implies a certain degree of financial sophistication among the experimental subjects: Subjects would have to be aware of their individual borrowing and saving opportunities and exhibit a good understanding of compound interest and inflation, i.e., possessing a certain level of financial literacy (Lusardi and Mitchell, 2014).

In order to better understand which type of experimental subjects engage in intertemporal arbitrage, we study the role of financial literacy for inter-temporal decision-making using an adapted version of the *Convex Time Budget Protocol* (CTB) (Andreoni and Sprenger, 2012a) in an incentivized experiment with time-dated monetary rewards. Our results reveal substantial heterogeneity in allocation behaviors and estimated preference parameters: (i) Respondents with higher levels of financial literacy are more likely to delay experimental payments to a later date, i.e., to make more patient inter-temporal choices within the CTB task, (ii) respondents are more likely to select corner-choices, i.e., to allocate the entire budget to a single payment date, (iii) are more likely to exhibit a choice pattern where the entire budget is allocated to the earlier payment date at low interest and the entire budget is shifted to the later payment date as interest rates increase, and (iv) respondents' individual discount factors and annual discount rates are more in line with extra-experimental credit-market rates.

At the same time, we show that financial literacy is uncorrelated with choice consistency: At the individual-level, financial literacy does neither predict conformity to the law of demand nor are financial literacy scores correlated to estimated Fechner or Trembling-hand error parameters. Collectively, these results suggest that financially literate respondents are less likely to bracket the experimental choices narrowly, instead engaging in inter-temporal arbitrage. Our findings are contributions to two recent literatures:

First, recent evidence from field experiments show that intertemporal choices in the monetary domain may be malleable during childhood and adolescence: Alan and Ertac (2018) show that primary school children in turkey make more patient choices in both CTB and MPL tasks after being exposed to a financial education treatment. The treatment effects persist up to three years after the intervention. Similarly, Bover et al. (2018) show that being assigned to

financial education treatment in secondary school in Spain is associated with delaying payment to a later date in CTB tasks and self-reported saving behavior. Recently, Frisancho (2019) reports positive treatment effects on self-control from a large-scale financial education program for youth in Peru while the program appears to not affect the probability of having hyperbolic preferences.

Finally, Lührmann et al. (2018) study a financial education program for adolescents in Germany. While they also document positive treatment effects on financial knowledge and more patient inter-temporal choices, they also find allocation patterns consistent with decreased narrow bracketing, suggesting that the results do not necessarily reflect a change in deep parameters but rather differential behavior within the experimental elicitation task. Consistent with this finding they also do not find any treatment effects on extra-experimental savings. Thus, the mechanism behind the effects of financial education programs on intertemporal choices are not yet fully understood. Whether financial education interventions affect deep parameters or merely lead to differential intra-experimental behaviors is an open question. As financial education programs basically aim at improving financial knowledge (Hastings et al., 2013), one may hypothesize that increased financial knowledge may enable individuals to consider extra-experimental market rates, thus allowing the experimental subjects to engage in inter-temporal arbitrage. Our results are consistent with this interpretation and suggest, indeed, that financially literate respondents show very different allocation behaviors from those with lower levels of financial literacy.

Second, we contribute to the methodical discourse on the use of time-dated monetary payments in intertemporal preference elicitation tasks. Many recent studies have found that the canonical finding of dynamically time-inconsistent preferences appears to be observationally eliminated in the aggregate when the potential confounds such as lack of trust (introducing risk and uncertainty) and differential transaction costs are addressed within the experimental design (Andreoni and Sprenger, 2012a; Giné et al., 2018).

The paper by Augenblick et al. (2015) has raised skepticism regarding the use of time-dated monetary rewards for time-preference elicitation, in general. Specifically, they directly compare estimated preference parameters using monetary and real-effort tasks and find no evidence of time-inconsistent preferences when using monetary rewards in the elicitation, but the standard finding of present-bias when eliciting choices over consumption (measured in real effort tasks). A potential mechanism behind this finding may be the that intertemporal arbitrage in choices over consumption is harder to realize relative to choices over monetary-rewards, i.e., money being more fungible and easier to perfectly substitute relative to the substitution of effort

with extra-experimental behaviors (cf. Augenblick et al., 2015, p. 1112). A central implication of their study is to question the validity of eliciting intertemporal preferences in the monetary domain. Instead, moving to the domain of consumption appears to be a more reliable way of inferring discounting in a framework of time-inconsistent preferences.

This result is also in line with the results from a recent meta-analysis of 220 present bias parameters (β) reported in 31 studies which show that studies involving time-dated monetary rewards report estimates of β much closer to 1, i.e., consistent with standard exponential discounted utility models, while studies eliciting intertemporal choices over consumption (effort) report estimates of β close to 0.9, on average, indicating dynamically time-inconsistent preferences in this set of studies (Imai et al. 2019). Recently, and as a response to Augenblick et al. (2015), Andreoni et al. (2018) study the prevalence of arbitrage in a CTB-experiment in the monetary domain by experimentally inducing arbitrage through forcing the respondents to consider extra-experimental market rates in their decisions. They conclude they find no evidence of intertemporal arbitrage in this experiment with monetary rewards, instead suggesting that the experimental subjects bracket their choices narrowly even when arbitrage was made easy.[1]

While there may be no evidence of arbitrage on aggregate levels in many monetary CTB-applications, our results may be viewed as complementary and cautionary evidence that specific groups of respondents, i.e., the financially most sophisticated individuals, may still be engaging in intertemporal arbitrage when confronted with choices over time-dated monetary rewards. If researchers are interested in the predictive validity of preference parameters for a wide range of subjects (rather than just aggregate patterns), caution in using time-dated monetary rewards may still be warranted.

This paper is structured into three further sections: Section 2 describes the experimental design, including descriptive statistics of our sample (2.1), procedures of the experimental elicitation task (2.2), the properties of the empirical methods employed to estimate the preference parameters (2.3), the measurement of financial literacy (2.4) and the empirical strategy employed (2.5). Section 3 presents results in two steps: First, we discuss allocation behaviors within the CTB task (3.1, 3.2), and then move to a discussion of elicited preference parameters (3.3, 3.4). Section 4 concludes.

2 Methods and Experimental Design

[1] This evidence is also in line with an early study (using multiple price lists), where the treatment effect of providing extra-experimental information on arbitrage was small (see Coller and Williams, 1999).

2.1 Sample

Our sample consists of 204 undergraduate students enrolled at the University of Koblenz-Landau in the South-West of Germany. They were recruited from four different introductory (weekly) lectures including environmental science, psychology, educational science and social sciences. Students were told that they could participate in an experiment about monetary decisions over time. The average *age* in our sample is 22.2 years and 66.7 percent are *female* (Table 1). 15.2 percent of all participants didn't speak German in their childhood as their primary language (*non-native*) and 13.2 percent grew up in a household with less than 25 *books* available. The subjects report to have a mean monthly disposable *income* of 486.6 Euros. 23 percent received prior mandatory economic education in school (*Econschool*).

Table 1: Sample characteristics

Variable	N	Mean	Std. Dev.	Min	Max
Female	201	0.667		0	1
Age	203	22.192	2.951	19	45
Primary language (non-German)	204	0.152		0	1
Cognitive reflection	200	1.365	1.117	0	3
Financial literacy	204	0.030	1.189	-4.670	3.390
≤ 25 books at home	204	0.132		0	1
Disposable income (€)	197	486.631	287.805	0	1400
Econschool	204	0.230		0	1

Note: This table reports individual sample characteristics. The variable *female* takes the value 1 if the participant is female, else 0. *Primary language* = 1 is defined as having spoken German as the primary language at home during childhood. *Cognitive reflection* is measured by the CRT and *financial literacy* is an IRT-score based on the responses to 14 financial literacy items (see section 2.4). ≤ 25 *books at home* is a dummy variable indicating less than 25 books at home during childhood. *Disposable income* is a continuous measure of monthly disposable income in Euro (€). *Econschool* is a dummy variable indicating whether the respondent had exposure to mandatory economic education in school. Due to missing values sample sizes vary across demographic variables.

We split the laboratory session in two parts, the time budgeting task (in paper and pencil) and an online questionnaire which includes questions about socio-demographics, savings and consumption habits, a financial literacy performance test (see section 2.4 and Appendix A), and the *Cognitive Reflection Test* (CRT) (Frederick, 2005). To avoid order effects, we randomized the order of both parts and the blocks of questions within the online questionnaire. Instructions were given in-person and to make sure that they were fully understood, we walked students through an example (see details in Appendix B). In the following, we describe the elicitation method, procedures for establishing payment reliability and the parameter estimation process.

2.2 Elicitation method and payment reliability

In order to elicit time preference parameters, we implemented an incentivized decision experiment by means of the *Convex Time Budgeting Task* (CTB) (Andreoni and Sprenger, 2012a). The CTB tackles the problem of confounding curvature by convexifying the choice environment. Instead of facing a discrete budget constraint, individuals maximize their intertemporal utility, e.g., $U(c_t, c_{t+k})$, subject to a convex budget set, $(1+r)c_t + c_{t+k} = m$, allowing them to choose interior choices. While subjects in Andreoni and Sprenger (2012) choose c_t and c_{t+k} along a continuous budget set, the questionnaire was simplified to four interior choices in a follow-up study (Andreoni et al., 2013a) and even further simplified to two interior choices in a recent study with 8th grade school students in Germany (Lührmann et al., 2018). This study also uses a simplified version of the CTB task. Because we are implementing the task with a sample of university-students, we adapt the version proposed by Lührmann et al. (2018) but raise the stakes and extend the choice-set to three interior choices while maintaining the exact same delays. Figure 1 shows the first budgeting sheet (translated from German) with start date $t = 0$ and delay $k = 21$ days with six different budget constraints, i.e., intra-experimental interest rates. The second sheet doubles the delay of later payments to $k = 42$ days while the third sheet shifts the front-end delay, i.e., the early payment to $t = 21$ days and the later payment remains at $t = 42\ days$ (see Appendix B). Within each budget constraint, participants can either allocate 100 %, 75%, 50%, 25% or 0 % of the budget to the sooner payment date.

Sensitivity to the varying interest rates allows for deriving the curvature parameter, varying the later payment dates allows for the identification of long-run discount rates, and varying the front-end delay accounts for the occurrence of present bias. At the end of the experiment, one (out of 18) budget constraints was randomly chosen for actual payment at the dates chosen by the students.

Figure 1: Budgeting sheet for $t = 0$ and $k = 21$ (translated from German)

Today and in 3 weeks

April							May							June						
Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su	Mo	Tu	We	Th	Fr	Sa	Su
1	2	3	4	5	6	7			1	2	3	4	5						1	2
8	9	10	11	12	13	14	6	7	8	9	10	11	12	3	4	5	6	7	8	9
15	16	17	18	19	20	21	13	14	15	16	17	18	19	10	11	12	13	14	15	16
22	23	24	25	26	27	28	20	21	22	23	24	25	26	17	18	19	20	21	22	23
29	30						27	28	29	30	31			24	25	26	27	28	29	30

For each decision below (A.1 – A.6), decide which amounts you would like for sure today AND in 3 weeks. Remember to choose only one box per decision!

A.1	payment today	€ 10.00	€ 7.50	€ 5.00	€ 2.50	€ 0.00
	and payment in 3 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐
A.2	payment today	€ 9.00	€ 6.75	€ 4.50	€ 2.25	€ 0.00
	and payment in 3 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐
A.3	payment today	€ 8.00	€ 6.00	€ 4.00	€ 2.00	€ 0.00
	and payment in 3 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐
A.4	payment today	€ 7.00	€ 5.25	€ 3.50	€ 1.75	€ 0.00
	and payment in 3 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐
A.5	payment today	€ 6.00	€ 4.50	€ 3.00	€ 1.50	€ 0.00
	and payment in 3 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐
A.6	payment today	€ 5.00	€ 3.75	€ 2.50	€ 1.25	€ 0.00
	and payment in 3 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐

We implement several measures to equalize transaction costs and build trust and confidence across time periods: First, with regard to the invitation within the aforementioned lectures, students are only allowed to participate in the experiment if they can assure their attendance in the next lectures within three and in six weeks. The delayed payments are scheduled to take place at the entrance of the lecture room three and six weeks later. Next, each participant is given a payment pass with a university seal, including the signature of the

experimenter and the exact information on when and how much money they are entitled to receive at the two payment dates (following the procedure in Lührmann et al., 2018). Finally, in order to account for residual convenience arising from allocating the complete budget to one payment date, participants receive an additional participation fee of 5 Euro which is split in two payments: 2.50 Euro sooner and 2.50 Euro later regardless of the participants' choices (see also in Andreoni et al., 2013b; Lührmann et al., 2018)

2.3 Parameter estimation

The theoretical framework assumes a stationary, time-separable and quasi-hyperbolic utility function (Laibson, 1997) with experimental earnings c_t and c_{t+k}, formally expressed as

$$U(c_t, c_{t+k}) = \begin{cases} (c_t - \omega_t)^\alpha + \beta\, \delta^k (c_{t+k} - \omega_{t+k})^\alpha \; if\; t = 0 \\ (c_t - \omega_t)^\alpha + \delta^k (c_{t+k} - \omega_{t+k})^\alpha \quad if\; t = 1 \end{cases} \quad (1),$$

where δ^k denotes the (one period) long-run discount factor, and α, the risk coefficient under the assumption of constant relative risk aversion (CRRA). The additional present bias parameter β shrinks utility from future consumption when payments are immediate ($t = 0$). Therefore, present bias occurs if $\beta < 1$, future bias occurs when $\beta > 1$, whereas $\beta = 1$ represents standard exponential discounted utility (Samuelson, 1937). Parameters ω_t and ω_{t+k} represent background consumption terms as used in Anderson et al. (2008) and Andreoni and Sprenger (2012a). These parameters can either be set by the negative of students self-reported daily consumption such that $\omega_t + \omega_{t+k} = -B$ or estimated from the data via non-linear least squares. With regard to parameter estimation, individuals maximize equation (1) subject to the convex budget constraint $(1 + r)c_t + c_{t+k} = m,$ which yields (if $t = 0$) the intertemporal Euler equation

$$\frac{c_t - \omega_t}{c_{t+k} - \omega_{t+k}} = (\beta \delta^k (1 + r))^{\frac{1}{\alpha - 1}} \quad (2).$$

Variation in the price ratio $(1 + r)$ allows the estimation of the curvature parameter α, while variation in the length of delay k allows the estimation of the long-run discount factors δ. Finally, by varying the frond-end delay t, intertemporal preference reversals are considered, i.e., present bias. Andreoni and Sprenger (2012a) propose two parameter estimation strategies: The first approach estimates the parameter of the optimal demand for sooner consumption. This is obtained from equation (2) by non-linear least squares. The main benefit of this method is that one can estimate ω_t and ω_{t+k} directly. However, it does not account for the censored data structure with corner solutions (i.e., allocating the entire budget to a single payment-date), which is why a two-limit tobit regression is also proposed (see details in Appendix C). In

essence, by taking the logs of the tangency condition in (2) the data becomes linear and by adding an additive error term to the equation, one can estimate β, α und δ via nonlinear combinations of the estimated coefficients.

Additionally, we ask the students how much money they spend in a typical week. Thus, we are also able to provide two-limit Tobit results with different background consumption specifications in Section 4 and in Appendix D.

2.4 Measuring financial literacy

We implement a comprehensive set of items from a psychometrically validated financial knowledge scale (Knoll and Houts, 2012) in order to arrive at precise estimates of financial literacy levels. This scale (which includes all of the canonical financial literacy items proposed by Lusardi and Mitchell (Lusardi and Mitchell, 2014)) represents a collection of items with adequate psychometric properties and commonly used in large-scale household surveys. While the original scale proposed by Knoll and Houts (2012) consists of 20 items, we translated, adapted and re-validated the items for our purposes. The final measurement scale consists of 14 test items (see Table A1 in Appendix A) and we estimate individual financial literacy levels within an Item Response Theory (IRT) framework (see Appendix A for a detailed description of the measurement model). Additionally, we implement the Cognitive Reflection Test (CRT) (Frederick, 2005) in order to control for cognitive abilities. Details and descriptive statistics for both measures are reported in Appendix A.

2.5 Regression models

In order to study the relationship between financial literacy and intertemporal decisions, we regress intertemporal choice outcomes (y) (i.e., allocation to sooner payment dates, corner choices, and estimated preference parameters) on financial literacy scores ($fin\ lit$), a vector (V) of experimentally varied features within the convex time budget ($(1+r), (k), (t)$) and a set of control variables included in X (cognitive reflection, gender, age, the log of monthly income, number of books at home, and the primary language).

$$y = \alpha + \beta_1 fin\ lit + \beta_2 V + \beta_3 X + \varepsilon \quad (3)$$

In addition to OLS and probit models, we address potential endogeneity of financial literacy arising from reverse causation and measurement error. As a field study by Meier and Sprenger (2013) suggests, patient individuals might be more inclined to acquire financial education, and financial literacy scores may be subject to measurement error (Lusardi and

Mitchell, 2008; Lusardi et al., 2010). Also, Behrman et al. (2012) argue that measured financial literacy might be a result of unobserved factors such as individual's patience. We follow a recent study by Deufelhard et al. (2019) and provide instrumental variable (IV) regression estimates relying on an (plausibly) exogenous instrument as well as instruments that are constructed within the model (Lewbel, 2012). The approach by Lewbel (2012) does not rely on the standard assumptions of instrumental variable regressions with external instruments (i.e., the exclusion restrictions) but leverages the heteroskedasticity of the first stage to generate instruments from within the model using $(Z - \bar{Z})\hat{\varepsilon}$, where Z denotes a subset of variables included in equation (3), $\bar{Z}$ its mean and $\hat{\varepsilon}$ estimated residuals in a first stage regression. We use the generated instruments in combination with the (weak) exogenous instrument (prior mandatory economic education in school) and probe identifying assumptions (heteroskedasticity of errors from the first stage regression of the endogenous regressor on Z, and a test of overidentification) below.

2.6 Hypotheses

Our main hypothesis is that financial literacy may be associated with decreased narrow bracketing in the experimental time budgeting task. Thus, financial literacy may enable respondents to consider extra-experimental market rates for credit and savings in their intra-experimental decisions (i.e., to engage in intertemporal arbitrage). As it is impossible to directly observe a decrease in narrow bracketing, we spell out behavioral patterns consistent with such an interpretation (cf. Lührmann et al. 2018).

First, financial literacy should be negatively related to time-inconsistency (i.e., present bias), because respondents with lower levels of financial literacy may consider intertemporal choices over monetary rewards equivalent to choices over consumption, whereas respondents with higher levels of financial literacy may realize the fungibility of these monetary payments. As an implication, financial literacy scores should be negatively correlated with estimated present bias parameters ($\hat{\beta}$). An implication that is specific to our particular context is, that financial literacy should be positively correlated with patience, on average, (i.e., negatively correlated with the tendency to choose the earlier payment date), because all of the offered interest gross interest rates at $(1 + r) > 1$ should dominate the current extra-experimental rescheduling opportunities. Thus, we expect financial literacy to be positively correlated to estimated discount factors ($\hat{\delta}$).

Second, as financial literacy levels increase, respondents should be more likely to allocate the entire budget to a single payment date (i.e., to select corner choices). The reason

why one would expect such a choice pattern, is that these patterns are informative of the degree of consumption smoothing exhibited within the experimental elicitation task. When individuals do not bracket their choices narrowly, they should be less likely to treat time-dated monetary payments as consumption, and thus should be less likely to choose interior allocations offered at the within-lab gross interest-rate. Moreover, respondents with higher levels of financial literacy should be more likely to allocate the entire budget to the earlier payment date at low-interest rates and allocate the entire budget to the later payment date as interest rates increase. Thus, we expect a choice-pattern resembling perfectly aligned corner choices: A participant exhibits perfectly aligned corner choices if the entire budget is allocated to the sooner payment date in case of $(1 + r) = 1$, and when the entire budget is allocated to the later payment date in case of $(1 + r) > 1$.

Third, if financial literacy is associated with less narrow bracketing, the estimated preference parameters for financially literate respondents should be less predictive of extra-experimental field behaviors. We probe this hypothesis by regressing types of commonly studied field behaviors on estimated individual discount factors, financial literacy scores, and the interaction between the two variables.

While all of these patterns consistent with our arbitrage hypothesis, they are not definitive evidence thereof. Another possibility would be that financial literacy is associated with higher choice consistency, such that individuals with lower levels of financial literacy exhibit higher errors in decision-making. This would indicate that these respondents do not allocate their budget to corner choices, because of errors in decision-making. We probe this alternative interpretation by examining correlations between financial literacy scores and a) conformity of choices to the law of demand at the individual level, as well as, b) to estimated Fechner error parameters for each individual.

3 Results

In this section, we first show descriptive results from the Convex Time Budgeting Task (CTB). Thereby, we compare intertemporal allocation behaviors for respondents with different levels of financial literacy.

3.1 Descriptive results

Table 2 shows summary statistics for allocation patterns. With regard to intertemporal allocation, we distinguish the tendencies to allocate the budget to sooner payments and also the prevalence of corner choices, i.e., allocating the entire budget to a single payment date. In addition, we examine determinants of perfectly aligned corner choices which are defined by the

following choice pattern: A participant exhibits perfectly aligned corner choices if the entire budget is allocated to the sooner payment date in case of $(1 + r) = 1$, and when the entire budget is allocated to the later payment date in case of $(1 + r) > 1$. Finally, we analyze choice consistency, i.e., the degree of conformity to the law of demand.

Table 2: Descriptive statistics of the CTB allocation task

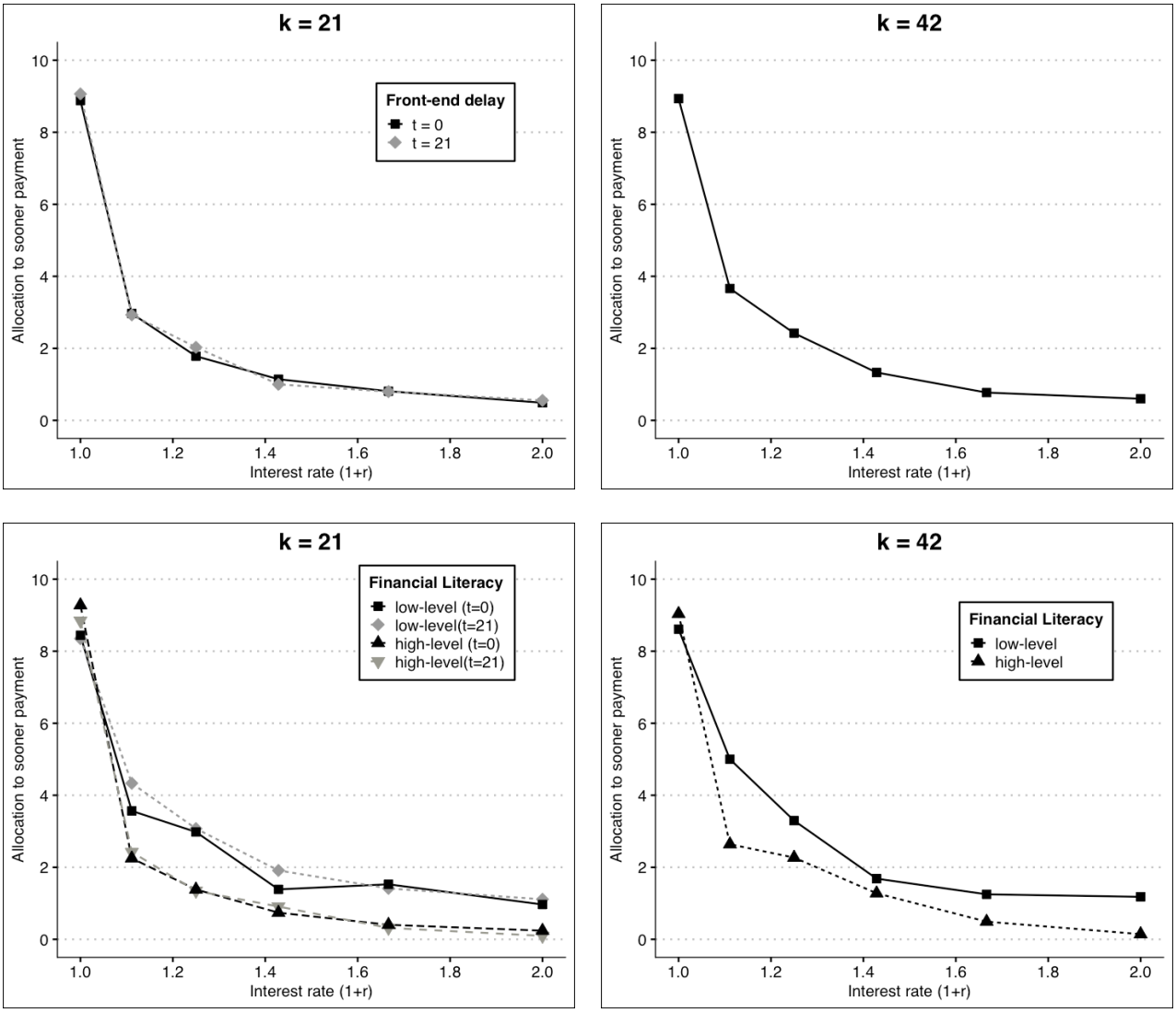
	N	Mean	SD	Min	Max
Allocation to sooner payment	3,658	0.320	0.424	0	1
Corner choice	3,658	0.825		0	1
Perfectly aligned corner choice	204	0.554		0	1
Choice consistency	3,658	0.945		0	1
Payment today	3,671	0.668		0	1
$k = 42$	3,671	0.280		0	1
$(1 + r)$	3,671	1.409	0.341	1	2

Note: This table shows mean statistics of intertemporal choices in the budgeting protocol. *Payment today* takes value 1 if the sooner payment is immediate, else 0. $k = 42$ takes value 1 of the delay for the later payment is 42 days. $(1 + r)$ represents gross interest rates for six budget sets: 1.00, 1.11, 1.25, 1.42, 1.66 and 2.00.

The mean allocation to sooner payment dates is 0.32, i.e., on average, in 32 percent of the cases the entire budget is allocated to the respective sooner payment-date, and in 82.5 percent of all choices the entire budget is allocated to a respective single payment-date (i.e., a corner choice) which is in line with previous studies in this age group (Andreoni et al., 2015; Andreoni and Sprenger, 2012a). 55.4 percent of all individuals exhibit corner choices that are perfectly aligned to changes in interest rates. Regarding violations of the law of demand, we find that 94.5 percent of all choices are consistent indicating that most participants understood the inter-temporal trade-offs in the task.

In Figure 2 we plot mean allocations to the sooner point in time against all gross interest rates $(1 + r)$ administered across experimentally manipulated delays. The first column represents allocations for a delay of $k = 21\ days$ and the second column for $k = 42\ days$. Furthermore, within the first column, we differentiate between the two front-end delays ($t = 0\ and\ t = 21\ days$). Additionally, we present allocations with respect to different financial literacy levels in the lower panels of the figure.

Figure 2: Allocations to sooner payments by financial literacy levels



Overall, allocations to the respective sooner payment dates decrease monotonically as interest rates increase among both subgroups, which corresponds to the law of demand. At the aggregate-level, only respondents with low levels of financial literacy show inconsistent choices when gross interest rates exceed 1.43 for $k = 21$ and $t = 0$. Furthermore, allocations to the sooner payment increase when the delay length is extended to $k = 42$.

The first panel of Figure 2 indicates no sensitivity to changes in the front-end delay on aggregate levels. The first graph with delay $k = 21$ reveals almost no differences when changing the front-end delay to $t = 21$ in the allocation indicating an absence of time-inconsistent choices on aggregate levels. With regard to financial literacy, we found larger degrees of patience in high-ability respondents defined as being in the highest quartile, i.e., IRT-score > 0.77, for both delays, $k = 21$ and $k = 42$, as interest for sooner consumption

increases (see Figure 2). Changes in the front-end delay reveal no different allocation behavior within the group with high financial literacy levels whereas low ability respondents defined as being in the lowest quartile, i.e., IRT score < -0.78, show slight deviations.

3.2 Regression results

In the following regression models, we study the determinants of allocations to sooner payment dates (as a measure of impatience) and of tendencies to allocate the whole budget to one single payment date (corner choices). Moreover, we investigate determinants of perfectly aligned corner choices and choice consistency (see Table 3).

Overall, we find that the probability to be financially patient within the task increases as financial literacy levels increase (column 1). This result holds after controlling for several individual characteristics including gender, age, income and cognitive reflection. In column 2, we extend the analysis to an estimation relying on constructed instruments for identification. We use the generated instruments in combination with the (weak) exogenous instrument. In order to apply the Lewbel (2012) approach, the error term in the first stage, i.e., a regression of regressors on the potentially endogenous variable (financial literacy) needs to be heteroscedastic. We therefore run Breusch-Pagan tests for heteroscedasticity and are able to reject homoscedasticity at the 1-percent-level. As we obtain more than one instrument from this combined method, we are able to test for overidentification. Hansen-J-statistics show that the models are not overidentified. We find that relying on the IV-regression doesn't alter our results substantially (column 2). We still see a significant negative effect of financial literacy on impatience. With regard to changes in the experimental protocol, we find that individuals become more impatient by extending the delay to 42 days while, as suggested by the descriptive results in section 3.1. Changing the front-end delay, however, shows no effect. Furthermore, as price ratios $(1 + r)$ for sooner payments increase, individuals become less impatient which is in line with the law of demand. Regarding socio-demographic characteristics, female individuals, students with high disposable income and higher cognitive reflection scores show more patient behavior which corresponds with existing regression analyses in experimental time preference research (Harrison et al., 2002; Tanaka et al., 2010).

Table 3: Predictors of intertemporal choice patterns

	Allocation to sooner payment dates		Corner choice		Perfectly aligned corner choice		Choice consistency	
	(1) OLS	(2) IV	(3) Probit	(4) IV	(5) Probit	(6) IV	(7) Probit	(8) IV
Financial literacy	-0.048***	-0.066**	0.032*	0.047	0.096***	0.144***	0.011	0.024
	(0.014)	(0.032)	(0.018)	(0.053)	(0.031)	(0.055)	(0.008)	(0.018)
Cognitive reflection	-0.069***	-0.066***	0.033*	0.032	0.086***	0.082**	0.024***	0.021***
	(0.013)	(0.014)	(0.018)	(0.020)	(0.031)	(0.034)	(0.009)	(0.008)
Front-end delay = today	0.002	0.002	-0.027**	-0.027**			-0.019**	-0.020**
	(0.012)	(0.012)	(0.014)	(0.014)			(0.008)	(0.008)
k=42	0.030***	0.030***	0.002	0.001			0.010	0.011
	(0.009)	(0.009)	(0.012)	(0.012)			(0.008)	(0.008)
(1+r)	-0.593***	-0.593***	0.049**	0.045**			-0.025**	-0.026**
	(0.021)	(0.021)	(0.020)	(0.019)			(0.010)	(0.011)
Female	-0.090***	-0.105**	-0.004	0.015	0.081	0.123	-0.007	0.006
	(0.034)	(0.044)	(0.047)	(0.065)	(0.081)	(0.090)	(0.020)	(0.022)
Age	-0.003	-0.003	0.013	0.010**	0.010	0.009	0.005	0.003*
	(0.006)	(0.006)	(0.008)	(0.005)	(0.013)	(0.013)	(0.003)	(0.002)
Native language	0.006	-0.001	-0.035	-0.035	-0.033	-0.007	0.006	0.013
	(0.041)	(0.041)	(0.051)	(0.060)	(0.094)	(0.097)	(0.020)	(0.023)
≤ 25 books at home	-0.031	-0.033	-0.028	-0.030	-0.111	-0.111	0.005	0.007
	(0.036)	(0.036)	(0.053)	(0.059)	(0.095)	(0.096)	(0.021)	(0.020)
ln(monthly income)	-0.037*	-0.031	0.029	0.027	0.007	-0.006	0.008	0.005
	(0.020)	(0.022)	(0.025)	(0.033)	(0.049)	(0.049)	(0.013)	(0.015)
Constant	0.379***	0.392***		0.841***		0.483***		0.949***
	(0.029)	(0.036)		(0.054)		(0.077)		(0.019)
Observations	3,425	3,425	3,425	3,425	191	191	3,425	3,425
R-squared	0.290	0.288		0.049		0.123		0.023
Hansen J-stat.		4.852		6.354		4.677		11.73
Hansen J-stat. (p-val)		0.773		0.608		0.586		0.229

Note: Columns (1) and (2) show regression estimates for allocation to sooner payments. Column (1) shows OLS estimates with clustered standard errors. Column (2) shows estimates for regressions using a combination of generated and external instruments. Column (3) shows probit estimates (marginal effects) for corner choices (takes value 1 if 0 or 100 percent was allocated to one payment date). Column (4) shows instrumental variable estimation using combined instruments by means of a linear probability model (LPM). Columns (5) and (6) show regression and IV estimates for perfectly aligined (i.e., interest-sensitive) corner choices at the individual-level. This variable takes the value 1 if a participant allocates 100 percent of the budget to the sooner payment in case of zero interest (r=0) and allocates 100 percent of the budget. to the later payment date in case of r>0. Columns (7) and (8) show results for choice consistency at the individual level, which is measured as the number of Due to missing responses in demographic variables (see table 1) sample sizes are slightly reduced. Standard errors (clustered at the individual level in Columns 1 to 4) in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

In the next step we address allocations of the entire budget to a single payment date (corner choices) (columns 3-4). As interior choices are seen as a sign for consumption smoothing indicating higher degrees of narrow bracketing, it is hypothesized that individuals with higher levels of financial literacy are more inclined to select corner choices as a result of decreased narrow bracketing (Lührmann et al., 2018). Similar to the analysis of patience, individuals with higher financial literacy scores show less consumption smoothing and therefore appear to exhibit less narrow bracketing (see column 3). In the IV estimation (column 4), however, we see that the effect does not change substantially in magnitude but is estimated with a larger standard error. Although reverse causation is presumably less prevalent in this

specification, endogeneity concerns might also arise from measurement error which is why the effect of financial literacy scores in the probit specification (column 3) is possibly biased. With regard to the control variables, cognitive reflection levels are positively associated with the probability of selecting a corner choice and the results also indicate sensitivity to both changes in the front-end delay and the gross interest rate, as individuals smooth consumption when payments are immediate, and as interest rates for sooner payment dates increase. Also, we find that financial literacy scores are positively associated with perfectly aligned (i.e., interest-sensitive) corner choices, with results shown in columns 5 and 6. More specifically, a one unit increase in financial literacy leads to increase in the probability for perfect aligned corner choices by 14.4 percentage points.

Finally, we analyze the correlation of financial literacy scores to two measures of choice consistency to probe whether the observed differences in allocation behaviors may simply be the result of random noise (or the reduction thereof) at different levels of the financial literacy distribution. First, we test whether financially literate individuals exhibit less violations of the law of demand. Columns 7 and 8 reveal that levels of financial literacy do not affect consistent choices. At the same time, a one-unit increase in the test score on the CRT marginally increases the probability of allocating consistently by almost three percent indicating that cognitive reflective individuals display a slightly better understanding of the CTB task. While the two variables are correlated $(r = 0.26, p < 0.01)$, we interpret this finding as evidence of only financial literacy enabling respondents to engage in arbitrage irrespective of their cognitive ability. To summarize, financial literacy scores are correlated to behavioral patterns which are consistent with the arbitrage hypothesis. At the same time, financial literacy does not predict choice consistency, indicating that these effects are not the result of a reduction in random noise among financially literate respondents.

3.3 Aggregate parameters

In this section, we show estimated parameters on aggregate levels. Following the estimation process described in section 2.2., we present, utility parameter estimates with two econometric estimation strategies and different background consumption specifications (see Table 4, columns 1 to 5). Further, we probe the robustness of results to the consideration of stochastic errors in decision-making using an interval-censored tobit regression model with Fechner errors (von Gaudecker et al., 2011) (Table 4, column 6).

Table 4: Aggregate parameters

	(1) NLS	(2) NLS	(3) Tobit	(4) NLS	(5) Tobit	(6) Interval regression
$\hat{\alpha}$	0.9353	0.9291	0.9839	0.3578	0.8459	0.9761
	[0.0042]	[0.0048]	[0.0020]	[0.0159]	[0.0186]	[0.0029]
$\hat{\delta}$	0.9999	0.9969	0.9964	0.9962	0.9965	0.9981
	[0.0001]	[0.0002]	[0.0006]	[0.0005]	[0.0006]	[0.0005]
$\hat{\beta}$	0.9987	0.9966	0.9897	0.9938	0.9896	0.9842
	[0.0012]	[0.0050]	[0.0142]	[0.0100]	[0.0137]	[0.0120]
$\widehat{\omega}_t$	0.9399					
	[0.0972]					
$\widehat{\omega}_{t+k}$	-6.3422					
	[0.4329]					
$\hat{\tau}$						8.0394
						[0.7221]
$\widehat{\omega}_t = \widehat{\omega}_{t+k}$		0	-0.01	-9.02	- 9.02	
$\hat{\beta} = 1$ (p-val.)	0.288	0.534	0.450	0.533	0.450	0.187
N	3,658	3,658	3,658	3,658	3,658	3,658
Clusters	204	204	204	204	204	204

Note: This table shows aggregate utility parameters with respect to different estimation procedures. We provide estimates from non-linear least squares (NLS) and from two-limit tobit regressions across different background parameter specifications. In column (3), we set the background parameter to 0.01 instead of 0 in order to keep the log-ratio in equation (2) well-defined. Column (6) shows estimates from interval regression with Fechner errors $\hat{\tau}$. Clustered standard errors in brackets

The estimated present bias parameters β range from 0.9896 to 0.9942 and show no sensitivity to alternative background parameter specification or to censored regression models. χ^2- Tests reveal no significant difference across all models which is in line with most studies examining undergraduate students (Imai et al., 2019). Also, daily discount factor estimates δ reveal no significant difference across models (columns 1 to 6) indicating no impatience on aggregate levels. However, estimates for curvature parameters α show substantial sensitivity to changes in the econometric specification and background parameter restrictions. Setting ω_t and ω_{t+k} to the self-reported average daily consumption of -9.02, makes the curvature substantially pronounced, although its magnitude is reduced when we account for corner solution censoring (column 5). Therefore, results from curvature parameters suggest a substantial sensitivity to extra-experimental consumption while estimates of β and δ are insensitive to these changes.

3.4 Financial literacy and individual parameters

In this section, we investigate associations between financial literacy levels and individual time preference parameters. Table 5 shows regression results for utility parameters

estimated with non-linear least squares and the Stone-Geary consumption minimal level set to zero.

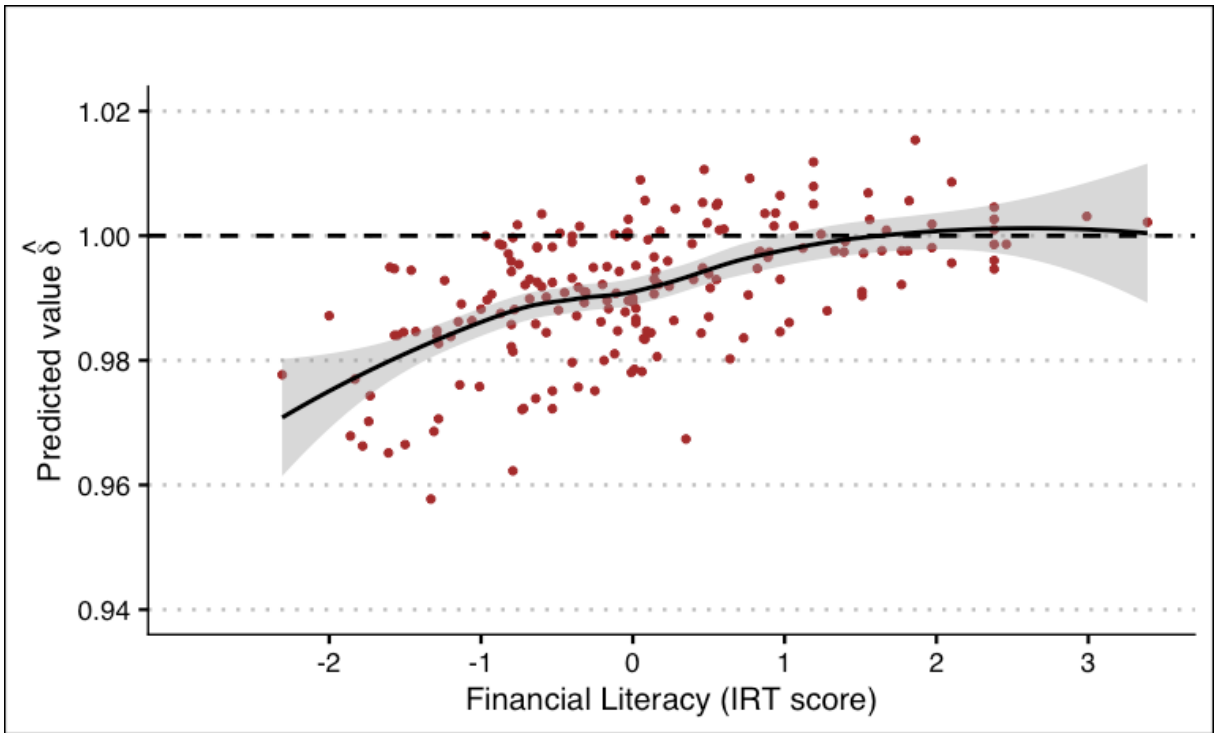
Table 5: Determinants of estimated utility parameters

	Discount factor $\hat{\delta}$		Present bias $\hat{\beta}$		CRRA $\hat{\alpha}$	
	(1) OLS	(2) IV	(3) OLS	(4) IV	(5) OLS	(6) IV
Financial Literacy	0.005*	0.011*	-0.032	-0.017	0.042	-0.070
	(0.003)	(0.006)	(0.036)	(0.059)	(0.031)	(0.078)
Cognitive Reflection	0.005**	0.004*	-0.064	-0.066	0.036*	0.053
	(0.002)	(0.002)	(0.045)	(0.054)	(0.019)	(0.033)
Female	0.013	0.018*	0.020	0.032	0.011	-0.079
	(0.008)	(0.010)	(0.041)	(0.085)	(0.027)	(0.079)
Age	0.000	0.000	0.006	0.006	0.008	0.009
	(0.001)	(0.001)	(0.005)	(0.005)	(0.006)	(0.007)
Native Language	-0.013	-0.011	-0.021	-0.015	0.021	-0.023
	(0.010)	(0.009)	(0.108)	(0.085)	(0.062)	(0.052)
≤ 25 books at home	-0.001	0.001	-0.004	-0.001	0.013	-0.011
	(0.010)	(0.010)	(0.071)	(0.062)	(0.041)	(0.041)
ln(monthly income)	0.003	0.001	-0.055	-0.060	0.024	0.060*
	(0.003)	(0.003)	(0.048)	(0.067)	(0.020)	(0.035)
Constant	0.985***	0.980***	1.053***	1.042***	0.898***	0.978***
	(0.007)	(0.008)	(0.072)	(0.047)	(0.042)	(0.047)
Observations	195	195	195	195	195	195
R-squared	0.119	0.077	0.028	0.028	0.080	0.081
Hansen J-stat.		1.773		1.677		2.054
Hansen J-stat. (p-val)		0.939		0.947		0.914

Note: This table reports OLS regression as well as regressions using a combination of generated and external instruments on estimated time preference parameters $\hat{\delta}$, $\hat{\beta}$ and CRRA parameter $\hat{\alpha}$. All regressions models contain individual characteristics as described in Table 1 (gender, age, native language, books at home as a child and natural logs of disposable income). Within the estimation process for $\hat{\delta}$, $\hat{\beta}$ and $\hat{\alpha}$, we set Stone-Geary consumption minima to 0. Robust standard errors in parenthesis. *** p<0.01, ** p<0.05, * p<0.1.

We provide regression results with different background consumption specifications in Appendix D. In order to ease interpretation of estimated intercepts, we mean-centered all non-categorial variables. The determinants of daily discount factors delta widely correspond with results from Table 3 in section 3.2.

Figure 3: Financial literacy scores and predicted values of individual discount factors ($\widehat{\delta}$)



Note: Predicted values based on the model presented in Table 5, Column 2 relying on a combination of generated and external instruments. The model contains individual characteristics as described in Table 1 (gender, age, native language, books at home as a child and natural logs of disposable income). Stone-Geary consumption minima are set to 0. The shaded area around the line plot indicates the 95% CI based on robust standard errors.

The estimated mean daily discount factor in (2) is 0.985 which, by applying $r = \left(1/\hat{\delta}\right)^{365} - 1$, yields high annual discount rate of 247.75. However, a one standard deviation increase in financial literacy scores increases daily discount factors by 0.011. At two standard deviations above the mean, daily discount factors converge to one, i.e., converging to annual discount rates that are more in line with extra-experimental credit market rates (see Figure 3). Together with the evidence on corner choices, these results suggest that financially literate individuals may behave at odds with general assumptions about narrow bracketing. Turning to an analysis of the present bias, we find no evidence for a systematic relationship between financial literacy scores and the estimated parameter. Finally, the coefficients from the OLS regression on the estimated CRRA parameter, suggests that the curvature decreases with financial literacy which is in line with the observed effect of financial literacy on the probability of corner choices. However, the effect is insignificant and appears not robust to changing the approach to the IV-regression.

As an additional robustness exercise, we investigate individual errors in decision-making and their correlations with financial literacy scores. Using Fechner errors and Trembling-hand errors, our results in Table 6 display that an increase in financial literacy levels does not significantly alter the likelihood of making stochastic errors.

Table 6: Determinants of errors in decision-making

	Fechner error ($\hat{\tau}$)		Trembling-hand error ($\hat{\gamma}$)	
	(1)	(2)	(3)	(4)
	OLS	IV	OLS	IV
Financial literacy	-0.153	-0.734	-0.003	-0.014
	(0.362)	(0.683)	(0.007)	(0.012)
Cognitive reflection	-0.368	-0.266	-0.006	-0.004
	(0.468)	(0.461)	(0.009)	(0.008)
Female	-0.267	-0.758	-0.006	-0.016
	(1.068)	(1.146)	(0.019)	(0.021)
Age	-0.094	-0.101*	-0.002	-0.002*
	(0.059)	(0.059)	(0.001)	(0.001)
Native language	-0.321	-0.483	0.000	-0.003
	(1.221)	(1.183)	(0.022)	(0.021)
≤ 25 books at home	-1.296*	-1.443**	-0.019	-0.022*
	(0.661)	(0.720)	(0.012)	(0.013)
ln(monthly income)	0.804*	0.952*	0.015*	0.017*
	(0.469)	(0.520)	(0.009)	(0.010)
Constant	2.842***	3.233***	0.032*	0.040**
	(0.919)	(1.028)	(0.017)	(0.019)
Observations	2,502	2,502	2,502	2,502
R-squared	0.025	0.013	0.021	0.008

This table shows regression estimates on different errors in decision-making using ordinary least squares (OLS) and instrumental variable estimation specified in chapter 2.3. Columns 1 and 2 show results for Fechner errors $\hat{\tau}$ as shown on aggregate levels in table 4 and columns 3 and 4 show results for Trembling-hand errors $\hat{\gamma}$ (Harless and Camerer 1994) assuming a probability that participants make a random choice among five allocation options. Cluster-robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

To summarize: Our results indicate that financial literacy scores are predictive of allocation behaviors (corner choices and perfectly aligned corner choices) and discount factors. These patterns may be interpreted as evidence of violations of the assumption of narrow bracketing among financially literate individuals. We provide complementary evidence in Appendix D that correlations between utility parameters and intertemporal field behaviors decrease with higher levels of financial literacy indicating that estimated preference parameters become less informative for financial literate individuals.

4 Discussion

This paper has combined a financial knowledge test with an incentivized decision experiment using time-dated monetary rewards (CTB, Andreoni and Sprenger 2012a) to study the role of financial literacy for inter-temporal choice. In line with previous research using time-dated monetary rewards within the CTB-protocol, we find no evidence of present bias on

aggregate levels regardless of different background consumption specifications and regression methods. This reflects a discounting pattern, mostly found in the monetary domain when subjects have access to credit markets and physical transaction costs of future payments are equated. On individual levels, however, we document that financial literacy may play an important role in respondents' allocation behaviors within the experiment: While respondents with higher levels of financial literacy are more likely to delay payments to a later date, i.e., exhibit more patience, they are also more likely to allocate the entire budget to a single payment date and to show the pattern of perfectly aligned corner choices. We interpret the latter behavior as evidence of intertemporal arbitrage. In line with this interpretation we show that financial literacy is positively related to individual discount factors. At the same time, financial literacy is uncorrelated to choice-consistency and errors in decision-making at the individual-level. Thus, results appear to be systematic and not merely the result of a reduction in random-noise among financially literate individuals.

Our results shed new light on recent suspicions among economists about violations of the assumption of narrow bracketing. Taken together, our results suggest that financial literacy has a meaningful impact on intertemporal allocations. Financially literate individuals are more likely to show rational discounting behavior and are less likely to consider experimental earnings as consumption. Our results have implications both for the interpretation of treatment effects of financial education programs studied in field experiments (e.g., Alan and Ertac 2018, Lührmann et a. 2018, Bover et al. 2018, Frisancho 2018) and the methodical debate on using time-dated monetary rewards in CTB applications (Augenblick et al. 2015, Andreoni et al. 2018): treatment effects of educational interventions on intertemporal choices (measured via incentivized decision experiments in the monetary domain) may be mediated by increased financial knowledge. Financial knowledge may allow experimental subjects to engage in intertemporal arbitrage. If this was the case, financial education treatment effects may not represent a change in deep time-preference parameters but a change in intra-experimental behavior made possible by an increased understanding of external market interest rates. With regard to the methodical debate on using time-dated monetary rewards in preference elicitation, our results show that it may be important to consider the heterogeneity in financial knowledge among experimental subjects. Highly sophisticated individuals may violate standard assumptions necessary for the identification of deep preference parameters when relying on observed experimental choices over money. If researchers are interested in the predictive validity of preference parameters for a wide range of subjects (rather than just aggregate patterns), caution in using time-dated monetary rewards may be warranted. While our empirical

strategy addresses the possibility of endogeneity in financial literacy through adequate measurement models and instrumental variables, an important extension of our research would be to experimentally manipulate financial literacy levels of respondents to study the effect of financial literacy on the allocation behaviors studied in this paper in a causal mediation analysis.

References

Alan, S., Ertac, S., 2018. Fostering patience in the classroom: Results from randomized educational intervention. J. Polit. Econ. 126, 1865–1911. https://doi.org/10.1086/699007

Andersen, S., Harrison, G.W., Lau, M.I., Rutström, E., 2008. Eliciting Risk and Time Preferences. Econometrica 76, 583–618. https://doi.org/10.1111/j.1468-0262.2008.00848.x

Andreoni, J., Gravert, C., Kuhn, M.A., Saccardo, S., Yang, Y., 2018. Arbitrage Or Narrow Bracketing? Experimental Tests of Money as a Primary Reward, NBER Working Paper. Cambridge, MA. https://doi.org/10.3386/w25232

Andreoni, J., Kuhn, M., Sprenger, C., 2013a. On Measuring Time Preferences. Cambridge, MA. https://doi.org/10.3386/w19392

Andreoni, J., Kuhn, M., Sprenger, C., 2013b. On Measuring Time Preferences. Natl. Bur. Econ. Res. https://doi.org/10.3386/w19392

Andreoni, J., Kuhn, M.A., Sprenger, C., 2015. Measuring time preferences: A comparison of experimental methods. J. Econ. Behav. Organ. 116, 451–464. https://doi.org/10.1016/j.jebo.2015.05.018

Andreoni, J., Sprenger, C., 2015. Risk Preferences Are Not Time Preferences: Reply. Am. Econ. Rev. 105, 2287–2293. https://doi.org/10.1257/aer.20150311

Andreoni, J., Sprenger, C., 2012a. Estimating Time Preferences from Convex Budgets. Am. Econ. Rev. 102, 3333–3356. https://doi.org/10.1257/aer.102.7.3333

Andreoni, J., Sprenger, C., 2012b. Risk preferences are not time preferences. Am. Econ. Rev. 102, 3357–3376. https://doi.org/10.1257/aer.102.7.3357

Augenblick, N., Niederle, M., Sprenger, C., 2015. Working over time: Dynamic inconsistency in real effort tasks. Q. J. Econ. 130, 1067–1115. https://doi.org/10.1093/qje/qjv020

Bover, O., Hospido, L., Villanueva, E., 2018. The Impact of High School Financial Education on Financial Knowledge and Choices: Evidence from a Randomized Trial in Spain. SSRN Electron. J. https://doi.org/10.2139/ssrn.3116054

Cohen, J.D., Ericson, K.M., Laibson, D., White, J.M., 2020. Measuring Time Preferences. J. Econ. Lit. 58, 299–347. https://doi.org/10.1257/jel.20191074

Coller, M., Williams, M.B., 1999. Eliciting individual discount rates. Exp. Econ. 2, 107–127. https://doi.org/10.1007/bf01673482

Deuflhard, F., Georgarakos, D., Inderst, R., 2019. Financial literacy and savings account returns. J. Eur. Econ. Assoc. 17, 131–164. https://doi.org/10.1093/jeea/jvy003

Frederick, S., 2005. Cognitive Reflection and Decision Making. J. Econ. Perspect. 19, 25–42. https://doi.org/10.1257/089533005775196732

Frederick, S., Loewenstein, G., O'Donoghue, T., 2002. Time discounting and time preference: A critical review. Time Decis. Econ. Psychol. Perspect. Intertemporal Choice 40, 13–86.

Frisancho, V., 2019. The impact of financial education for youth. Econ. Educ. Rev. https://doi.org/10.1016/j.econedurev.2019.101918

Giné, X., Goldberg, J., Silverman, D., Yang, D., 2018. Revising Commitments: Field Evidence on the Adjustment of Prior Choices. Econ. J. 128, 159–188. https://doi.org/10.1111/ecoj.12378

Golsteyn, B.H.H., Grönqvist, H., Lindahl, L., 2014. Adolescent Time Preferences Predict Lifetime Outcomes. Econ. J. 124, F739–F761. https://doi.org/10.1111/ecoj.12095

Harrison, G.W., Lau, M.I., Williams, M.B., Rutström, E., 2002. Estimating Individual Discount Rates in Denmark: A Field Experiment. Am. Econ. Rev. 92, 1606–1617. https://doi.org/10.1257/000282802762024674

Hastings, J.S., Madrian, B.C., Skimmyhorn, W.L., 2013. Financial Literacy, Financial Education, and

Economic Outcomes. Annu. Rev. Econom. 5, 347–373. https://doi.org/10.1146/annurev-economics-082312-125807
Imai, T., Rutter, T., Camerer, C.F., 2019. Meta-Analysis of Present-Bias Estimation using Convex Time Budgets, Forthcoming in Am. J., https://doi.org/10.1093/ej/ueaa115
Knoll, M.A.Z., Houts, C.R., 2012. The Financial Knowledge Scale: An Application of Item Response Theory to the Assessment of Financial Literacy. J. Consum. Aff. 46, 381–410. https://doi.org/10.1111/j.1745-6606.2012.01241.x
Laibson, D., 1997. Golden Eggs and Hyperbolic Discounting. Q. J. Econ. 112, 443–478. https://doi.org/10.1162/003355397555253
Lührmann, M., Serra-Garcia, M., Winter, J., 2018. The impact of financial education on adolescents' intertemporal choices. Am. Econ. J. Econ. Policy 10, 309–332. https://doi.org/10.1257/pol.20170012
Lusardi, A., Mitchell, O.S., 2014. The economic importance of financial literacy: Theory and evidence. J. Econ. Lit. 52, 5–44. https://doi.org/10.1257/jel.52.1.5
Meier, S., Sprenger, C., 2012. Time Discounting Predicts Creditworthiness. Psychol. Sci. 23, 56–58. https://doi.org/10.1177/0956797611425931
Meier, S., Sprenger, C., 2010. Present-biased Preferences and Credit Card Borrowing. Am. Econ. J. Appl. Econ. 2, 193–210. https://doi.org/10.1257/app.2.1.193
Rabin, M., Weizsäcker, G., 2009. Narrow bracketing and dominated choices. Am. Econ. Rev. 99, 1508–1543. https://doi.org/10.1257/aer.99.4.1508
Samuelson, P.A., 1937. A Note on Measurement of Utility. Rev. Econ. Stud. 4, 155. https://doi.org/10.2307/2967612
Shoda, Y., Mischel, W., Peake, P.K., 1990. Predicting adolescent cognitive and self-regulatory competencies from preschool delay of gratification: Identifying diagnostic conditions. Dev. Psychol. 26, 978–986.
Sutter, M., Kocher, M.G., Daniela, G.R., Trautmann, S.T., 2013. Impatience and uncertainty: Experimental decisions predict adolescents' field behavior. Am. Econ. Rev. 103, 510–531. https://doi.org/10.1257/aer.103.1.510
Tanaka, T., Camerer, C.F., Nguyen, Q., 2010. Risk and time preferences: Linking experimental and household survey data from Vietnam. Am. Econ. Rev. https://doi.org/10.1257/aer.100.1.557
von Gaudecker, H.M., Van Soest, A., Wengström, E., 2011. Heterogeneity in risky choice behavior in a broad population. Am. Econ. Rev. 101, 664–694. https://doi.org/10.1257/aer.101.2.664

Appendix

(online appendix not intended for print publication)

to accompany

"Financial Literacy and Intertemporal Arbitrage"

Appendix A: Measuring financial literacy and cognitive reflection

Appendix B: Instructions for the CTB

Appendix C: Econometric Models

Appendix D: Robustness checks

Appendix A:

Measuring financial literacy and cognitive reflection

We measure financial literacy by administering a subset of a well-established and psychometrically validated test items described in Knoll and Houts (2012). We work with a reduced set of items, because certain financial products referenced in the original version are not available in Germany. Item analysis and person ability estimation is based on Item Response Theory (IRT; Baker and Kim, 2004; Hambleton and Swaminathan 1985) where manifest variables, i.e. item responses, are attributed to an underlying latent ability (financial literacy), a procedure that is increasingly applied in educational and psychological research. An important benefit of using IRT models lies in the sample independency property i.e., estimation of ability differences between two persons independently of the test administered (see Rasch 1960 and Birnbaum 1985). By contrast, the use of raw item scores i.e., the number of correctly solved items, might result in a biased estimation of ability estimates and item difficulties when the test items are administered to a high-ability or to a low-ability group.

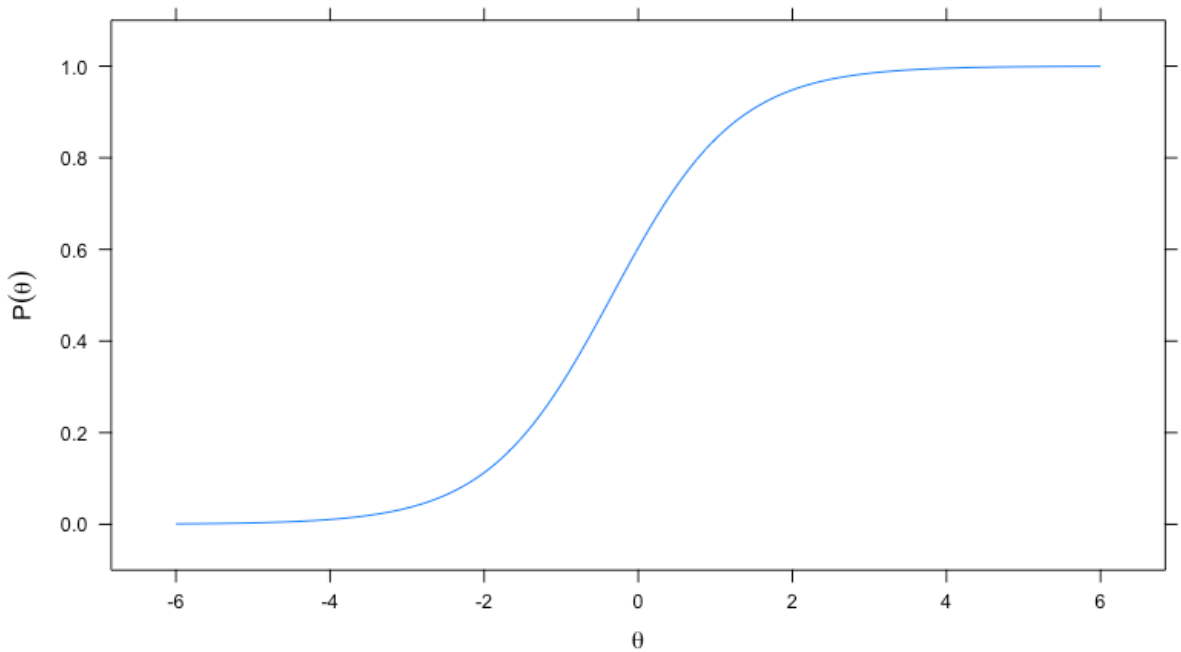
A key requirement for using IRT models is the unidimensionality of the underlying construct which ensures that only the intended type of ability is measured by the instrument. Similarly, a common way for assessing dimensionality is through factor analysis. Thus, the Principal Component Analysis (PCA) to the item set revealed an Eigenvalue of 2.83 for the first component which accounts for 20.2 percent of the total variance whereas all the following components explain less than ten percent indicating the dominance of the first component and therefore the unidimensional character of the instrument.

We estimate latent abilities and item characteristics by means of the Two-Parameter-Logistic Model, which defines the probability of solving an item correctly as

$$P(X_i = 1|\theta, \sigma, a) = \frac{exp\{a_i(\theta_v - \sigma_i)\}}{1+exp\{a_i(\theta_v - \sigma_i)\}} \quad (1),$$

where $\theta_v$denotes the ability of person v and σ the difficulty of item i on a common logit scale of [-4:4]. a_i represents thereby the discrimination parameter which describes how accurate an item i differentiates between low-ability and high-ability students. The parameters are estimated by maximization of the likelihood function with respect to θ_v, σ_i and a_i. In contrast to factor analysis, item response theory models assume a probabilistic relationship between an ability continuum and solving an item correctly, which can be graphically represented by Item Characteristic Curves (ICC). Figure A1 shows the ICC for Item 2 (see comprehensive item characteristics in appendix Table A1).

Figure A1: Item Characteristic Curve (Item 2)



The difficulty parameter σ identifies the point on the logit scale where $P(X_i = 1|\theta_v) = 0.5$ applies. As the ability continuum is assumed to have zero mean by definition, an item i appears relatively easier if σ is smaller than zero and relatively harder if σ is greater than zero. The discrimination parameter a represents the slope of the ICC.

With regard to parameter extraction, we maximize the likelihood function of equation (1) with respect to θ, σ and a

$$\max_{\theta,\sigma,a_i} \quad L = \prod_{v=1}^{N}\prod_{i=1}^{M}\frac{\exp(x_{vi}(a_i(\theta_v - \sigma_i)))}{1 + \exp(a_i(\theta_v - \sigma_i))} \quad (2)$$

where x_{vi} denotes a data matrix with all single responses of n persons to m items. As person abilities extracted from maximum likelihood procedures tend to show statistical bias, we rely on weighted likelihood estimators (WLE) (Warm 1989) which takes individual item information into account. Estimation of above equation (2) yields item difficulty and discrimination parameters shown in Table A1. Difficulty parameters ranges from -2.22 to 2.81 with a mean of -0.08 indicating a broadly covered item scale. Discrimination parameters range from 0.28 and 2.27 and have a mean of 1.03.

Additionally, we then approximate cognitive abilities by means of the simple three-item Cognitive Reflection Test (CRT). It consists of three simple questions with a wrong intuitive answer and a correct answer which is more complicated to find. The scale consists of the following three questions:

1) A bat and a ball cost €1.10 in total. The bat costs €1.00 more than the ball. How much does the ball cost? ____ cents
2) If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets? ____ minutes
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? _____ days

The item scale is characterized by meaningful correlations to other well-established cognition tests such as the Wonderlic Personnel Test (WPT), the "need for cognition" scale, or the Scholastic Achievement Test (SAT). In addition, our results showed positive associations to patience and predictive power to bias-and-heuristics tasks (Oechsler 2009) (available on request). Thus, the CRT enables to approximate cognitive abilities in an efficient way. In the

subsequent analysis, we implement cognitive abilities by using a raw score index i.e., the number of correctly answered questions, ranging from 0 to 3.

On average, about 30 percent of our sample had no correct answers, about 24 percent had one, about 25 percent had two correct answers and the rest 19.5 percent were able to solve all three items correctly (see Table A2), which is in line with the 17 percentage points found in Frederick (2005). As reported in earlier findings (e.g., Bucher-Koenen and Ziegelmeyer 2011), we found a positive and significant correlation between cognition and financial literacy scores ($r = 0.26$, $p < 0.01$).

Table A1: Item characteristics for the Two-Parameter-Logistic model

	Item	a_i (Std. Err.)	σ_i (Std. Err.)	Percent correct
1)	Imagine that interest rate on your saving account was 1% per year and inflation was 2% per year. After 1 year, how much would you be able to buy with the money in this account? - More than today - Exactly the same - **Less than today** - Do not know / Don't´ want to answer	1.147 (0.069)	-1.338 (0.067)	0.779
2)	Assume a friend inherits $10,000 today and his sibling inherits $10,000 three years from now. Who is richer because of the inheritance? - **The friend** - His sibling - They are equally rich - Do not know / Don't´ want to answer	1.242 (0.064)	-0.338 (0.035)	0.584
3)	Considering a long time period (for example 10 or 20 years) which asset normally gives the highest return? - Savings accounts - Bonds - **Stocks** - Do not know / Don't´ want to answer	0.477 (0.044)	1.437 (0.140)	0.335
4)	Normally, which asset displays the highest fluctuations over time? - Savings accounts - Bonds - **Stocks** - Do not know / Don't´ want to answer	0.281 (0.040)	0.801 (0.159)	0.445
5)	When an investor spreads his money among different assets, does the risk of losing money: - Increase - **Decrease** - Stay the same - Do not know / Don't´ want to answer	2.273 (0.152)	-1.274 (0.045)	0.847
6)	Suppose you owe $3,000 on your credit card. You pay a minimum payment of $30 each month. At an Annual Percentage Rate of 12% (or 1% per month), how many years would it take to eliminate your credit card debt if you made no additional new charges? - Less than 5 years - Between 5 and 10 years - Between 10 and 15 years - **Never, you will continue to be in debt** - Do not know / Don't´ want to answer	1.245 (0.063)	-0.221 (0.034)	0.555
7)	If you buy a company's stock... - **You own a part of the company** - You have lent money to the company - You are liable for the company's debt - Do not know / Don't´ want to answer	0.810 (0.070)	2.819 (0.207)	0.110
8)	Buying a company stock usually provides a safer return than a stock mutual fund. - True - **False**	0.717 (0.049)	-1.164 (0.084)	0.679
9)	Bonds are normally riskier than stocks. - True - **False**	0.614 (0.045)	-0.208 (0.058)	0.524
10)	"Housing prices in the US can never go down" - True - **False**	1.041 (0.056)	0.498 (0.043)	0.402

11) If you were to invest $1000 in a stock mutual fund, it would be possible to have less than $1000 when you withdraw your money. - **True** - False	0.730 (0.058)	-2.215 (0.156)	0.813
12) A mutual fund combines the money of many investors to buy a variety of stocks, not a single stock. - **True** - False	1.257 (0.066)	-0.612 (0.039)	0.649
13) A 15-year mortgage typically requires higher monthly payments than a 30-year mortgage, but the total interest paid over the life of the loan will be less. - **True** - False	1.965 (0.100)	0.185 (0.027)	0.445
14) Suppose you had $100 in a savings account and the interest rate was 2% per year. After 5 years how much do you think you would have in the account if you left the money to grow? - **More than $102** - Exactly $102 - Less than $102 - Do not know / Don't´ want to answer	0.577 (0.044)	0.515 (0.069)	0.421

Table A2: Cognitive Reflection Test (n = 215)

Cognition score	Frequency	Percent	Cum.
0	66	30.70	30.70
1	52	24.19	54.88
2	55	25.58	80.47
3	42	19.53	100.00

Appendix B:

Instructions for the Convex Time Budgeting Task

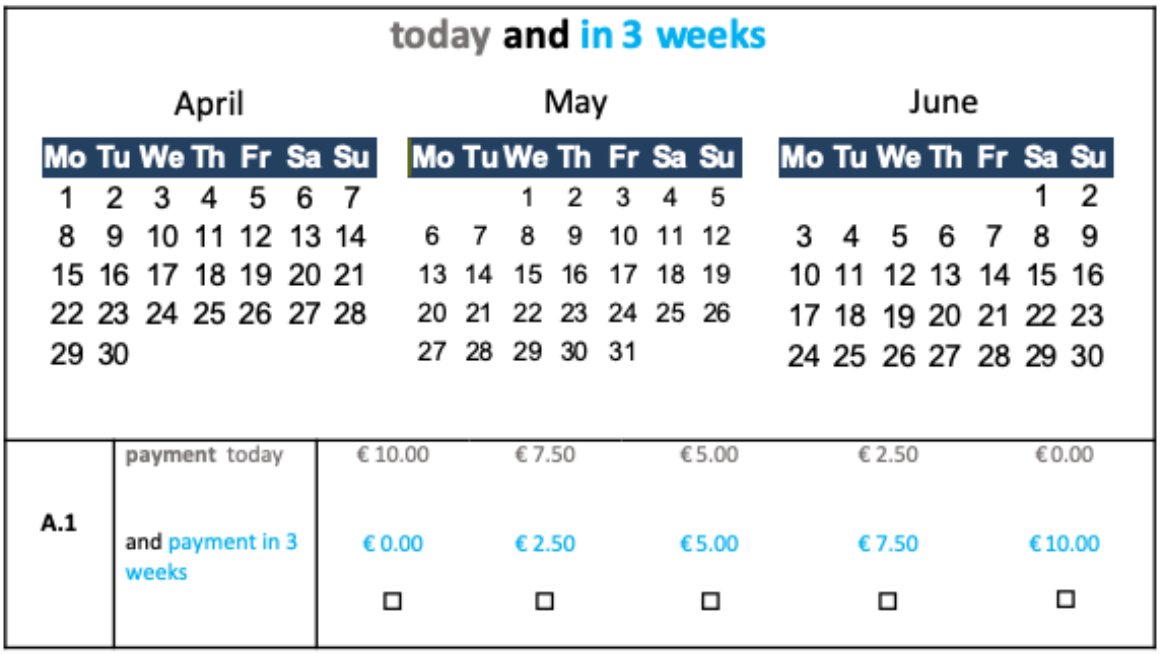
Hello all, we really appreciate your participation in our experiment.

What is this study about? Well, in this game you will basically be asked to choose between two payments on different time dates. You will make several decisions about allocating a certain money amount between a sooner point in time (e.g. today) or a later point in time (e.g. in three weeks). One of these decisions will be randomly selected for actual payments at the end of this study. So, make sure to take every decision as if it were the decision that is paid out.

We show you an example how it works: *(showing example on the screen)*

Here you have to decide between a payment today and a payment made in exactly three weeks. There are five different possibilities from which you have to choose only one. If you tick, for instance, the first box you will receive €10 today and €0 in three weeks. If you choose instead, for instance, the second box, you will receive €7.50 today and €2.50 Euro in three weeks and so on and so forth…

Any questions so far?



In this study, you will have to take more than one decision like in our example. Please take a look at this slide *(showing Budgeting Sheet 1 on the screen).* As you can see, on this sheet you have to make six different decisions from A.1 to A.6. with the difference that the payment today decreases along the decisions while the amount for the payment in three weeks remains constant. Within each decision, you decide on exactly one box you which to choose. Please remember that only one of these decisions will be randomly selected for actual payment. Therefore, make sure to make decisions that you really want.

Any questions so far?

Once you'll have completed the first sheet, you will work through two more sheets, but with different points of time (*show Budgeting Sheet 2 on the screen).* As you can see, this is the exact same sheet. The difference is the timing. Here you decide between a payment today and a payment in six weeks instead of three weeks. The third sheet alters the points of time again (*showing Budgeting Sheet 3 on the screen).* Here you decide between a payment in three weeks and a payment in six weeks.

Any questions so far?

How are payments going to work? As already indicated, only one out of 18 decisions will be chosen at the end of the experiment which yields into actual payments. As a thank you for participating, you will also receive additional €5 Euros which will be split in half across the two payment dates. This means you receive additional €2.50 per point of time, irrespective of your choices on the sheets. Let's assume decision C.4 will be chosen randomly in the end and you ticked the second box. Then you receive €5.25 plus 2.50, i.e. €7.75, in three weeks and €2.50 plus €2.50, i.e. 5€, in six weeks.

Any questions so far?

The delayed payments in three and six weeks take place directly in front of the auditorium maximum at the beginning of your lecture. This is why you receive a payment card (*holding up payment card),* where the exact amount you will receive, and the point of time is listed. Please

keep this card in your wallet. In three and/or six weeks you will find us at the entrance of the lecture hall so that you can exchange your card against cash.

Payment Card (translated from German)

University of Koblenz-Landau,
Department of Economics

UNIVERSITÄT KOBLENZ · LANDAU

Payment Card

This card shows all payments you receive through participating in our study. Payments take place in front of the auditorium maximum at the beginning of your lecture _____

Your payments:

Today, April 16, 2019	In 3 weeks, May 7, 2019	In 6 weeks, May 28, 2019
EURO	EURO	EURO

Budgeting Sheets

Today and in 3 weeks

April						
Mo	Tu	We	Th	Fr	Sa	Su
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

May						
Mo	Tu	We	Th	Fr	Sa	Su
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

June						
Mo	Tu	We	Th	Fr	Sa	Su
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

For each decision below (A.1 – A.6), decide which amounts you would like for sure today AND in 3 weeks. Remember to choose only one box per decision!

A.1	payment today	€ 10.00	€ 7.50	€ 5.00	€ 2.50	€ 0.00
	and payment in 3 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐
A.2	payment today	€ 9.00	€ 6.75	€ 4.50	€ 2.25	€ 0.00
	and payment in 3 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐
A.3	payment today	€ 8.00	€ 6.00	€ 4.00	€ 2.00	€ 0.00
	and payment in 3 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐
A.4	payment today	€ 7.00	€ 5.25	€ 3.50	€ 1.75	€ 0.00
	and payment in 3 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐
A.5	payment today	€ 6.00	€ 4.50	€ 3.00	€ 1.50	€ 0.00
	and payment in 3 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐
A.6	payment today	€ 5.00	€ 3.75	€ 2.50	€ 1.25	€ 0.00
	and payment in 3 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐

today and in 6 weeks

April						
Mo	Tu	We	Th	Fr	Sa	Su
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

May						
Mo	Tu	We	Th	Fr	Sa	Su
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

June						
Mo	Tu	We	Th	Fr	Sa	Su
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

For each decision below (B.1 – B.6), decide which amounts you would like for sure today AND in 6 weeks. Remember to choose only one box per decision!

B.1	payment today	€ 10.00	€ 7.50	€ 5.00	€ 2.50	€ 0.00
	and payment in 6 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐
B.2	payment today	€ 9.00	€ 6.75	€ 4.50	€ 2.25	€ 0.00
	and payment in 6 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐
B.3	payment today	€ 8.00	€ 6.00	€ 4.00	€ 2.00	€ 0.00
	and payment in 6 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐
B.4	payment today	€ 7.00	€ 5.25	€ 3.50	€ 1.75	€ 0.00
	and payment in 6 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐
B.5	payment today	€ 6.00	€ 4.50	€ 3.00	€ 1.50	€ 0.00
	and payment in 6 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐
B.6	payment today	€ 5.00	€ 3.75	€ 2.50	€ 1.25	€ 0.00
	and payment in 6 weeks	€ 0.00 ☐	€ 2.50 ☐	€ 5.00 ☐	€ 7.50 ☐	€ 10.00 ☐

In 3 weeks and in 6 weeks

April						
Mo	Tu	We	Th	Fr	Sa	Su
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

May						
Mo	Tu	We	Th	Fr	Sa	Su
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

June						
Mo	Tu	We	Th	Fr	Sa	Su
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

For each decision below (C.1 – C.6), decide which amounts you would like for sure today AND in 3 weeks.
Remember to choose only one box per decision!

C.1	payment in 3 weeks	€ 10.00	€ 7.50	€ 5.00	€ 2.50	€ 0.00
	and payment in 6 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐
C.2	payment in 3 weeks	€ 9.00	€ 6.75	€ 4.50	€ 2.25	€ 0.00
	and payment in 6 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐
C.3	payment in 3 weeks	€ 8.00	€ 6.00	€ 4.00	€ 2.00	€ 0.00
	and payment in 6 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐
C.4	payment in 3 weeks	€ 7.00	€ 5.25	€ 3.50	€ 1.75	€ 0.00
	and payment in 6 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐
C.5	payment in 3 weeks	€ 6.00	€ 4.50	€ 3.00	€ 1.50	€ 0.00
	and payment in 6 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐
C.6	payment in 3 weeks	€ 5.00	€ 3.75	€ 2.50	€ 1.25	€ 0.00
	and payment in 6 weeks	€ 0.00	€ 2.50	€ 5.00	€ 7.50	€ 10.00
		☐	☐	☐	☐	☐

Appendix C: Econometric Models

In this section, we describe two econometric specifications for the utility parameter estimation proposed by Andreoni and Sprenger (2012) and applied in most empirical follow-up studies using the CTB. The first approach transforms tangency condition (2) into the optimal Stone-Geary demand for sooner consumption c_t,

$$c_t = \frac{1}{1 + (1+r)((1+r)\beta\delta^k)^{\frac{1}{\alpha-1}}}\omega_t + \left[\frac{\left(\beta\delta^k(1+r)\right)^{\frac{1}{\alpha-1}}}{1 + (1+r)\left(\beta\delta^k(1+r)\right)^{\frac{1}{\alpha-1}}}\right](m - \omega_{t+k}) \qquad (3)$$

which is simply estimated by means of non-linear least squares regression. Parameters β, δ, α, ω_t and ω_{t+k} are recovered via non-linear combinations of the estimated coefficients. This approach carries the advantage that background consumption parameters can be directly estimated. However, it does not account for the censored data structure with corner choices in the data which is why a two-limit tobit model is proposed. This approach assumes background consumption to be known and takes the log of the Euler Equation (2) which linearizes it to

$$ln\left(\frac{c_t - \omega_t}{c_{t+k} - \omega_{t+k}}\right) = \frac{1}{\alpha - 1} \cdot ln(\beta) + \frac{1}{\alpha - 1}\ln(\delta) \cdot k + \frac{1}{\alpha - 1} \cdot \ln(1 + r) \qquad (4).$$

To address corner choice issues, we estimated (4) by means of a two-limit tobit maximum likelihood regression. By entering the data *t, k* and *r,* we obtain δ, β and α via non-linear combinations accordingly. Beside the limiting factor that the consumption ratio $\frac{c_t - \omega_t}{c_{t+k} - \omega_{t+k}}$ needs to be positive in this approach, background consumption restriction needs to be known in advance. Therefore, we asked participants how much money they spend in a typical week. We ran parameter estimation with ω_t and ω_{t+k} set to 0.01 (representing the case zero such that the log-ratio is well-defined) and to 9.02 Euros, i.e. the average of participants' self-reported daily consumption.

Appendix D: Robustness checks

Table D1: Predictive validity of preference parameters

	(1) ln(Savings)	(2) Impulsivity (CRT)	(3) Patience (self-reported)	(4) Drugs (1/0)
Present bias ($\hat{\beta}$)	-0.563	-0.492*	0.508	-0.427*
	(0.672)	(0.287)	(0.376)	(0.253)
Discount factor ($\hat{\delta}$)	-3.432	-28.114***	18.480*	-9.937*
	(16.150)	(8.204)	(9.537)	(5.469)
Financial literacy	-4.761	19.082***	-13.541*	6.499*
	(10.643)	(5.721)	(6.929)	(3.797)
Present bias ($\hat{\beta}$) × Financial literacy	-0.329	-0.483**	0.409	-0.219
	(0.507)	(0.217)	(0.289)	(0.208)
Discount rate ($\hat{\delta}$) × Financial literacy	5.391	-18.714***	13.196*	-6.200*
	(10.282)	(5.619)	(6.738)	(3.677)
Constant	11.948	28.150***	-19.035*	
	(16.472)	(8.281)	(9.680)	
Observations	158	195	194	195
R-squared	0.121	0.147	0.055	

Note: This table contains regression models with different self-reported intertemporal behaviors. Predictors are estimated utility parameters β̂,δ̂ and financial literacy scores. To accompany results in section 4, we use utility parameters with background consumption set to 0. Columns (1-3) report OLS regression estimates on the natural logarithm of total savings, on the sum score of impulsive responses in the Cognitive Reflection Test and on the self-reported ability to delay a gratification. Column 4 shows marginal effects of a probit model on the likelihood that an individual consumes stimulants. Individual characteristics as controls (gender, age, native language, books at home, disposable income) are included in all models. Robust standard errors in parentheses.*** p<0.01, ** p<0.05, * p<0.1

Table D2: Regressions with Financial literacy raw scores (rs)

	(1) Sooner payments	(2) Corner choice	(3) Perfectly aligned corner choice	(4) Discount factor ($\hat{\delta}$)	(5) Present bias ($\hat{\beta}$)
Financial literacy (rs)	-0.036***	0.025**	0.057***	0.004*	-0.066
	(0.009)	(0.010)	(0.020)	(0.002)	(0.061)
Cognitive reflection	-0.169***	0.101**	0.195**	0.014	-0.308
	(0.039)	(0.045)	(0.094)	(0.009)	(0.260)
Financial literacy (rs) ×	0.013***	-0.009	-0.015	-0.001	0.033
Cognitive reflection	(0.005)	(0.006)	(0.012)	(0.001)	(0.029)
today	0.001	-0.026*			
	(0.013)	(0.014)			
k42	0.029***	-0.000			
	(0.009)	(0.012)			
(1+r)	-0.590***	0.050**			
	(0.021)	(0.021)			
female	-0.073**	-0.013	0.047	0.012	0.026
	(0.034)	(0.046)	(0.079)	(0.008)	(0.040)
age	-0.003	0.012	0.011	0.000	0.008
	(0.005)	(0.008)	(0.013)	(0.001)	(0.007)
native	0.003	-0.032	-0.049	-0.013	-0.066
	(0.039)	(0.052)	(0.094)	(0.010)	(0.143)
≤ 25 books at home	-0.020	-0.034	-0.122	-0.001	0.007
	(0.037)	(0.054)	(0.096)	(0.010)	(0.064)
ln(income)	-0.040**	0.030	0.009	0.003	-0.049
	(0.019)	(0.026)	(0.048)	(0.003)	(0.044)
Constant	1.329***			0.967***	1.197***
	(0.071)			(0.014)	(0.210)
Observations	3,371	3,371	188	192	192
R-squared	0.297			0.146	0.057

This table contains various regression models with financial literacy as raw score, i.e. number of correctly solved questions. Regression models (1-3) contain OLS and Probit regressions on different allocation behaviors analogous to Table 3. Models (4-5) contain regressions on estimated utility parameter $\hat{\delta}$ (daily discount rate) and $\hat{\beta}$ (present bias) analogues to Table 4. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table D3: Determinants of utility parameters with different background consumption specifications

	$\omega_t = \omega_{t+k}$ = -9.02		Individual daily consumption (self-reported)	
	(1) Present bias ($\hat{\beta}$)	(2) Discount factor ($\hat{\delta}$)	(3) Present bias ($\hat{\beta}$)	(4) Discount factor ($\hat{\delta}$)
Financial literacy	-0.040	0.007*	-0.039	0.005*
	(0.044)	(0.004)	(0.043)	(0.003)
Cognitive reflection	-0.028	0.003**	-0.027	0.003**
	(0.019)	(0.001)	(0.018)	(0.001)
Financial literacy × Cognitive reflection	0.018	-0.003	0.018	-0.002
	(0.021)	(0.002)	(0.020)	(0.001)
Constant	1.016***	0.995***	1.015***	0.995***
	(0.019)	(0.001)	(0.018)	(0.001)
Observations	205	205	205	205
R-squared	0.021	0.081	0.021	0.083

This table contains regression models on utility parameters estimated with different background consumption specifications. In Models (1-2), background consumption was set to the average self-reported daily consumption (9.02 Euros). In Models (3-4) individual daily consumption was used to estimate utility parameters. Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

References (Appendix)

Baker, F.B., Kim, S.-H., 2004. Item response theory: parameter estimation techniques. Marcel Dekker, New York.

Birnbaum, A., 1968. Some Latent Trait Models and Their Use in Inferring an Examinee's Ability, in: F. M. Lord and M. R. Novick,Statistical Theories of Mental Test Scores. Addison-Wesley, Reading, Massachusetts.

Bucher-Koenen, T., Ziegelmeyer, M.H., 2011. Who Lost the Most? Financial Literacy, Cognitive Abilities, and the Financial Crisis. ECB Working Paper 1299. https://doi.org/10.2139/ssrn.1738368

Hambleton, R.K., Swaminathan, H., 1985. Item response theory : principles and applications. Kluwer-Nijhoff Pub.

Harless, D. W., Camerer C.F., 1994. The Predictive Utility of Generalized Expected Utility Theories. Econometrica 62, 1251–1289.

Knoll, M.A.Z., Houts, C.R., 2012. The Financial Knowledge Scale: An Application of Item Response Theory to the Assessment of Financial Literacy. Journal of Consumer Affairs 46, 381–410. https://doi.org/10.1111/j.1745-6606.2012.01241.x

Oechssler, J., Roider, A., Schmitz, P.W., 2009. Cognitive abilities and behavioral biases. Journal of Economic Behavior and Organization 72, 147–152. https://doi.org/10.1016/j.jebo.2009.04.018

Rasch, G., 1960. Probabilistic models for some intelligence and attainment tests. Danish Institute for Educational Research, Kopehagen:

Warm, T.A., 1989. Weighted likelihood estimation of ability in item response theory. Psychometrika 54, 427–450. https://doi.org/10.1007/BF02294627