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Looking Ahead: Subjective Time Perception and Individual Discounting

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Abstract

Time discounting is at the heart of economic decision-making. We disentangle hyperbolic discounting from subjective time perception using experimental data from incentive-compatible tests to measure time preferences, and a set of experimental tasks to measure time perception. The two behavioural parameters may be related to two factors that affect how we look ahead to future events. The first is that some component of time preferences reflect hyperbolic discounting. The second factor is that non-constant discounting may also be a reflection of subjective time perception: if people's perception of time follows a near logarithmic process (as all other physiological perceptions such as heat, sound, and light do) then all existing estimates of individual discounting will be mis-measured and incorrectly suggest "hyperbolic" discounting, even if discounting over subjective time is constant. To test these hypotheses, we empirically estimate the two distinct behavioural parameter s using data collected from 178 participants to an experiment conducted at the London School of Economics Behavioural Research Lab. The results support the hypothesis that apparent non-constant discounting is largely a reflection of subjective time perception.

Key words: Time preferences, Time perception, Hyperbolic discounting
JEL Classifications: D1, D10, D91

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1. INTRODUCTION

Time discounting is considered a fundamental characteristic of human decision-making. (Frederick, Loewenstein et al. 2002) For example, higher rates of discounting will lead an individual to more strongly shift consumption to the present, implying lower savings rates – a regularity that has both individual and macro-economic implications. (Ameriks, Caplin et al. 2007) Individuals with higher discount rates may also be less willing to invest in painful activities in the present (such as preventive health care or stopping the use of some addictive good with long-term negative health consequences) even if such investments yield substantial benefits in the future (Barsky, Juster et al. 1997; Chapman and Coups 1999; Bernheim and Rangel 2004; Chabris, Laibson et al. 2008; Sutter, Kocher et al. 2011).

Multiple empirical methods have been developed over the past decades to estimate individual levels of discounting, ranging from real-world natural experiments (Warner and Pleeter 2001); to survey questions involving hypothetical payouts (van der Pol and Cairns 2001); to laboratory or "artefactual field" experiments (in the sense of Harrison and List, 2004), mainly using incentive-compatible methods (Coller and Williams 1999; Harrison, Lau et al. 2002; Andersen, Harrison et al. 2008).

Perhaps the most widely debated finding in the literature is that individuals do not appear to discount the future at a constant rate: discount rates are higher for more proximate time periods and lower for more distal ones. (Thaler 1981; Benzion, Rapoport et al. 1989; Horowitz 1991; Kirby and Marakovic 1995; Coller, Harrison et al. 2012) This phenomenon has been typically explained in terms of hyperbolic or quasi-hyperbolic time discounting. (Loewenstein and Prelec 1992; Laibson 1997; Gul and Pesendorfer 2001; Rubinstein 2003; Benhabib, Bisin et al. 2010)

Several alternative accounts have been proposed to explain hyperbolic discounting. Ainslie (1975) relates it to individual impulsivity, whereas Loewenstein (1996) to the tempting influence and temporal proximity of "visceral factors" such as hunger, sexual arousal, cravings, and physical pain.(Ainslie 1975; Loewenstein 1996) Trope and

Liberman (2003, 2010) point to different representations of near and distant future events in terms of cognitive concreteness. (Trope and Liberman 2003; Trope and Liberman 2010) Others argue that declining discounting rates could be also due to "sub-additive discounting": the fact that the overall time horizon is partitioned into subintervals can increase the salience of the partitioned time components, and lead to higher discounting. (Read 2001; Trope and Liberman 2003; Scholten and Read 2006; Trope and Liberman 2010; Dohmen, Falk et al. 2012) Frederick, Loewenstein, and O'Donoghue (2002) observe that, as future payouts are inextricably associated with uncertainty, our valuation of inter-temporal trade-offs not only depends on our "pure" time preferences, but also on perceived risks associated with the delay. Epper, Fehr-Duda, and Bruhin find, in fact, that hyperbolic discounting is significantly associated with non-linear probability weighting in the subjective perception of probabilities ("sub-proportionality"). (Epper, Fehr-Duda et al. 2011) Andersen, and colleagues notice that most incentive-compatible evidence of hyperbolic discounting occurs in samples of college students and hardly apply to real money choices of adult respondents over typical horizons of months.(Andersen, Harrison et al. 2011)

There is a separate branch of the literature that suggests that the observed behavior may be less based in inconsistencies in actual time preferences than in perceptions about time duration. (Read 2001; Takahashi 2005; Zauberman, Kim et al. 2009) The implications of this (which we will explain below) is that, if human understanding of time – either retrospectively or projected forward in time – is not a linear mapping from calendar time (e.g., if two years are perceived as less than twice as far away as one year) then we have made an error in our fundamental assumptions when calculating upper and lower bounds of the discount rates in past empirical studies. That people would perceive time in this manner can be explained by appeal to what is known as the "Weber-Fechner Law" – a fundamental principle in the psychology of perception that has been widely documented for other neuro-physiological stimuli such as heat, sound, and light (Stevens, 1957).

In this paper, we explore these questions and bring the multiple strands of the existing literature closer together in one incentive-compatible experiment whereby we simultaneously estimate individual's subjective perception of time and their implied discount rates. We improve on existing studies in at least five ways, including: i) explicitly accounting for subjective time perception when calculating upper and lower bounds on discount rates; ii) measuring within-person changes to perceptions and discounting; iii) taking "now" versus "later" more seriously; iv) using information on immediate time-perception errors; and v) minimizing the potential for framing effects.

We find that individuals do indeed compress future time perceptions in ways very reminiscent of the general Weber-Fechner principle. Further, once that compression is taken into account, we find evidence that discount rates are higher for today versus later times, but essentially constant and statistically undistinguishable for all later times from one week onwards. While discounting rates based on "objective time" replicate the usual hyperbolic preferences, much of the hyperbolic pattern is absent in the curve of the discounting factors obtained from "subjective time". Thus, we argue that there is good reason to suspect that much of the worry about hyperbolic-like discounting is a case of "getting the math wrong": rather that questioning whether there are widespread time-inconsistencies, we should focus on the implications of compression of future time perception.

The rest of the article is structured as follows. In Section 2 we review the background, the objectives, and the main features of our study, and its contributions to the literature. Section 3 describes the experiment, while in Section 4 we present the econometric model. Section 5 discusses the results, while in Section 6 we conclude by discussing some of the implications of our findings.

2. BACKGROUND AND CONTRIBUTIONS

2.1. THE DISCOUNTING FUNCTION

As reviewed by Frederick, Loewenstein, and O'Donoghue (Frederick, Loewenstein et al. 2002), the study of intertemporal choice has a long and fascinating tradition in the history of economics. It is useful to follow their conceptual distinction between "time discounting", which includes any reason for caring less about a future outcome, and "time preference", which refers, more specifically, to the "pure" preference for immediate over delayed utility. In the early economists' views, time discounting was thought as an amalgamation of disparate psychological motives, which can explain why even now it overlaps with different concepts in psychology, such as lack of self-control and impulsiveness. (Patton and Stanford 1995; Zakay and Block 1997; Kirby, Petry et al. 1999)

The basic modern theoretical approach in economics, however, was introduced by Paul Samuelson. (Samuelson 1947) His discounted utility (DU) model assumed that individuals maximize the present value of a stream of separate utilities, where future utilities were weighted less heavily compared to the current level of utility. Thus individuals were assumed to select some level of consumption in each time period, x_t, in order to maximize

$$U^t(x_1,...,x_T) = \sum_{t=0}^{T} \beta(t)u(x_t) \quad (1)$$

subject to an income/wealth constraint. In Samuelson's model the weighting factor, β(t) was constant across all time periods in this model, and corresponded to the most common economic understanding of a "discount rate" in that the rate of discounting future periods is invariant to the distance of time *t* in the future. Generally, β(t) has the form:

$$\beta(t) = \left(\frac{1}{1+d}\right)^t \quad (2)$$

which implies an exponential discount rate that is constant for all time periods.

For several decades after Samuelson's work, the DU model was the standard conceptual basis for economists' understanding of inter-temporal choice. In the early 1990s, however, a body of psychometric and (what came to be called) behavioral economics literature developed – based in part on work from the middle of the 20th century (Strotz 1955) – that suggested such a "constant discount rate" view was mistaken (Ainslie 1991; Ainslie and Haslam 1992; Loewenstein and Prelec 1992; Kirby and Marakovic 1995; Laibson 1997). In this formulation, the discount function takes the form:

$$\beta(t) = \left(\frac{1}{1+\alpha t} \right)^{\frac{\beta}{\alpha}}. \tag{3}$$

Functionally, this implies that the rate of change in $\beta(t)$ (i.e., the derivative of $\beta(t)$ with respect to time) declines as *t* increases – that is, that individual's rate of discounting for consumption delayed until tomorrow is larger than the rate of discounting for consumption that must be delayed by a day one year from now. Behaviorally, this implies that people's preferences are time-inconsistent: given some return on delay, a person may want to shift consumption to the present from tomorrow, even though when planning for tomorrow she will want to delay that same consumption until a later time. Naturally, such systematic inconsistencies are problematic for neoclassical economists (which only serves to increase the idea's attractiveness to behavioral economists).

2.2. DEFINING THE FIRST PERIOD

Empirically, non-constant discounting rates have been found quite commonly, and we refer to the existing reviews for a comprehensive discussion of this broad literature. (Coller and Williams 1999; Frederick, Loewenstein et al. 2002; Andersen, Harrison et al. 2011; MacKillop, Amlung et al. 2011) One interesting departure from the traditional pure hyperbolic is the "quasi-hyperbolic" form popularized in economics by Laibson. (Laibson 1997) The basic logic of this framework is that people discount the future in discrete ways, where the first period is essentially undiscounted and all subsequent periods are discounted in an increasing level (with or without a constant rate). The observational consequences are that the discount function mimics many of the traits of a hyperbolic discounting function (hence the "quasi-"), though this is driven entirely by the greater weight to first-period utility compared with all other periods.

This Strotz-Ainslie-Laibson framework is appealing. In many ways, however, the most appealing aspect of the idea is typically ignored in empirical applications – namely that the first period is different from subsequent periods. Even empirical applications that do explicitly model quasi-hyperbolic behaviors do not directly solve the first period question. So, the first unresolved question here is: what should be considered as the "first" period? Or, equivalently, when the line should be drawn to separate the "near" from the "far" future? (Ebert and Prelec 2007)

The quasi-hyperbolic model itself is silent about this question. (Loewenstein and Prelec 1992; Prelec 2004) In the literature the first period is typically equated to the first year (Frederick, Loewenstein, and O'Donoghue, 2002). In the experimental literature with real incentives, period 1 is usually as proximate as six months (Harrison, Lau and Williams, 2002), two months (Coller and Williams, 1999), one month (Andersen, Harrison, Lau, and Rutström, 2008), or 2 weeks (Andersen, Harrison, Lau, and Rutström, 2011), although occasionally time horizons of few days are used. (Kirby and Marakovic 1995; Coller and Williams 1999; Frederick, Loewenstein et al. 2002; Andersen, Harrison et al. 2011) Also in the studies exploring subjective time perception, the first time horizon is usually three months. (Kim and Zauberman 2009; Zauberman, Kim et al. 2009)

The original hypothesis supporting hyperbolic preferences, however, assumed the source of the behaviors was competition between two internal systems – an automatic, impulsive, and myopic self (often referred to as "System 1") and a controlled, conscious, and more farsighted self (often referred to as “System 2”). (Tversky and Kahneman 1974; Thaler and Shefrin 1981; Tversky and Kahneman 1981; Chaiken and Trope 1999; Kahneman 2003) Such notions would appear to have a strong evolutionary basis. If we consider how such an evolutionary conflict would be plausibly established, we might suspect that the “first period” is considerably closer than few months or weeks away. If a group of ancient ancestors came into contact with a food source, then survival may be enhanced by gathering and eating it soon (certainly for perishable sources): in very primitive settings waiting until tomorrow to consume may mean the food source is first eaten by a competitor.

Thus, if there is some internal conflict driving temporal decisions, we may anticipate that they show up when comparing today (literally) with any other time period. Considering a one-day “first” period would be consistent with the observation that periods of time beyond that are treated as categorically different also for biological reasons: the circadian clock, in fact, regulates basic aspects of human physiology and behavior, and is synchronized by the natural periodicity of light, so that a 24-hours cycle is likely to be perceived as a special duration. (Wittmann and Paulus 2009)

We designed our experiment with an eye toward testing the implications of this today vs. all later time hypothesis more closely than is typically done. We assess time preferences (and, as discussed below, time duration perception) by comparing subjects’ tradeoffs between today and: tomorrow, one week, one month, three months, six months, and one year, using an overlapping design (OD). Thus, we are able to distinguish between a “now versus any time in the future” conflict and a traditional “continuously declining discount rate” hyperbolic framework.

2.3. ACCOMMODATING NON-LINEAR SUBJECTIVE TIME

A second – and perhaps more important – problem with the general economic literature estimating individual rates of discounting arises from the difference between what people think when we ask them to compare today to one month and when we ask them to compare today to two months. Economists (naturally enough) assume that the individuals will then consider tradeoffs across two periods, one of which is exactly twice as far away as the other. However, there is good reason to be skeptical about this assumption.

Ernst Weber proposed in the early 1800s that people's senses do not function linearly. (Weber 1978) This fundamental idea was subsequently expanded by Gustav Fechner in the mid-1800s, and has come to be seen as one of the basic principles of the psychology of perception. Essentially, the Weber-Fechner law states that the minimum detectible difference between two levels of a stimulus is proportional to the percentage change in the input. Thus, the perceived difference, dp, between two stimuli, S_0 and S (e.g., the intensity of heat) are:

$$dp = k\frac{dS}{S}.$$

Integrating this relationship, solving for the constant of integration, and rearranging yields:

$$p = k\ln\left(\frac{S}{S_0}\right).$$

In other words, the perception of a stimulus is proportional to the log of the change in the actual stimulus. (Bruss and Ruschendorf 2010)

The Weber-Fechner principle has been widely documented for a range of neuro-physiological perceptions, such as heat, sound, and light. Abstract constructs, such as numbers, appear to also induce logarithmic relationships between stimulus and perception, even among non-human subjects. (Dehaene 2003) Thus, this non-linearity in subjective experiences relative to the objective stimulus appears universal and operating at a biological level. More recently, evidence is growing that the Weber-Fechner principle may be important also for human subjective perception of time. (Read 2001; Takahashi 2005; Wittmann and Paulus 2008; Zauberman, Kim et al. 2009)

If this principle does extend to how long people perceive time, this would present a fundamental problem in the empirical measurement of individual discount rates conducted to date. After all, often we do not have access to "objective time", especially prospectively, and we can only access our subjective perception of how long a time interval was, or will be.

This means that as we ask subjects about longer time frames, people may well perceive the differences to be less than we assume: for instance, two months may be perceived to be less than twice one month. Thus, we may expect that when our experimental subjects hear questions about getting something in 30 days vs. 60 days, they may be really making their choices using time frames of $f(30)$ and $f(60)$, where $f(.)$ reflects their *subjective perception* of how long 30 and 60 days are. It may well be the case that for some respondents $f(60) < 2*f(30)$, so that they perceive more vividly the duration of the time periods which are close to the present. If this is the case, then nearly all estimates of individual discount rates in the past could be mis-calculated. We will explicitly illustrate this point in the next sub-section.

2.4. ESTIMATING DISCOUNT RATES AND THE IMPLICATIONS OF NON-LINEAR SUBJECTIVE TIME

The empirical economic literature which estimates discount rates for individuals can be divided generally into three groups: research that takes advantage of natural experiments; research that uses surveys for eliciting discount rates; and research utilizing laboratory-based or "artefactual field" experiments. Other articles review this literature in great detail. (Frederick, Loewenstein et al. 2002; MacKillop, Amlung et al. 2011) We will only highlight a few archetypical examples of this broad literature in order to motivate the research we propose.

The first approach mentioned is to use natural experiments in which individuals must choose between alternatives with differential time dimensions, such that a discount rate can be inferred. An example of this literature is Warner and Pleeter's work (Warner and Pleeter 2001), which took advantage of data generated from an early retirement program in the U.S. military to estimate discount rates for enlisted men and officers. Retirees were required to decide whether to take their retirement benefit as a lump-sum or as an annuity payment. The value of each depended on rank, years of service, and other factors. Since the retirees were choosing between an immediate and a delayed payout which had a fixed rate of return, it is possible to use that information to infer the strength of preference for the present versus the future (i.e., the discount rate) of the retirees. Warner and Pleeter estimate discount rates in the 25% per year range for officers and in the 45% per year range for enlisted men. Other researchers have used this method (existing data from natural experiments) to estimate individual level discount rates, and find similar results (Hausmann 1979; Gately 1980; Pender 1996). Some other studies using natural experiments, however, find much lower rates of discount (Moore and Viscusi 1990), and in general the literature also discusses the difficulties of making robust inferences from naturally occurring data. (Harrison 2005)

A second methodology employed is to present survey subjects with a set of hypothetical present and future payouts – often by asking respondents to imagine they have won a lottery and hypothetically choosing an immediate vs. delayed payout; these studies estimate discount rates using a contingent valuation (CV) method based upon respondent answers. Questions of this sort can be found in the 2004 wave of the Health and Retirement Survey, for example. These large-scale survey questions typically lack real monetary payouts, although attempts have been recently made to use incentive-compatible tests within households surveys. (Tanaka, Camerer et al. 2010; Galizzi, 2012) There are a number of studies that utilize the survey method and the usual finding is that estimated discount rates are generally in the range of 10-30% a year, although with some figures also in the region of hundreds percent a year (Moore and Viscusi 1988; Chapman and Winquist 1989; Redelmeir and Heller 1993; Chapman and Elstein 1995; Wahlund and Gunnarsson 1996; Cairns and van der Pol 1997; Johannesson and Johansson 1997; Holden, Shiferaw et al. 1998; Hesketh 2000; van der Pol and Cairns 2001; Bradford 2010; Bradford, Zoller et al. 2010; Bradford and Burgess 2011).

The third methodology is to present individuals with payouts that vary in their time dimension in a lab-based experimental setting. There are numerous examples of experimental methods used to assess individual discount rates (Cairns 1994; Green, Fristoe et al. 1994; Dolan and Gudex 1995; Kirby and Marakovic 1995; Coller and Williams 1999; Andersen, Harrison et al. 2008). A preliminary distinction can be made between studies that use hypothetical amounts and scenarios, from the ones that employ incentive-compatible tests with real monetary payments. The key distinction between these approaches is related to the concern that, absent real monetary incentives, respondents may not consider their questions carefully enough. Collier and Williams' work (Coller and Williams 1999) represents perhaps the first well-known example of an incentive-compatible study. In this study, the authors offered their subjects payouts of real money under controlled laboratory settings. They estimated rates in the 20% per year range. The approach taken by Coller and Williams, and further developed by Harrison, Lau, and Williams (2002), Andersen, Harrison, Lau, and Rutström (2008), and others, has become the standard method to elicit and estimate time preferences with real monetary incentives. Alternative elicitation procedures have been recently proposed.

(Andreoni and Sprenger 2012) A number of shortcomings remain in the method, which we propose addressing in this study.

Consider the typical methodology of these studies. Figure 1 is a reproduction of the Table from Coller and William (1999) that contained their experimental test. Respondents were presented with options to choose between two different monetary payouts – either in one month or in 3 months – and asked to choose in each row the option that would be preferred. The logic of the method is that if a person has a personal discount rate of, say, 5.5% per year, then they will prefer Option A for the first four rows of the experiment, and Option B for row five and every row thereafter. Thus, while the econometrician cannot know the discount rate is 5.5%, she can know that it is bounded by 5.13% below and 7.79% above. After that, the econometric methods are typically simple grouped or interval regression; ordered probit using the information on the upper and lower bounds; non-linear least squares; or "structural" estimation of the latent parameters in the utility functions using maximum-likelihood methods.

The difficulty arises in how the econometrician arrives at the specific values for the upper and lower bounds. Economically, of course, the answer is clear: a person will choose the proximate payoff if the present value of that is higher than the present value of the future payoff amount, given her discount rate. If we use the basic framework in Figure 1, but assume Option A is for an immediate payout rather than one month away (which merely simplifies the illustration, without changing the basic point), then we know the respondent would choose Option A *iff*

$$(4) \qquad 500 > \frac{501.67}{(1+d)^{60/365}}$$

where *d* is the respondent's daily discount rate. Using this logic, the econometrician will infer that the upper and lower bounds can be calculated using the relationship

$$(5) \qquad d = \exp\left(\frac{\ln 501.67 - \ln 500}{60/365}\right) - 1.$$

Note that this calculation – which, one way or another, underlies all empirical estimation of discount rates published to date – require that the respondent be thinking "60 days" when making the implicit calculation that permits her to provide an answer to which option is preferred. If, on the other hand, some version of the Weber-Fechner effect is in play, the respondent cannot actually think "60 days" when choosing options for the rows in Figure 1. Rather, she is imagining her subjective perception of how long 60 days actually is: *f*(60). Thus, the econometrician should be calculating the upper and lower bounds based on the subjective rather than objective time, using

$$(6) \qquad d = \exp\left(\frac{\ln 501.67 - \ln 500}{f(60)/365}\right) - 1.$$

More generally, without reference to the specific values from Figure 1, the lower bound for the daily discount rate should be calculated as

$$(7) \qquad d = \exp\left(\frac{\ln FV^{\min} - \ln PV}{f(t)/365}\right) - 1$$

and not (5) - with the obvious shift for the upper bound. Thus, the traditional bounds using (6) may simply be mis-measured.

Notice the close relation between the discounting rate function in (7) and the several operational specifications of hyperbolic discounting reflecting time perception as discussed in Andersen, Harrison, Lau, and Rutström (2011): in particular, the "Weibull" specification originally proposed by Read (Read 2001); its general functional form due to Roelofsma (Roelofsma 1996); the "Constant Sensitivity" (CS) power function proposed by Prelec (Prelec 2004; Ebert and Prelec, 2007); and a variety of others (Takahashi, Oono, and Radford, 2008; Bleichrodt, Rodhe, and Wakker, 2009; Kim and Zauberman, 2009). The key difference with those specifications is that the discounting rate function in (7) does not a priori impose any specific functional form for the shape of the individual perception of time, and, rather, it directly infers it from the data from each subject's responses.

In particular, if the function *f*(t) is non-linear and reasonably logarithmic in shape, then this measurement error could produce estimated discount rates that appear hyperbolic – even when underlying time preferences for all periods "not today" are actually constant. Our goal in this paper is to assess the degree to which such mis-measurement occurs and determine whether it contributes at all to the hyperbolic discounting behaviors observed so commonly in the past.

2.5. WHAT WE WILL CONTRIBUTE

Our experiment seeks to contribute to the literature in five main ways.

First, we will assess individual subjective perception of time in a way that will allow us to estimate the function *f*(t) in Equation (7) above, and so correctly estimate the bounds on each respondent's revealed discount rate. We will do this by asking people to indicate on a line (which is 152 mm in length) how far away they believe six time durations are (e.g. one day, one week, four weeks, thirteen weeks, 26 weeks, 52 weeks). We later ask them to make binary choices as in Figure 1 using the same intervals. This information will allow us to estimate *f*(t), and thereby estimate the subjective days associated with each objective (calendar) delay. In and of itself, the method is not novel. At least two other studies have used a similar approach, one where the interval was fixed as in our experiment (Zauberman, Kim et al. 2009) and one computer-assisted design where the interval was essentially open ended (Kim and Zauberman 2009), both approaches yielding essentially identical results. Neither study, however, has examined 1) substantial within-person variation in the perception of more than two time frames; or 2) time frames short enough to plausibly evaluate hyperbolic versus quasi-hyperbolic behaviors (three months was the shortest evaluated frame).

We particularly want to contrast the experimental design and empirical strategy employed by Zauberman, Kim, Malkoc, and Bettman (2009) with the design of our study. Zauberman and coauthors do not fully address our questions for at least four reasons. First, they do not employ any incentive-compatible payments in the experimental tests to elicit time preferences, but instead rely on purely hypothetical questions. In contrast, our experimental tests are incentive-compatible. Second, the evidence on subjective time perception presented by Zauberman, Kim, Malkoc, and Bettman (2009) is mostly based on between-subjects results, so that they do not have two points in the horizontal line for the same subject in the time perception task. Third, the questions for the 12 and 36 months time frames in the same subjective time perception task is arbitrarily "anchored" to the average level of the 3 months treatment - not the individual level, nor the level for an appropriate one-day treatment - so the left end point of the horizontal line ("now") essentially works as a population average reference point. Finally, the empirical analysis does not explicitly fit any time discounting function, neither with objective nor subjective time.

Our second contribution to the literature is that we designed the experiment to capture within-person changes in subjective time. Each person was asked to assess the subjective distance of all six time frames and then make discount-related choices between lottery payments today versus each of those six time delays. This allows us to rescale the responses so that individual heterogeneity in the implied subjective time scales are normalized out – permitting straightforward cross-person comparisons.

Third, we asked about time frames that plausibly span the range where an evolutionary theory of preferences might suggest "present day" effects all the way through a time frame long enough in the future to be near the point where discount rates stop falling under the traditional hyperbolic preferences hypotheses. Thus, we ask respondents to evaluate today compared to: tomorrow, one week, four weeks, thirteen weeks, 26 weeks and 52 weeks.

Fourth, we explicitly investigate the effect on choice consistency of "broken" sequences of time preferences questions. Frederick, Loewenstein, and O'Donoghue, (2002) have discussed an "anchoring" effect potentially occurring when respondents are asked to make a sequence of choices between a "Smaller-Sooner" (SS) and a "Larger-Later" (LL) reward, with the first faced choice biasing subsequent choices. Andersen, Harrison, Lau, and Rutström (2011) have explored the effect of presenting subjects time preferences questions in either an ascending or a descending order of time horizons (i.e. from 2 weeks to 12 months, or the other way around), and found that using ascending time horizons leads to a decrease of about 2.3% in the implicit discounting rates. In both their treatments, however, within each time horizon block, the list of time preferences questions were presented in an unbroken increasing order of the amounts of money paid in the LL option, that is, in an ascending order of implicit discounting rates. One potential concern about the method of asking people to choose Option A (SS) or Option B (LL) in a series of questions with the usual presentation as in Figure 1 is that one may expect people to realize that once they switch from Option A to Option B, it would be inconsistent to switch back. That is - one may wonder - the series of binary choices framed in an unbroken ascending order of implicit discounting rates may in principle impose consistency in choices where there is none in reality. To assess the extent to which respondents make genuinely consistent choices, we broke our six discounting choice tables into individual rows, and presented all the choices in random order, alternating pairs differing both for time delays and implicit discounting rates, so that as they answer the question respondents would be unable to detect whether they were being consistent or not. Next, we also presented our subjective time questions in random order (four weeks was asked first). (Appendix A has examples of our time frame questions.)

Our fifth contribution to the literature is to introduce a measure of recall time dilation over the short term, which can be used as an instrument in identifying the subjective time function from the discount rate function. Respondents sat in their lab cubicles in a basement room without windows or clocks, and all watches and cell phones were taken prior to entry in the room. Thus, participants had no objective (external) means of knowing what time it was. Twice during the experiment and at the end, respondents were asked how many minutes they thought had passed since the experiment began. While the estimated minutes were remarkably accurate on average (the mean guess for how long the experiment lasted in total, 66.1 minutes, was very close to the average actual duration of 61.3 minutes, presumably because anchored to the typical one-hour duration of a standard experiment in the lab), 33.7% of the respondents under-estimated the time. This group of people compressed time retrospectively, and therefore may be more likely to compress their perceptions of distant time prospectively. However, there would seem to be little reason to expect that this would be a direct predictor of impatience (discount rate) for a given subjective time frame once the compression is taken into account. Thus, we will use the measure of bias in estimating recent time as a instrument in our econometric model.

3. THE EXPERIMENT

We recruited subjects to participate in experiments at the LSE Behavioural Research Lab (BRL) in the summer of 2011. All subjects were recruited from volunteers within the BRL mailing list (about 5,000 subjects), which includes current undergraduate and post-graduate students of LSE and other institutions within the University of London, former students, members of staff, and non-student subjects. A total of 178 subjects, from different background, accepted to participate to the experiment, and signed up in of one the 18 experimental sessions. All experimental sessions were run at the BRL. There were no other eligibility or exclusion criterion to select participants. In the email invitation, subjects were not informed about the exact nature of the experiment that would be conducted, and were only told that: the experiment would last about an hour; they would receive £10 for their participation; they would have the chance to get an extra payment related to their tasks. Subjects could sign up to any of four one-hour sessions taking place between 11 am and 3 pm at every working day of the week. The experiment received full approval from the LSE Research Ethics Committee.

Participants were brought into the BRL lab in small groups. Upon arrival at the lab, subjects received an anonymous four-digit ID code assigned by the online recruitment system (SONA), read and signed an informed consent form, and were randomly assigned to a corresponding desk. Subjects were asked to wear a sticker tag with their ID code, as well as their assigned desk for all the duration of the experiment. Also, as mentioned, all timepieces and cell phones were taken from participants before entering the lab and kept in a safe room during the all experiment. The lab is in the basement of a building at LSE with florescent lighting, no windows and no clocks, and has individual cubicles divided by large partitions to prevent visual contact between subjects. In the lab, respondents were not given access to internet at their desks, and were given verbal and written instructions on paper forms.

The experiment progressed in three phases. Subjects were given specific instructions at the beginning of each phase and answered each of the three phases separately. Phase 1 consisted of gathering responses to a comprehensive questionnaire on socioeconomic and health characteristics, subjective well-being questions, as well as questions about the subjective belief about how far away various durations of time seemed in the future.

In particular, the subjective time questions involved asking respondents to imagine, for instance, "a day in four weeks from now". Subjects were presented a slider task and told that in the line presented below, the left-most end of the line represented "very short" while the right-most of the line represented "very long". Participants were then asked to place a mark on the line to indicate how long they perceived the duration to be "between now and one day four weeks from now". The time frames asked were: tomorrow, one week, four weeks, 13 weeks, 26 weeks, and 52 weeks. (See Appendix A for a sample question.) Each question was presented separately and the order of the different time frames was randomly assigned (beginning with the four weeks time frame question). The text of the question explicitly instructed the participants to consider where they would place the mark carefully and that they could not change their choice.

Phase 2 of the experiment involved playing a sound of constant frequency but different volumes to assess subject's subjective perception of sound. Subjects were asked to rate the perceived volume of each sound using the same slider task described above, which was also employed to measure other individual perceptions such as brightness and temperature in the room. For each individual response, the length between the beginning of the line and each mark was measured, in millimeters. As mentioned, in phase 2, as well as at several points in time during the sessions, subjects were also asked how much time they thought to have passed from the beginning of the experiment.

During Phase 3 of the experiment subjects made binary choices (108 in total) of when they would like to receive real monetary amounts over the same time frames across which the earlier subjective time questions were asked. In particular, following Harrison, Lau, and Williams (2002), and Andersen, Harrison, Lau, and Rutström (2008), we used a sequence of questions within a multiple price list (MPL) test to elicit time preferences. In each question, subjects were asked to choose between two paired options. Option A (the SS option) gave a "principal" amount X in a "sooner" period of time t. This was either the same day, or the day immediately following the day, of the experiment (see below). On the other hand, Option B (the LL option) gave a monetary amount $X+Y$ in a future period of time $t+T$, with T corresponding to each of the specific time frames used in the subjective time perception test, namely one day, one week, four weeks, 13 weeks, 26 weeks, and 52 weeks from the "sooner" period of time. We chose the "principal" amount of money X to be equal to £100, a relatively large nominal value that helps i) making salient the perceived differences in the largest delayed payments even for short time horizons; and ii) mitigating distortions due to subjects possibly rounding the delayed payments up to the nearest dollar (Andersen, Harrison, Lau, and Rutström, 2011). The amounts of money Y where chosen in a way that a subject switching from option A to option B would reveal the upper and lower bounds of her implicit discount for the time interval T. In particular, monetary amounts Y in each time frame were chosen in a way to associate to each pairs of options a minimum implicit annual discount rate – assuming objective time perception - of 5, 10, 20, 30, 40, 50, 60, 70, 80 percent, respectively. Amounts for the LL monetary values were calculated using simple - rather than compounded (e.g. bi-annually, quarterly) - annualized discounting rates. This was done to ensure consistency with the standard practices and current regulations within the banking and financial sectors in the UK where, typically, interest rates for mortgages, bonds, and credit cards, are always expressed as simple annualized rates.

There were thus nine SS-LL paired options questions for each of the six time frames corresponding to the ones used in the subjective time perception test. For all subjects, each of these 54 questions was repeated twice: half of the 108 questions referred to "now" as the time in the SS option, while half of them referred to "tomorrow" as the sooner date. That is, in the 54 "front-end delay" (FED) choices (Coller and Williams, 1999), both the SS and the LL rewards were shifted forward by one day. Including questions both with and without FED allows to capture genuine occurrence of non-constant discounting rates: by exclusively using FED choices, in fact, one may incorrectly infer exponential discounting simply because the questions design is unable to record non-constant discount rates occurring within the FED horizon (Andersen, Harrison, Lau, and Rutström, 2011). As already discussed, the MPL test presented to subjects the different pairs of options and the delay frames in a broken sequence and a randomly presented order.

In addition to the 108 time preferences questions, to control for individual risk preferences, subjects also answered 3 sets of 10 binary lottery questions each. Unlike for the time preferences questionnaire, within each set of risk preference questions the binary choices were presented in an unbroken, ordered, MPL, with the probabilities of the high prize increasing in increments of 0.1.

Crucially, subjects were told in advance that their answers to the questions in the MPL tests were going to determine their final payments for the experiment. Respondents were informed in advance that, at the end of the experiment, one of the 108 pairs of options for the time preferences, and one of the 30 pairs of lotteries for the risk preferences, would be randomly selected to be used for real for the final payment; and that, for each set of choices, each participant in the session had a 5% chance to be randomly selected to actually receive the payout corresponding to the option (or the outcome of the lottery) that she would prefer within the randomly selected pair.

To maximize the transparency and credibility of the payment procedure, all random selections took place physically in a room next to the lab in front of all subjects: they consisted in the draw of a ball from a bag containing either 108, or 30, numbered ping pong balls, to select the pair of option relevant for the payment, and then selections from a bag containing 20 balls, one for each desk in the lab, to determine whether each participant received the payment or not. To ensure that subjects were able to perfectly recall and check their preferred choices in the selected pairs, participants retained the handbook with their actual answers during all the random selections procedure (and of course could always check their assigned desk from the sticker tag).

Another key concern in time preferences experiments is to ensure that transaction costs and credibility of payments are the same across options at sooner and later dates. To achieve this, all payments for the time preferences questions were paid out using checks not payable before the due date, so that every subject selected for the payment had to make a trip to the bank to collect her earnings, regardless of the payment date. To maximize the credibility of the payments, each check (from the largest bank in the UK) was signed by the experimenter in front of the subjects, and secured by a stamp with the recognized logo of the LSE Behavioural Research Lab. A registry of all present and future due payments was also signed by both the experimenter and each selected subject under an official LSE letterhead. The payments based on the outcome of the selected lotteries in the risk preferences questions, as well as the £10 fixed show-up fees, were all paid in cash at the end of each session. In the instructions, participants were made aware of all these details prior to their choices.

4. ECONOMETRIC MODEL

Assume that each respondent can be characterized by two latent variables: the subjective perception of time, s^*, which depends on an innate tendency toward time compression, the objective time frame being assessed, and potentially other characteristics; and an individual discount rate, d^*, which depends on individual characteristics. Formally,

$$s_i^* = Z_i \underline{\gamma} + \eta_i \tag{8}$$

and

$$d_i^* = X_i \underline{\beta} + \varepsilon_i \tag{9}$$

Empirically, we observe neither s^* nor d^*. Rather, we observe some individual index of subjective time, s (as based on the millimeters measures), and upper and lower bounds on the latent discount rate, d^l and d^u. As for the latter, ultimately we know that an individual will reveal that their latent discount rate is between the upper an lower bounds according to the probability

$$\Pr\left[d_i^l < d_i^* \le d_i^u\right] = \Pr\left[d_i^l - X_i\beta < \varepsilon_i \le d_i^u - X_i\beta\right]$$
$$= \Phi\left(\frac{\exp\left(\dfrac{\ln FV^{\max} - \ln 100}{s_i^* / 365}\right) - 1 - X_i\beta}{\sigma}\right) - \Phi\left(\frac{\exp\left(\dfrac{\ln FV^{\min} - \ln 100}{s_i^* / 365}\right) - 1 - X_i\beta}{\sigma}\right)$$

where Φ(.) represents the standard normal CDF; ln 100 represents the £100 payout that was offered as the immediate payout for each discount choice; FV^{min} is the future value offer for the (implicit) row just prior to the respondent switching from preferring the immediate to the future payout; FV^{max} is the future value offered for the (implicit) row where the respondent switches to preferring the future option; and β and σ parameters to be estimated.

One key complication is that, to define the upper and lower bounds correctly, requires some estimate of s^* - the latent number of subjective days the respondent feels when confronted with some specific calendar time (e.g., one week). If we define the inverse function of (8) as $f^{-1}(t)$ as the implied number of subjective days associated with every objective time period, t, then the log likelihood function for the individual discount rate becomes:

(10)

$$\ln L =$$

$$= \sum_{d_i^* \in [0, d_i^u]} \ln\left(\Phi\left(\frac{\exp\left(\dfrac{\ln FV^{\max} - \ln 100}{f^{-1}(Z_i\gamma) \big/ 365} \right) - 1 - X_i\beta}{\sigma} \right) \right)$$

$$+ \sum_{d_i^* \in [d_i^l, d_i^u]} \ln\left(\Phi\left(\frac{\exp\left(\dfrac{\ln FV^{\max} - \ln 100}{f^{-1}(Z_i\gamma) \big/ 365} \right) - 1 - X_i\beta}{\sigma} \right) - \Phi\left(\frac{\exp\left(\dfrac{\ln FV^{\min} - \ln 100}{f^{-1}(Z_i\gamma) \big/ 365} \right) - 1 - X_i\beta}{\sigma} \right) \right)$$

$$+ \sum_{d_i^* \in [d_i^l, \infty]} \ln\left(1 - \Phi\left(\frac{\exp\left(\dfrac{\ln FV^{\min} - \ln 100}{f^{-1}(Z_i\gamma) \big/ 365} \right) - 1 - X_i\beta}{\sigma} \right) \right)$$

We will use an iterated maximum likelihood approach to estimating the parameter vector. First, we need an estimate for $f^{-1}(t)$.

Recall that each respondent filled in distances (in mm) on a defined line that represents how long they feel each calendar time frame (one day, one week, four weeks, thirteen weeks, 26 weeks and 52 weeks). Each person uses a distinct frame for this, some using most of the line and some using much less of the line. In order to allow pooling of the observations, we assume that individuals' subjective perception of one day is equal to the actual time of one day (or, at least approximately so). We then divide the length of the line for each response by the one-day length for each respondent. This has two benefits. First, it controls for individual heterogeneity in scaling by normalizing the distances for each person's individual scaling behavior. Second, it expresses the distances for each time period in subjective one-day units. Thus, when we estimate Equation (8) in terms of normalized lengths, we are estimating the relationship between subjective days and Z_i.

Additionally, given that our specification included objective days and objective days squared as predictors, once we have the estimated parameters $\hat{\gamma}$ in hand, then we can generate specific values of $s = f^{-1}(t)$ for all t using a simple quadratic equation. With the estimates of $f^{-1}(t)$ in hand, the upper and lower bounds of the latent discount rates for each time frame for each person were calculated and the primary log likelihood function in (10) was maximized. Since the discount bounds were based on predictive values for $f^{-1}(t)$, standard errors for the β from (10) were estimated via a bootstrap.

Furthermore, subjects in our experiments could have opted for the same SS option in all pairs in the list, indicating that their implicit discounting rate lay beyond the maximum value of 80%. This upper-bound censoring for those respondents is built into the definition of the likelihood function in (10) and so is fully accounted for in our model.

Finally, recall that our experimental design broke the Coller and Williams-style payoff table apart for each of our six delay frames and randomly presented each row. This provided respondents with the maximum opportunity to be inconsistent, if their choices actually were random or uncertain. For those inconsistent responses we have two options. First, we can assume that the lower bound to the latent discount rate is the implied rate for the row before the first switch occurs (if the table was constructed in a proper ascending order) and that the upper bound is the implied rate for the row where the final switch to Option B takes place. In this way, we would preserve each subject's responses, and merely have broader bands on some subject's implied discount rates. The second option is to just drop the multiple switches. Our empirical analysis has explored both options and results are qualitatively very similar under either approach. The model is more precisely estimated for the second approach, however, and those are the results that we will present here.

5. RESULTS

As for the question on "multiple-switching" consistency, we found that the vast majority of our subjects were consistent in their responses: around 11% of the responses exhibited multiple switches, that is, switched from Option A to Option B, and then back to Option A (and eventually then back again to Option B). We see this as tentative evidence that the usually high frequencies of consistent choices in (incentive-compatible) time preferences experiments are not a mere experimental artifact due to the design feature of using an unbroken ascending order of questions within each time horizon block.

The parameter estimates from the subjective time model are presented in Table 1. In order to avoid forcing the specific Weber-Fechner log-shaped relationship on the data (since that is a primary hypothesis being tested here) we included the delay for the payout and delay squared, rather than the log of delay. We found that the relationship is strongly non-linear in a manner that is consistent with Weber-Fechner. (Indeed, a version of the model where delay is entered as the natural log performs essentially identically to this specification, both in terms of the statistical significance of logged delay and in terms of R^2.)

In addition, subjects who under-estimated the length of the experiment in minutes were significantly different in terms of their prospective subjective perception of time. Intriguingly, none of the other personal characteristics significantly affected the subjective perception of time (and did not do so in any of the sensitivity analyses we ran). This is consistent with the hypothesis that non-linear subjective time perspective is something determined on a fundamental neuro-physiological level (as in the Weber-Fechner law), and not subject to much cultural or environmental modification.

In order to generate the predictions of $f^{-1}(t)$ needed to calculate the upper and lower bounds of the discount function, we estimated a limited version of the model in Table 1, with only the delay and delay squared included, then solved for the implied number of subjective days. Figure 2 plots the average results. Note the similarities to the revealed shape of the subjective days function with the Weber-Fechner hypothesis. Perception of subjective time appears to behave much like perceptions of heat, light and sound, and closely follow a log-shaped curve.

We then estimated two versions of the discount rate model. The first was one where the upper and lower bounds were calculated using objective time in, as in Equation (5). This is the approach taken in all past literature estimating individual discount rates. The second column in Table 2 are the results from maximizing the log likelihood in (10) using the upper and lower bounds on the latent discount function taking subjective time into account. In addition to the linear and squared terms for the delay in the payout, we also included an indicator variable for whether the SS date was "today" or "tomorrow" to account for the front end delay and to provide a more precise test of the evolutionary motivation for quasi-hyperbolic preferences: is today versus tomorrow different than today versus any other time frame? Finally, we also include the socio-economic variables that were also included in our subjective time model.

We found that in both the objective time and subjective time versions of the model the implied discount factor is a function of the delay in the payment, as would be expected. In addition, given the statistically significant parameter of the "SS date is today" variable, there is strong evidence for the hypothesis that the current day discounting differs from discounting in all future periods: unlike Andersen, Harrison, Lau, and Rutström (2011) we find that implicit discount rates were significantly higher in the individual responses to the questions without front end delay.

Ultimately, however, we want to know whether accounting for the fact that individuals make choices based on subjective time rather than objective time can explain the hyperbolic behavior observed in most existing studies. To test this, we predicted the implied discount rate for each person in each time frame under both models. The predicted values and the 95% confidence intervals are presented in Tables 3a. and 3b. and in Figures 3 and 4. We find a striking difference between the pattern of predicted discount rates under the two models. When (incorrectly) assuming that people respond to objective time, we find discount rates that are high (i.e. above 57% and up to 110% per year, consistently with most other estimates of individual discount rates in the literature) and that exhibit a sharply declining rate as the delay increases. This is most easily seen in Figure 3.

However, when we account for the non-linearities in each respondent's subjective perception of time, we find predicted discount rates that are: 1) much lower than usually found in the hyperbolic discounting literature, and much more in line with what found by Andersen, Harrison, Lau, and Rutström (2011) (i.e. in the region of 12-22% per year) and, ultimately, with market interest rates; 2) higher for "today" compared to all other delays; and 3) statistically indistinguishable from one another for all time delays after today. Much of the hyperbolic pattern evident in Figure 3 is absent from Figure 4. It is true that as a point estimate, the discount rate for the one-day delay appears higher than for the one-week through one-year delays. But, as can be seen in Table 3b and Figure 4, all the discount rate point estimates for time periods from one week to one year fall within the 95% confidence intervals of each other. Thus, like Andersen, Harrison, Lau, and Rutström (2011), we cannot reject the null hypotheses that they are the same.

6. DISCUSSION AND CONCLUSIONS

Time preferences are fundamental to optimal dynamic decision-making, and likely to have a major impact on individual decisions with regard to health investments. One of the most common findings in experimental studies assessing individual time preferences is that discount rates are higher for more proximate time periods and lower for more distal ones. If true and ubiquitous, this would have profound implications for individual choices – and indeed for the possibility of learning about welfare from observed behavior. Sharply declining discount rates with increasing time delays, often referred to as hyperbolic time preferences – suggest that many decisions will be time-inconsistent. Several alternative motives have been proposed to explain hyperbolic time preferences, including individual impulsivity; tempting “visceral factors”; different cognitive concreteness in visualizing present and future events; sub-additive discounting; non-linear probability weighting in the perception of risk; and differences in students and adults subjects pools.

In this paper, we look at an alternative explanation and relate to the new branch of the behavioral economics literature that asks whether or not human perception of time is a linear mapping from calendar time (e.g., if two years are perceived as less than twice as far away as one year). If it is not the case that the subjective perception of time delays (at least prospectively) are identical to objective calendar time, then we have made a math error when calculating discount rates in empirical studies for several decades. We explore this question using data from a lab experiment conducted at LSE whereby we elicit both subjects’ perception of time duration, and incentive-compatible inter-temporal preferences across six time delays ranging from one day to one year. These responses permit us to estimate implied discount rates while simultaneously controlling for any non-linearities in the subjective perception of time.

Our data replicate the usual finding of rapidly falling discount rates with increasing delays when we assume subjective time is the same as calendar time. Our data, however reject the equivalence between subjective and calendar time, and when we adjust for the difference between calendar delay and perceived delay, we find very different patterns of discount rates: while discounting rates based on “objective time” replicate the usual hyperbolic preferences, the curve of the discounting factors obtained from “subjective time” does not exhibit much of the hyperbolic pattern and, if anything, resembles the shape of a quasi-hyperbolic function. Accounting for individual perception of time thus drives a wedge between time discounting and “pure” time preferences. We find that there remains a “first day” effect of delay on time preferences – where respondents appear to have genuinely higher impatience when choosing between today and tomorrow, or today and any further point in the future – but that discount rates for delays from one week to one year are statistically indistinguishable.

Thus, we argue that there is good reason to suspect that much of the hyperbolic-like discount rate estimates in the literature is a case of "getting the maths wrong".

Our results can be related to the recent findings by Andersen, Harrison, Lau, and Rutström (2011) who also find no significant evidence of hyperbolic discounting in most their empirical specifications. An exception is their Weibull specification, which, as noticed, is conceptually close to our discounting rate adjusted for individual time perception: in that case, discount rates were found to be slightly decreasing, although the hypothesis of exponential discounting could not be rejected. Our findings differ from Andersen, Harrison, Lau, and Rutström (2011) mainly in that, even after correcting for subjective time perception, we find a significantly higher discounting for the very "first day". This result could be due to differences in the studies' design (e.g. they use 2 weeks as a shortest time horizon, together with a 1-month FED, while we directly include 1-day time horizons), or by obvious differences in the students-adults, or the UK-Denmark, subjects pools.

We leave to further research the intriguing questions of whether the Weber-Fechner-shaped curvature of the individual perception of time may be related to decreasing impatience and other forms of non-stationary time preferences (Prelec, 2004; Bleichrodt, Rodhe, and Wakker, 2009), or to non-linear probability weighting and sub-proportionality, which have also been found to associate with hyperbolic discounting (Epper, Fehr-Duda et al. 2011). Other questions which deserve further explicit investigation are whether subjective time perception is associated to other self-reported personality measures commonly used in surveys (such as impulsiveness, self-control, or patience) or to non-personality factors such as age or individual cognitive skills.

In the meanwhile, our findings are of significant practical importance. Few economic decisions (other than, perhaps, whether to stop daily consumption of an addictive good) are made over the time frame of "today" compared to later. For those decisions that are, genuinely declining discounting rates may reflect underlying self-control problems. Most economic activities, however, – from paying utility bills to purchasing groceries, from planning savings and retirement, to making plans to attend a concert – involve committing to resource allocations where the consumption tradeoffs are delayed by more than a day in the future. For these activities the detrimental impact of time-inconsistencies may be practically of a lesser relevance than the effect of subjective time compression. Policy interventions which are designed on the assumption that, in our inter-temporal decisions, we are always time-inconsistent - such as the ones involving commitment devices, front-end monetary incentives, and pre-commitment defaults - may miss part of the broader picture. Behavioral scientists informing policy decision-making can fruitfully explore future interventions based on alternative psychological motives and mechanisms - such as subjective time perception- which can potentially underpin apparent inconsistencies in inter-temporal choices.

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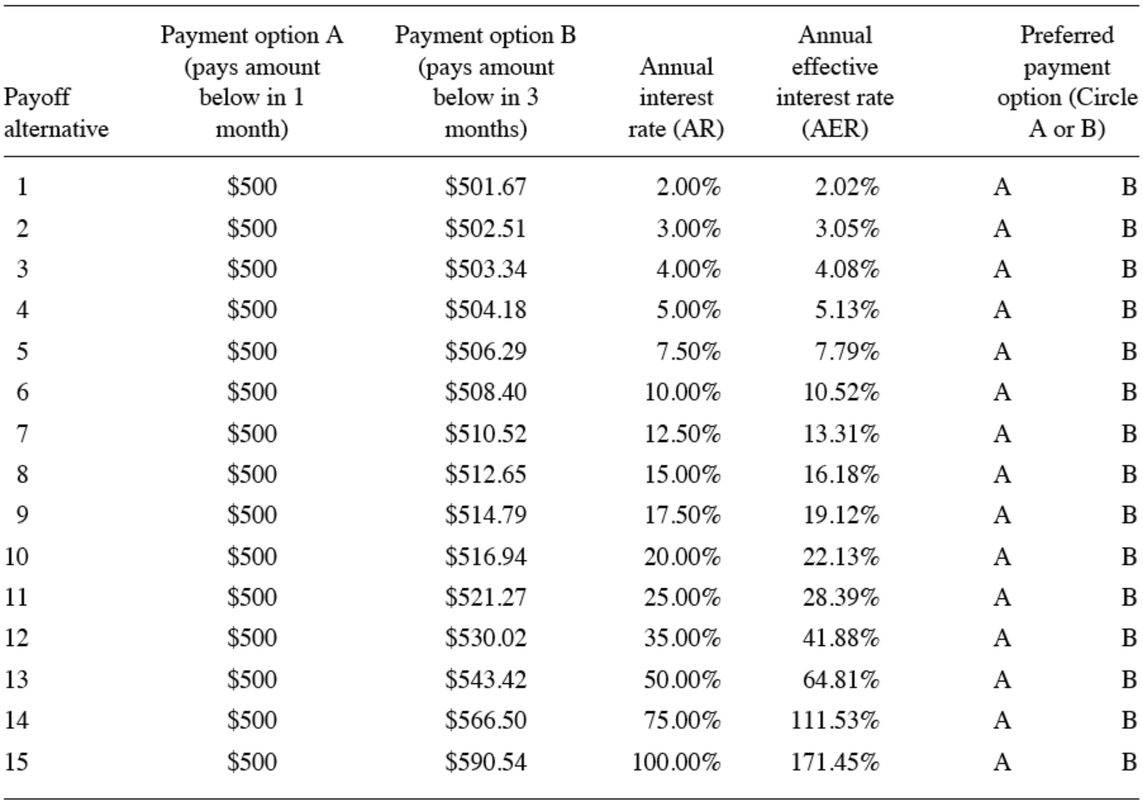
Figure 1: Example of discounting elicitation test



Payoff alternative	Payment option A (pays amount below in 1 month)	Payment option B (pays amount below in 3 months)	Annual interest rate (AR)	Annual effective interest rate (AER)	Preferred payment option (Circle A or B)	
1	$500	$501.67	2.00%	2.02%	A	B
2	$500	$502.51	3.00%	3.05%	A	B
3	$500	$503.34	4.00%	4.08%	A	B
4	$500	$504.18	5.00%	5.13%	A	B
5	$500	$506.29	7.50%	7.79%	A	B
6	$500	$508.40	10.00%	10.52%	A	B
7	$500	$510.52	12.50%	13.31%	A	B
8	$500	$512.65	15.00%	16.18%	A	B
9	$500	$514.79	17.50%	19.12%	A	B
10	$500	$516.94	20.00%	22.13%	A	B
11	$500	$521.27	25.00%	28.39%	A	B
12	$500	$530.02	35.00%	41.88%	A	B
13	$500	$543.42	50.00%	64.81%	A	B
14	$500	$566.50	75.00%	111.53%	A	B
15	$500	$590.54	100.00%	171.45%	A	B

Source: Coller, M. and Williams, M.B. (1999).

Figure 2

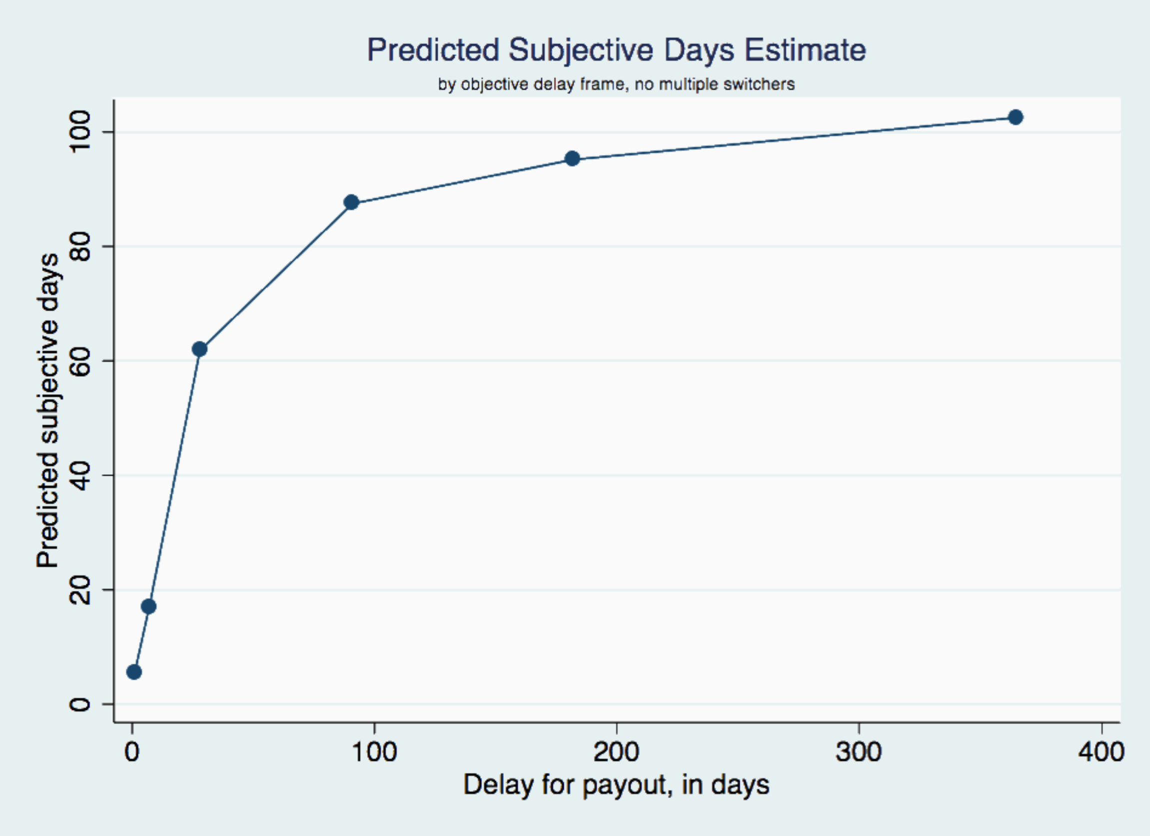

Predicted Subjective Days Estimate
by objective delay frame, no multiple switchers
Predicted subjective days
0
20
40
60
80
100
0
100
200
300
400
Delay for payout, in days

Figure 3

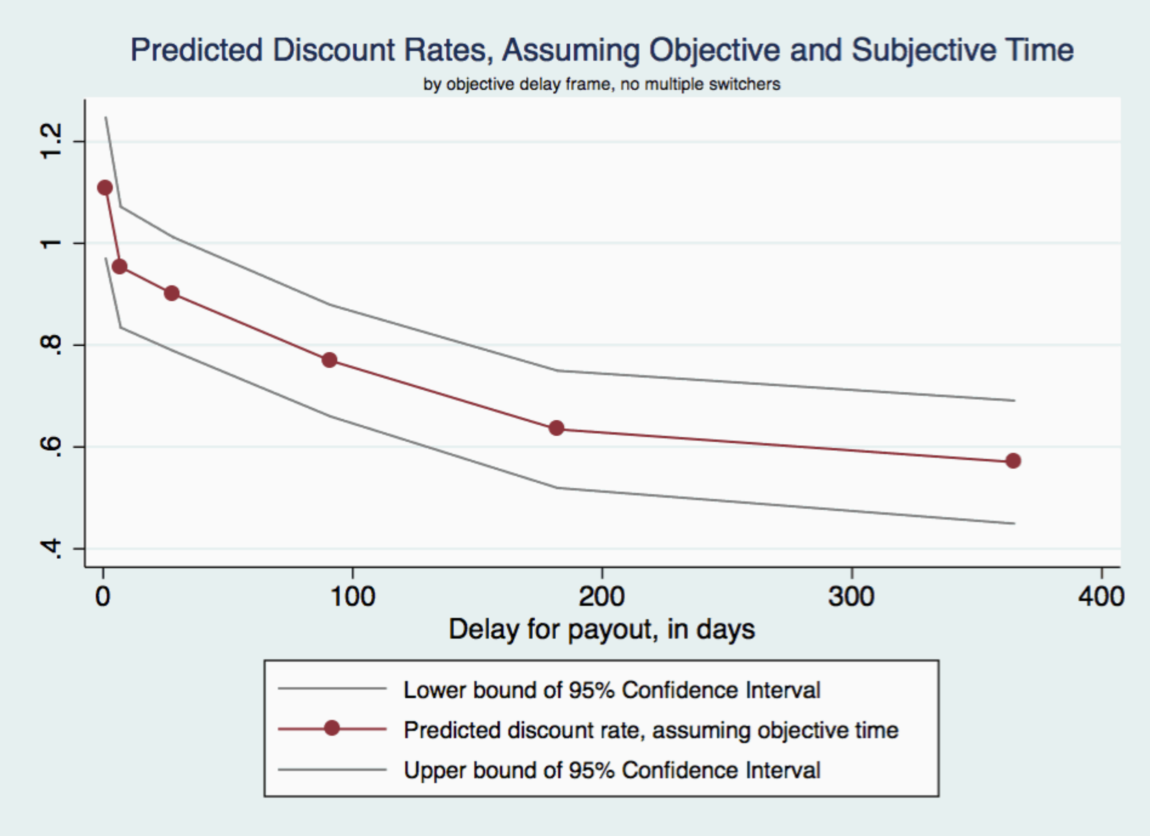

Predicted Discount Rates, Assuming Objective and Subjective Time
by objective delay frame, no multiple switchers
.4
.6
.8
1
1.2
0
100
200
300
400
Delay for payout, in days
Lower bound of 95% Confidence Interval
Predicted discount rate, assuming objective time
Upper bound of 95% Confidence Interval

Figure 4

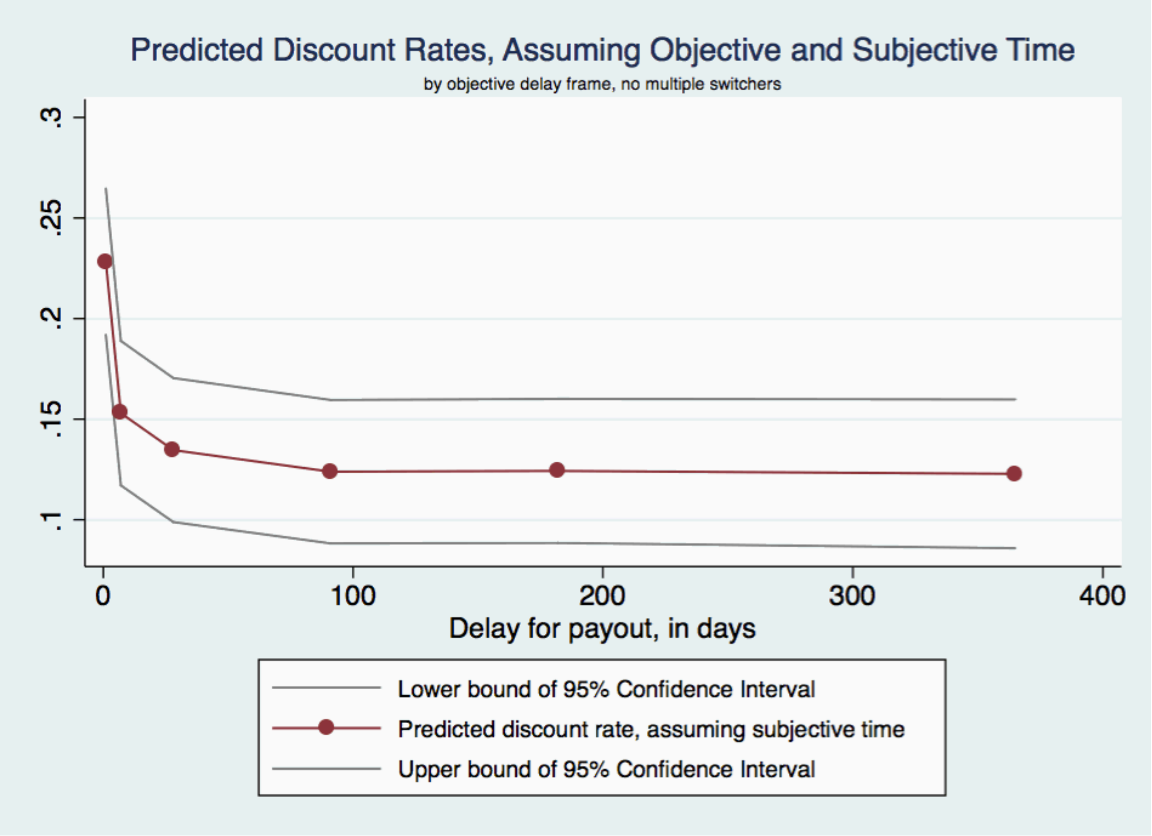

Predicted Discount Rates, Assuming Objective and Subjective Time
by objective delay frame, no multiple switchers
.1
.15
.2
.25
.3
0
100
200
300
400
Delay for payout, in days
Lower bound of 95% Confidence Interval
Predicted discount rate, assuming subjective time
Upper bound of 95% Confidence Interval

Table 1: Subjective Time Model

	(1) Normalized subjective perception of time b/t
Delay for payout, in days	0.19***
	(10.06)
Delay for payout, squared	-0.00026***
	(-7.14)
Respondent under-estimates length of experiment	8.90**
	(2.35)
Respondent is over age 25	-1.67
	(-0.60)
Respondent is female	-1.54
	(-0.63)
Respondent is Hindu	4.20
	(0.65)
Respondent is Muslim	2.47
	(0.64)
Respondent is active in religion	1.93
	(0.54)
Respondent has some savings	-2.01
	(-0.61)
Respondent will need savings in coming year	0.79
	(0.26)
How satisfied with life overall	0.73
	(0.78)
Respondent has good or better health	0.18
	(0.07)
Respondent's expected years of life	0.094
	(1.07)
Constant	-18.2
	(-1.65)
Observations	881

* p<0.10, ** p<0.05, *** p<0.01

Table 2: Interval Regression Model Coefficients for Discount - no multiple switchers

	(1) Assuming Objective Time b/t	(2) Assuming Subjective Time b/t
SS date is today	0.15**	0.067***
	(2.53)	(4.66)
Delay for payout, in days	-0.0025***	
	(-4.84)	
Delay for payout, squared	0.0000040***	
	(3.00)	
Predicted subjective days		-0.00081***
		(-3.86)
Predicted subjective days, squared		0.0000022***
		(2.91)
Respondent is over age 25	0.0063	0.0078
	(0.16)	(0.64)
Respondent is female	-0.057*	0.018*
	(-1.70)	(1.66)
Respondent is Hindu	0.053	-0.011
	(0.92)	(-0.64)
Respondent is Muslim	0.055	0.035**
	(0.95)	(2.02)
Respondent is active in religion	0.040	-0.024*
	(0.96)	(-1.86)
Respondent has some savings	-0.11***	-0.0058
	(-2.72)	(-0.50)
Respondent will need savings in coming year	-0.0070	0.021**
	(-0.20)	(2.05)
How satisfied with life overall	-0.014	0.0016
	(-1.19)	(0.42)
Respondent has good or better health	0.058	0.0046
	(1.59)	(0.45)
Respondent's expected years of life	0.0026*	-0.00062
	(1.77)	(-1.31)
Constant	0.92***	0.19***
	(6.00)	(3.51)
Lnsigma		
Constant	-0.87***	-2.39***
	(-22.24)	(-44.09)
Observations	887	744

* p<0.10, ** p<0.05, *** p<0.01

Table 3a: Predicted Discount Rate Assuming Objective Time, no multiple switchers

	(1) 95% CI Lower Bound Mean	(2) Predicted Discount Rate Mean	(3) 95% CI Upper Bound Mean
1	0.970	1.109	1.247
7	0.835	0.953	1.072
28	0.789	0.901	1.012
91	0.660	0.770	0.879
182	0.520	0.635	0.750
365	0.449	0.570	0.691
Observations	887	887	887

Table 3b: Predicted Discount Rate Assuming Subjective Time, no multiple switchers

	(1) 95% CI Lower Bound Mean	(2) Predicted Discount Rate Mean	(3) 95% CI Upper Bound Mean
1	0.192	0.228	0.265
7	0.117	0.153	0.189
28	0.0988	0.135	0.170
91	0.0882	0.124	0.160
182	0.0885	0.124	0.160
365	0.0858	0.123	0.160
Observations	754	754	754

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APPENDIX A

Slider task to measure subjective time perception.

Imagine a day **4 weeks** from now.

On the below line, the left-most end of the line represents “Very short”, and the right-most end of the line represents “Very long”.

Please place a mark on the line to indicate how long you consider the **duration** to be **between today** and one day **4 weeks from now**.

Once you have done your choice, you cannot go back and change it. If you make a mistake, please call immediately the experimenter.

Very short ____ Very long

APPENDIX B.

Example of time preferences questions.

Pair	**Option A**		**Option B**		**Your choice**: A	**Your choice**: B
	Receive £		**Receive £**			
1	100	Today	100.01	Tomorrow	A	B
2	100	Today	101.54	In 1 week	A	B
3	100	Today	100.76	In 4 weeks	A	B
4	100	Today	117.5	In 13 weeks (3 months)	A	B
5	100	Today	110	In 26 weeks (6 months)	A	B
6	100	Today	160	In 52 weeks (1 year)	A	B
7	100	Today	100.08	Tomorrow	A	B
8	100	Today	100.96	In 1 week	A	B
9	100	Today	103.08	In 4 weeks	A	B
10	100	Today	110	In 13 weeks (3 months)	A	B
11	100	Today	125	In 26 weeks (6 months)	A	B
12	100	Today	130	In 52 weeks (1 year)	A	B
13	100	Today	100.16	Tomorrow	A	B
14	100	Today	100.38	In 1 week	A	B
15	100	Today	105.38	In 4 weeks	A	B
16	100	Today	102.5	In 13 weeks (3 months)	A	B
17	100	Today	140	In 26 weeks (6 months)	A	B
18	100	Today	105	In 52 weeks (1 year)	A	B
19	100	Today	100.03	Tomorrow	A	B
20	100	Today	101.35	In 1 week	A	B
21	100	Today	101.54	In 4 weeks	A	B

Pair	**Option A**		**Option B**		**Your choice**: A	**Your choice**: B
	Receive £		**Receive £**			
22	100	Today	115	In 13 weeks (3 months)	A	B
23	100	Today	115	In 26 weeks (6 months)	A	B
24	100	Today	150	In 52 weeks (1 year)	A	B
25	100	Today	100.05	Tomorrow	A	B
26	100	Today	101.15	In 1 week	A	B
27	100	Today	102.31	In 4 weeks	A	B
28	100	Today	112.5	In 13 weeks (3 months)	A	B
29	100	Today	120	In 26 weeks (6 months)	A	B
30	100	Today	140	In 52 weeks (1 year)	A	B
31	100	Today	100.1	Tomorrow	A	B
32	100	Today	100.77	In 1 week	A	B
33	100	Today	103.85	In 4 weeks	A	B
34	100	Today	107.5	In 13 weeks (3 months)	A	B
35	100	Today	130	In 26 weeks (6 months)	A	B
36	100	Today	120	In 52 weeks (1 year)	A	B
37	100	Today	100.14	Tomorrow	A	B
38	100	Today	100.48	In 1 week	A	B
39	100	Today	104.62	In 4 weeks	A	B
40	100	Today	105	In 13 weeks (3 months)	A	B
41	100	Today	135	In 26 weeks (6 months)	A	B

Pair	**Option A**		**Option B**		**Your choice**: A	**Your choice**: B
	Receive £		**Receive £**			
42	100	Today	110	In 52 weeks (1 year)	A	B
43	100	Today	100.19	Tomorrow	A	B
44	100	Today	100.19	In 1 week	A	B
45	100	Today	106.15	In 4 weeks	A	B
46	100	Today	101.25	In 13 weeks (3 months)	A	B
47	100	Today	102.5	In 26 weeks (6 months)	A	B
48	100	Today	180	In 52 weeks (1 year)	A	B
49	100	Today	100.22	Tomorrow	A	B
50	100	Today	100.09	In 1 week	A	B
51	100	Today	100.38	In 4 weeks	A	B
52	100	Today	120	In 13 weeks (3 months)	A	B
53	100	Today	105	In 26 weeks (6 months)	A	B
54	100	Today	170	In 52 weeks (1 year)	A	B

Pair	**Option A**		**Option B**		**Your choice**: A	**Your choice**: B
	Receive £		**Receive £**			
55	100	Tomorrow	100.22	Day after tomorrow	A	B
56	100	Tomorrow	100.09	In 1 day and 1 week	A	B
57	100	Tomorrow	105.38	In 1 day and 4 weeks	A	B
58	100	Tomorrow	102.5	In 1 day and 13 weeks (3 months)	A	B
59	100	Tomorrow	130	In 1 day and 26 weeks (6 months)	A	B
60	100	Tomorrow	120	In 1 day and 52 weeks (1 year)	A	B
61	100	Tomorrow	100.14	Day after tomorrow	A	B
62	100	Tomorrow	100.48	In 1 day and 1 week	A	B
63	100	Tomorrow	103.08	In 1 day and 4 weeks	A	B
64	100	Tomorrow	110	In 1 day and 13 weeks (3 months)	A	B
65	100	Tomorrow	115	In 1 day and 26 weeks (6 months)	A	B
66	100	Tomorrow	150	In 1 day and 52 weeks (1 year)	A	B
67	100	Tomorrow	100.05	Day after tomorrow	A	B
68	100	Tomorrow	101.15	In 1 day and 1 week	A	B

Pair	**Option A**		**Option B**		**Your choice**: A	**Your choice**: B
	Receive £		**Receive £**			
69	100	Tomorrow	100.76	In 1 day and 4 weeks	A	B
70	100	Tomorrow	117.5	In 1 day and 13 weeks (3 months)	A	B
71	100	Tomorrow	102.5	In 1 day and 26 weeks (6 months)	A	B
72	100	Tomorrow	180	In 1 day and 52 weeks (1 year)	A	B
73	100	Tomorrow	100.19	Day after tomorrow	A	B
74	100	Tomorrow	100.19	In 1 day and 1 week	A	B
75	100	Tomorrow	104.62	In 1 day and 4 weeks	A	B
76	100	Tomorrow	105	In 1 day and 13 weeks (3 months)	A	B
77	100	Tomorrow	125	In 1 day and 26 weeks (6 months)	A	B
78	100	Tomorrow	130	In 1 day and 52 weeks (1 year)	A	B
79	100	Tomorrow	100.16	Day after tomorrow	A	B
80	100	Tomorrow	100.38	In 1 day and 1 week	A	B
81	100	Tomorrow	103.85	In 1 day and 4 weeks	A	B
82	100	Tomorrow	107.5	In 1 day and 13 weeks (3 months)	A	B

Pair	**Option A**		**Option B**		**Your choice**: A	**Your choice**: B
	Receive £		**Receive £**			
83	100	Tomorrow	120	In 1 day and 26 weeks (6 months)	A	B
84	100	Tomorrow	140	In 1 day and 52 weeks (1 year)	A	B
85	100	Tomorrow	100.1	Day after tomorrow	A	B
86	100	Tomorrow	100.77	In 1 day and 1 week	A	B
87	100	Tomorrow	102.31	In 1 day and 4 weeks	A	B
88	100	Tomorrow	112.5	In 1 day and 13 weeks (3 months)	A	B
89	100	Tomorrow	110	In 1 day and 26 weeks (6 months)	A	B
90	100	Tomorrow	160	In 1 day and 52 weeks (1 year)	A	B
91	100	Tomorrow	100.08	Day after tomorrow	A	B
92	100	Tomorrow	100.96	In 1 day and 1 week	A	B
93	100	Tomorrow	101.54	In 1 day and 4 weeks	A	B
94	100	Tomorrow	115	In 1 day and 13 weeks (3 months)	A	B
95	100	Tomorrow	105	In 1 day and 26 weeks (6 months)	A	B

Pair	**Option A**		**Option B**		**Your choice**: A	**Your choice**: B
	Receive £		**Receive £**			
96	100	Tomorrow	170	In 1 day and 52 weeks (1 year)	A	B
97	100	Tomorrow	100.01	Day after tomorrow	A	B
98	100	Tomorrow	101.35	In 1 day and 1 week	A	B
99	100	Tomorrow	106.15	In 1 day and 4 weeks	A	B
100	100	Tomorrow	101.25	In 1 day and 13 weeks (3 months)	A	B
101	100	Tomorrow	140	In 1 day and 26 weeks (6 months)	A	B
102	100	Tomorrow	105	In 1 day and 52 weeks (1 year)	A	B
103	100	Tomorrow	100.03	Day after tomorrow	A	B
104	100	Tomorrow	101.54	In 1 day and 1 week	A	B
105	100	Tomorrow	100.38	In 1 day and 4 weeks	A	B
106	100	Tomorrow	120	In 1 day and 13 weeks (3 months)	A	B
107	100	Tomorrow	135	In 1 day and 26 weeks (6 months)	A	B
108	100	Tomorrow	110	In 1 day and 52 weeks (1 year)	A	B

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