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Eliciting utility curvature and time preference

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Abstract

In both standard and behavioral theory, as well as experimental procedures to elicit time preference, it is commonly assumed that a single utility function is used to evaluate payoffs both under risk and over time. I introduce a novel experimental design to examine this assumption, by transposing the well-known Holt-Laury risk preference experiment from state-payoff space into time-dated payoff space. I find that the curvature of utility elicited directly from choices over time is significantly concave, but far closer to linear than utility elicited under risk. As a result, the effect of correcting discount rates for this curvature is modest.

JEL classification: C91, D03, D81, D90.

Keywords: Risk preference, time preference, measurement of utility, discounted utility, choice list.

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1 Introduction

In both standard and behavioral theories of choice under risk and over time, the value of a risky or temporal prospect is typically modeled as a weighted sum of the utilities of its constituent elements. Thus, in the standard model of risk preference (von Neumann and Morgenstern, 1944), the *expected utility* of a lottery is given by the probability-weighted sum of the utilities of the individual prizes, as evaluated by a Bernoulli utility function. Analogously, in the standard model of time preference (Samuelson, 1937), the *discounted utility* of a stream of payoffs is given by the (exponentially-) discounted sum of the utilities of the individual payoffs, as evaluated by an instantaneous utility function.[1] Leading behavioral alternatives such as rank-dependent utility (Quiggin, 1982), cumulative prospect theory (Tversky and Kahneman, 1992), and (quasi-) hyperbolic discounting (Laibson, 1997; Loewenstein and Prelec, 1992) retain this underlying structure, while relaxing the assumptions of linear probability weighting and exponential discounting.

In settings where both risk and time are present, it is common – and perhaps even natural – to assume that the Bernoulli utility function used to evaluate payoffs under risk is one and the same as the instantaneous utility function used to evaluate payoffs over time. In standard theory, this gives rise to the *discounted expected utility* model, which has been described as "arguably the workhorse of economic modeling" (Traeger, 2012, p. 1). Moreover it is not only in standard theory that this equivalence is assumed. For example, prospect-theoretic models of time-dependent probability weighting (Halevy, 2008; Epper et al., 2011; Epper and Fehr-Duda, 2012) also invoke the same assumption. These models view future payoffs as inherently risky, and posit a relationship between subproportional probability weighting and hyperbolic discounting, under the assumption that a single function characterizes utility for both risk and time. However, notwithstanding the ubiquity of the assumption, empirical evidence of its veracity remains sparse.

The question of whether utility under risk is interchangeable with utility over time is also a core issue in the design of experimental procedures to elicit time preferences. The primary objective of such studies is usually to estimate the parameters of a discount function, and many studies do so under the maintained assumption that utility is linear (e.g. Coller and Williams, 1999). However since subjects' choices in a time preference experiment are a product of both the utility and discount functions, such estimates will be biased if utility is in fact concave (Frederick et al., 2002, pp. 381–382).[2] It is therefore necessary to allow for the possibility of non-linear utility in the design of a time preference experiment.

Unfortunately, as noted by Abdellaoui et al. (2013), this task has been hindered by a dearth of methods to measure the curvature of utility outside the domain of risk. The existing experimental literature approaches the issue in three main ways, which differ in whether or not they assume the equivalence of utility for risk and time, and whether they yield estimates of both utility and discounting parameters.

[1]The nomenclature of Bernoulli utility is due to Mas-Colell et al. (1995, p. 184), while that of instantaneous utility is used by Frederick et al. (2002), among others.

[2]Consider a subject who is presented with a binary choice between a smaller-sooner payoff or a larger-later one, and suppose that the former is chosen. There are two factors that combine to lead this subject to reject the larger-later alternative, namely time discounting and diminishing marginal utility. Therefore if the latter is assumed away, then the effect of the former will be overstated.

Firstly, Takeuchi (2011) and Laury et al. (2012) develop experimental designs that enable them to identify discounting without knowledge of the utility function. To do so, these papers must assume both expected utility for the evaluation of risk, and a single (unobserved, but potentially non-linear) utility function that is applicable both under risk and over time.[3]

Secondly, in what is arguably the best-known approach, Andersen et al. (2008) measure utility by eliciting subjects' risk preferences and jointly estimate a utility function and a discount function corrected for utility curvature. This approach maintains the assumption that utility under risk is the same as utility over time, but has the advantage that it need not rely on the assumption of expected utility for the evaluation of risk.

Finally, and most closely related to the present paper, a number of recent studies attempt to elicit information on the curvature of utility directly from choices over time. Abdellaoui et al. (2013) do this by eliciting the present equivalent of a temporal prospect. For gains, they conclude that utility over time is close to linear, whereas for risk they find that utility is more concave. However, Abdellaoui et al. acknowledge that they are not interested in the measurement of discounting parameters (p. 2156), and moreover the procedures they use to elicit utility under risk and over time are not completely comparable.[4]

Andreoni and Sprenger (2012a) estimate both utility and discount functions from choices over time, by allowing subjects to allocate a budget between payments on two dates. When payments on both dates are sent with certainty, they find that utility is close to linear, reflecting the fact that subjects overwhelmingly make choices at the corners of the budget set. In a companion paper, Andreoni and Sprenger (2012b) study the case where payments on both dates are subject to risk, and find that interior choices are far more prevalent.[5] One interpretation for this result is that utility under risk may be more concave than utility under certainty, however the interpretation of the results of Andreoni and Sprenger (2012b) has been keenly debated due to the presence of a diversification confound in the experiment design (Harrison et al., 2013; Cheung, in press; Epper and Fehr-Duda, in press; Schmidt, 2014).

In this paper, I introduce a novel experimental procedure to elicit discount rates, allowing for non-linear utility, and without imposing the assumption of a single utility function for both risk and time. This approach builds upon the well-known Holt and Laury (2002, hereinafter HL) procedure for eliciting risk preference, by effectively transposing the HL design from state-payoff space into time-dated payoff space. The HL task is a popular and widely-accepted procedure to elicit the curvature of utility under risk. Moreover, it

[3]In particular, Takeuchi (2011) elicits both the equivalent probability under risk as well as the equivalent delay over time that make a subject indifferent between a given pair of payoffs, thereby "converting delay into risk". Laury et al. (2012) bypass the utility function by constructing an experiment involving only two payoff levels, in which the probability of future payment is varied instead of its size. (Although Laury et al. also report estimates for a specification that allows for probability weighting, this requires them to combine the data from their main instrument with that of additional experimental tasks.)

[4]For risk, Abdellaoui et al. elicit the certainty equivalent of a risky prospect, i.e. an amount that pays *equally* in both states of nature. This corresponds to the point at which an indifference curve intersects the *diagonal* in state-payoff space. By contrast for time, they elicit a present equivalent which is an amount that pays *solely* on a single date. This corresponds to the point at which an indifference curve intersects the *axis* in time-dated payoff space. Notice, however, that the impact of the curvature of utility upon preference is *minimized* on the diagonal (where the payoff difference between the two states or dates vanishes), whereas the impact of curvature is *maximized* on the axis (where the payoff distance is at its greatest, given that one of the payoffs is zero).

[5]Thus notice that this result involves an interaction of risk and time, whereas the results in Abdellaoui et al. (2013) and in the present paper compare atemporal choices under risk to intertemporal choices under certainty.

forms the basis for the risk-preference component of the equally well-known Andersen et al. (2008) joint estimation procedure, which assumes a single utility function for both risk and time in order to estimate discount rates corrected for utility curvature.[6] By comparing the results of the intertemporal HL design to those of the standard version under risk, I can compare the curvature of utility elicited over time to that elicited under risk, within a unified and highly comparable framework for the measurement of both.

The results of the experiment firstly confirm many previous findings that utility elicited under risk is concave (for a review, see Harrison and Rutström, 2008). This does not rely upon expected utility under risk: when rank-dependent specifications are estimated there is significant probability weighting, yet substantial utility curvature remains. Secondly, the curvature of utility elicited directly from choices over time is also significantly concave but less so that utility under risk, with the estimated CRRA coefficient being an order of magnitude smaller. This is consistent with the results of Abdellaoui et al. (2013) and Andreoni and Sprenger (2012a), who also find limited concavity of utility for choices over time. It follows that whereas Andersen et al. (2008) find that correcting for risk-elicited utility curvature has a substantial effect in lowering estimated discount rates, I find the effect of correcting for time-elicited curvature to be modest.

2 Design

2.1 The standard HL design for risk

The basic structure of the HL procedure for eliciting risk preference is well-known in the experimental economics literature. However, its representation in terms of the state-preference model has not, to the best of my knowledge, previously been elaborated, and is helpful in making the extension to the domain of time preference. I therefore begin by setting out this representation.

The HL experiment consists of a series of choices between two alternatives, labeled Options A and B, and is customarily presented in the format of a choice list. Each alternative is a risky prospect which pays some low prize x_b in the "bad" state, which occurs with probability $1-p_g$, and some high prize $x_g > x_b$ in the "good" state, with probability p_g. Options A and B represent two distinct payoff vectors (x_b, x_g), and within each choice the probability p_g of the better prize is the same for both alternatives. Moving down the rows of the choice list, the two payoff vectors remain unchanged and it is only the probability p_g that varies.

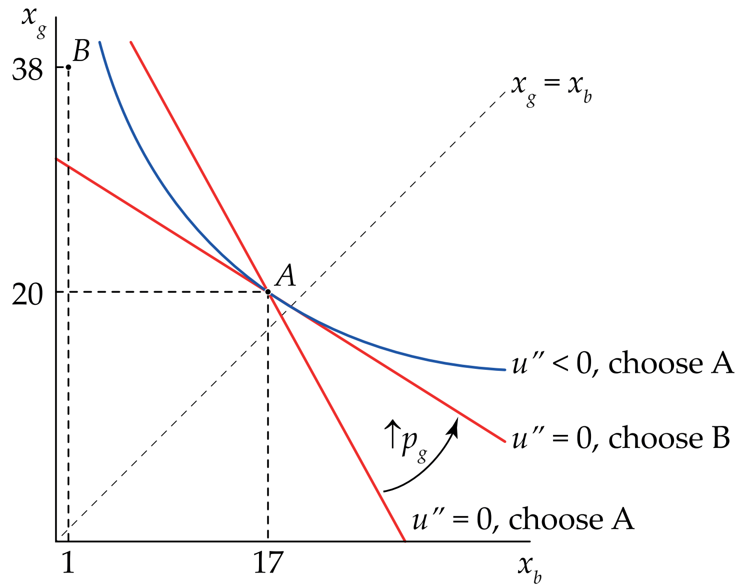
Figure 1 illustrates using the payoffs used in the experiment reported in this paper. Option A is a lottery that pays \$17 in the bad state (plotted on the horizontal axis), and \$20 in the good state (on the vertical).[7] Option B pays \$1 in the bad state, and \$38 in the good state.[8] Option A is safer in the sense that the difference in the

[6] In more recent work, Andersen et al. (2014) present choices one at a time, using a graphical format similar to Hey and Orme (1994), rather than as a choice list as in HL. However the underlying logic of the joint estimation procedure remains unchanged.

[7] All payments are in Australian dollars. At the time of the experiments, one AUD was worth roughly USD 0.93 or EUR 0.68.

[8] These payoffs are thus *approximately* ten times the nominal value of the stakes in the original HL experiment, however they have been modified slightly. (The original HL payoffs were A $=(\$1.60, \$2.00)$ and B $=(\$0.10, \$3.85)$.) The reason for adjusting the payoff vectors was to generate more moderate interest rates when they are transposed into time-dated payoff space.

Figure 1: State-preference representation of the HL design for risk



payoffs $x_g - x_b$ is relatively small, whereas Option B is risky in comparison – in Figure 1, this is represented by the fact that Option A lies closer to the diagonal, whereas Option B is close to the axis. In keeping with the original HL design, the probability p_g starts at 0.1 in the first row of the choice list, and increases in increments of 0.1 up to a value of 1.0 in the final row.[9] Thus the expected value of Option B increases more rapidly than that of Option A, and in the final row Option A is a dominated choice.

The rank-dependent utility of a risky prospect that pays x_b with probability $1 - p_g$ and $x_g > x_b$ otherwise is:

$$RDU\left(x_b, 1-p_g; x_g, p_g\right) = \left[1 - w\left(p_g\right)\right] \cdot u\left(x_b\right) + w\left(p_g\right) \cdot u\left(x_g\right) \tag{1}$$

where $w(p)$ is the probability weighting function, and $u(x)$ is the Bernoulli utility function. The (absolute) slope of an indifference curve in state-payoff space may then be derived as:

$$-\left.\frac{dx_g}{dx_b}\right|_{\overline{RDU}} = \frac{1 - w\left(p_g\right)}{w\left(p_g\right)} \cdot \frac{u'\left(x_b\right)}{u'\left(x_g\right)} \tag{2}$$

This slope is a product of two terms: $\left[1 - w\left(p_g\right)\right] / w\left(p_g\right)$ is the probability-weighted odds ratio of the bad state, while the ratio of marginal utilities $u'\left(x_b\right) / u'\left(x_g\right)$ captures a subject's preference to smooth payoffs across the good and bad states of nature.

For the benchmark case of expected utility with a linear utility function, $w(p) = p$ and $u(x) = x$, the slope in equation 2 reduces to the objective odds ratio $\left(1 - p_g\right) / p_g$ and the indifference curves are linear. In the

[9] Full parameters of the risk preference choice list used in the experiment are enumerated in Appendix A.1, available online.

early rows of the choice list, p_g is small and the indifference curves are steep, such that the subject prefers Option A. Moving down the rows of the choice list, as p_g increases the indifference curves become flatter, and the subject switches to preferring Option B. In particular, a risk-neutral subject chooses Option A in the first four rows, and then switches to Option B which has a larger expected value in all remaining rows.[10]

Relative to this benchmark, a risk-averse subject continues to choose the safer Option A at higher probabilities of the good state p_g. This may occur as the subject over-weights the odds of the bad state, such that $[1-w(p_g)]/w(p_g) > (1-p_g)/p_g$ and/or as the utility function is concave, such that $u'(x_b)/u'(x_g) > 1$. In particular, the impact of concave utility vanishes when $x_g = x_b$, while it increases as the difference in payoffs grows. Thus the indifference curves become steeper as they approach the vertical axis, such that the subject chooses Option A at larger values of p_g out of a preference to avoid unequal payoffs across states.

2.2 The intertemporal HL design for time

To translate the logic of the HL procedure into the domain of time preference, Options A and B are reframed as temporal prospects which pay some amount x_t on a "sooner" date t, and some additional amount x_{t+k} on a "later" date $t+k$. Letting the date of the experiment be 0, then t is the "front-end delay" to the sooner payment date, while k is the "back-end delay" between the sooner and later payments. Throughout this paper, all delay lengths t and k are expressed in weeks, while all interest and discount rates will be expressed on an annualized basis. Consistent with the standard HL procedure for risk, each set of choices is presented as a choice list. Within a given choice list, Options A and B represent two distinct payoff vectors (x_t, x_{t+k}), and within each choice the payment dates t and $t+k$ are the same for both alternatives. Moving down the rows of the choice list, the two payoff vectors remain unchanged and it is only the payment dates – and specifically only the back-end delay k – that varies.

Figure 2 presents the exact format of the choice list for the pair of payoff vectors that correspond directly to the risk preference elicitation described in Section 2.1. In the first row, Option A offers payments of \$17 in 1 week and \$20 in 28 weeks, while Option B offers \$1 in 1 week and \$38 in 28 weeks. Thus Option A is "smaller-sooner" in the sense that it offers a smaller total payment in undiscounted terms, but pays more on the sooner date. Conversely, Option B is "larger-later" in that it offers a larger undiscounted total, with more payment accruing on the later date. The front-end delay t is constant and equal to 1 week for all choices. The back-end delay k starts at 27 weeks in the first row and falls in decrements of 3 weeks down to 0 weeks in the final row. Thus in the final row all payments accrue in 1 week, and Option A is a dominated choice.

By choosing Option B in a given decision row, a subject forgoes \$16 from the sooner payment in Option A and in exchange receives an additional \$18 in the later payment, a gross return of 12.5%. Since the subject must wait k weeks to achieve this return, the implied annual interest rate is $r = 1.125^{52/k} - 1$. As k falls, the subject waits a shorter length of time to receive the same return, and so the interest rate increases.[11]

[10] This is true both under the original HL parameters in footnote 8, as well as for the modified parameters used here.

[11] At ten times the original HL stakes for risk (see footnote 8), we would have a gross return of 23.3%, and the resulting annual interest rates would thus be considerably higher.

Figure 2: Sample choice list instrument for time preference elicitation

DECISION TABLE 1

Make your choices by marking an "X" in the appropriate box in each row.

Weeks from today	Su	M	Tu	W	Th	F	Sa
	2014						
	May						
					1	2	3
0	4	5	6	7	8	9	10
1	11	12	13	14	15	16	17
2	18	19	20	21	22	23	24
3	25	26	27	28	29	30	31
	June						
4	1	2	3	4	5	6	7
5	8	9	10	11	12	13	14
6	15	16	17	18	19	20	21
7	22	23	24	25	26	27	28
8	29	30					
	July						
8			1	2	3	4	5
9	6	7	8	9	10	11	12
10	13	14	15	16	17	18	19
11	20	21	22	23	24	25	26
12	27	28	29	30	31		
	August						
12	31					1	2
13	3	4	5	6	7	8	9
14	10	11	12	13	14	15	16
15	17	18	19	20	21	22	23
16	24	25	26	27	28	29	30
	September						
17		1	2	3	4	5	6
18	7	8	9	10	11	12	13
19	14	15	16	17	18	19	20
20	21	22	23	24	25	26	27
21	28	29	30				
	October						
21				1	2	3	4
22	5	6	7	8	9	10	11
23	12	13	14	15	16	17	18
24	19	20	21	22	23	24	25
25	26	27	28	29	30	31	
	November						
25	30						1
26	2	3	4	5	6	7	8
27	9	10	11	12	13	14	15
28	16	17	18	19	20	21	22
29	23	24	25	26	27	28	29
	Su	**M**	**Tu**	**W**	**Th**	**F**	**Sa**

Decision	**Option A**	**Your Choice**	**Option B**
1	**$17** in **1 week** and **$20** in **28 weeks**	Option A ☐ Option B ☐	**$1** in **1 week** and **$38** in **28 weeks**
2	**$17** in **1 week** and **$20** in **25 weeks**	Option A ☐ Option B ☐	**$1** in **1 week** and **$38** in **25 weeks**
3	**$17** in **1 week** and **$20** in **22 weeks**	Option A ☐ Option B ☐	**$1** in **1 week** and **$38** in **22 weeks**
4	**$17** in **1 week** and **$20** in **19 weeks**	Option A ☐ Option B ☐	**$1** in **1 week** and **$38** in **19 weeks**
5	**$17** in **1 week** and **$20** in **16 weeks**	Option A ☐ Option B ☐	**$1** in **1 week** and **$38** in **16 weeks**
6	**$17** in **1 week** and **$20** in **13 weeks**	Option A ☐ Option B ☐	**$1** in **1 week** and **$38** in **13 weeks**
7	**$17** in **1 week** and **$20** in **10 weeks**	Option A ☐ Option B ☐	**$1** in **1 week** and **$38** in **10 weeks**
8	**$17** in **1 week** and **$20** in **7 weeks**	Option A ☐ Option B ☐	**$1** in **1 week** and **$38** in **7 weeks**
9	**$17** in **1 week** and **$20** in **4 weeks**	Option A ☐ Option B ☐	**$1** in **1 week** and **$38** in **4 weeks**
10	**$17** in **1 week** and **$20** in **1 week**	Option A ☐ Option B ☐	**$1** in **1 week** and **$38** in **1 week**

Relative to a more standard time-preference choice list design, such as Coller and Williams (1999), this intertemporal HL design differs in two key respects. Firstly, all choices involve bundles of payments on two dates, as opposed to payments on single dates. Secondly, variation in the interest rate is generated by varying payment dates while holding the magnitudes of the payoffs constant, rather than the other way around.

2.3 Disentangling utility curvature and time discounting

The discounted utility of a temporal prospect that pays x_t on date t and x_{t+k} on date $t+k$ is:

$$DU(x_t, t; x_{t+k}, t+k) = D(t) \cdot v(x_t) + D(t+k) \cdot v(x_{t+k}) \tag{3}$$

where $D(t)$ is the discount function, and $v(x)$ is the instantaneous utility function.[12] The (absolute) slope of an indifference curve in time-dated payoff space may then be derived as:

$$- \left. \frac{dx_{t+k}}{dx_t} \right|_{\overline{DU}} = \frac{D(t)}{D(t+k)} \cdot \frac{v'(x_t)}{v'(x_{t+k})} \tag{4}$$

This slope is again a product of two terms: $D(t)/D(t+k)$ is the relative value of utility at date t compared to $t+k$, while $v'(x_t)/v'(x_{t+k})$ captures the subject's preference to smooth payoffs over time.

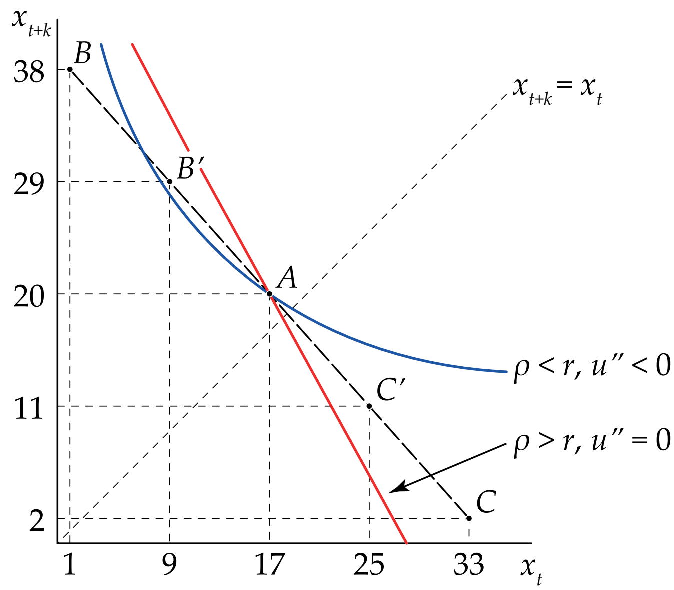
For the benchmark case of exponential discounting with linear instantaneous utility, $D(t) = 1/(1+\rho)^{t/52}$ (where ρ is the annual discount rate) and $v(x) = x$, the slope in equation 4 reduces to $(1+\rho)^{k/52}$ and the indifference curves are linear. In the early rows of the choice list, k is large and the indifference curves are relatively steep, such that the subject prefers Option A. Moving down the rows of the choice list, as k decreases the indifference curves become flatter, and the subject switches to preferring Option B. In particular, the subject chooses Option A when $(1+\rho)^{k/52} > 1.125$, i.e. as $\rho > r$, and Option B otherwise.

Thus in the benchmark case, the intertemporal HL design functions exactly as a conventional time-preference choice list, in that a subject's "switch point" from the smaller-sooner to the larger-later alternative identifies bounds on her discount rate. Therefore, in contrast to the benchmark case for risk, *there is no point prediction* for the number of sooner choices. This simply reflects the fact that, even in the benchmark case, the discount rate ρ is an additional preference parameter that must be estimated, whereas in the case of risk the odds ratio is objectively determined by the experimenter.

Turning to the more general case of non-linear utility, it follows that it will not be possible to also identify the curvature of utility from a single choice list. Figure 3 illustrates the fundamental identification problem. The figure depicts indifference curves for two subjects, both of whom prefer Option A in a given row of

[12]The predictions in this section also extend to certain specifications in which intertemporal utility is not additively separable, including the one studied by Andersen et al. (2011) and Cheung (in press). See Appendix B, available online, on this point.

Figure 3: Time-dated payoff representation of the HL design for time



the choice list. The first, represented by the linear indifference curve, has no preference to smooth payoffs over time. This subject prefers Option A simply because he is relatively impatient, i.e. $\rho > r$. The second, represented by the convex indifference curve, is relatively patient, i.e. $\rho < r$.[13] However, this subject has concave utility and prefers Option A because it offers a more balanced stream of payoffs over time. Clearly, it is not possible to distinguish these two cases by simply observing the switch point in a single choice list.

Figure 3 also suggests two strategies by which it may be possible to distinguish between these cases. Firstly, suppose that subjects also face choices between A and C, where C is the payoff vector $(\$33, \$2)$. Relative to A, whereas B represented a deferral of payment, C represents a shifting forward of payment at the same gross rate. Then at the same annual rate as before, the impatient subject with linear utility now prefers C. On the other hand, the patient subject with concave utility continues to prefer A, both because she is patient and because A offers a more balanced stream of payoffs over time. Secondly, consider choices between A and the payoff vector B' = $(\$9, \$29)$, which is the midpoint of AB. Relative to A, B' again represents a deferral of payment, however B' is less unbalanced than B. At the same annual rate as before, the impatient subject with linear utility continues to prefer A. However the patient subject with concave utility *may* choose B', if the interest rate suffices to compensate for accepting a somewhat unbalanced stream of payoffs.

2.4 Full experiment design

The full experiment design involves the five payoff vectors (x_t, x_{t+k}) depicted in Figure 3: C = $(\$33, \$2)$, C' = $(\$25, \$11)$, A = $(\$17, \$20)$, B' = $(\$9, \$29)$, and B = $(\$1, \$38)$. Of these, C is "smallest-soonest",

[13] At the point where the indifference curve meets the diagonal $x_{t+k} = x_t$, the impact of concave utility vanishes and the slope reflects the pure effect of discounting. At this point, the slope of the indifference curve is flatter than the chord AB.

while B is "largest-latest". By construction, for any pair of these vectors, the gross return for choosing the larger-later one is always 12.5% over k weeks. Each subject completed a total of six time preference choice lists, each presented in the format shown in Figure 2, using the following pairs of payoff vectors: CA, C'A, AB', AB, CB, and C'B'. In each list, the smaller-sooner payoff vector was always shown on the left and labeled as Option A, while the larger-later one was shown on the right as Option B – thus the alternatives were not identified as C, B' etc. in the materials presented to subjects. The front-end delay t was always one week, and the back-end delay k declined from 27 down to 0 weeks in each choice list, generating annual interest rates that increased from 25.46% up to infinity (in the final dominated choice).[14]

By varying the back-end delay, this design generates variation in interest rates independently of the magnitudes of the payoffs. This in turn makes it possible to independently vary the differences between the sooner and later payoffs – i.e. how near or far the payoff vectors are from the diagonal in Figure 3 – and thus the extent to which choices are potentially influenced by diminishing marginal utility and the preference to smooth payoffs over time. In this manner, it is possible to identify both time preference and the curvature of utility solely from choices made over time – without requiring a separate risk preference task, or relying upon the assumption that the utility function is the same for both risk and time.

Under linear utility, there is no preference to smooth payoffs over time and only the interest rate matters. Since by design the interest rate is the same at any given row across all six choice lists, a subject with linear utility should make the same number of sooner choices in each one.[15] On the other hand, a subject with concave utility prefers to smooth payoffs over time. This subject is predicted to make a larger number of sooner choices in the AB and AB' choice lists, in which the smaller-sooner option is more balanced, than in the CA and C'A choice lists, in which it is the larger-later option that is more balanced. Details of these predictions are set out in Appendix B, available online. It should be emphasized that *these predictions hold regardless of the shape of the discount function*, and do not rely upon exponential discounting.

In addition to the six time-preference choice lists, each subject also completed a single risk-preference choice list, using the classic AB parameter set described in Section 2.1 above. This makes it possible to compare the curvature of utility elicited under risk to that elicited over time, in a within-subjects design.

There are two limitations of the design that may be acknowledged. Each is attributable to the specific parametrization of the experiment, and not to any underlying weakness in the conceptual framework set out above. Firstly, the annual interest rates offered in the experiment are somewhat high, and thus the design has limited power to detect low discount rates.[16] This reflects the fact that lower interest rates are generated through longer back-end delays, and it was not possible to extend k beyond six months given that the last payment date fell shortly before the start of the summer vacation.[17] Secondly, since all choice lists have the

[14] The annual rates are: 25.46% at $k = 27$ weeks; 29.07% at $k = 24$; 33.86% at $k = 21$; 40.53% at $k = 18$; 50.43% at $k = 15$; 66.59% at $k = 12$; 97.49% at $k = 9$; 177.54% at $k = 6$; 670.27% at $k = 3$; and infinity at $k = 0$. Full parameters of the time preference choice lists used in the experiment are enumerated in Appendix A.2, available online.

[15] This is the analog to the point prediction that a subject with linear utility will make four safe lottery choices in the risk HL task.

[16] The interest rates are enumerated in footnote 14. They are comparable to those offered by Andreoni and Sprenger (2012a) (which vary from 20.5% up to 1,300.9%), but higher than those offered by Andersen et al. (2014) (which vary from 5% up to 50%).

[17] Alternatively, it would be possible to generate lower interest rates by making the payoff vectors closer in undiscounted terms.

same front-end delay of one week, it will not be possible to identify the parameters of a non-exponential discount model.[18] Rather, it will only be possible to estimate an exponential discount rate (which may also be interpreted as the exponential component of a quasi-hyperbolic model). This design choice was made because the focus in this paper is on the shape of the utility function. It is straightforward to see how additional discounting parameters may be identified by introducing variation in the front-end delay as a further dimension of the experiment design. Moreover, it should be reiterated that the implications of linear versus concave utility do not rely on assuming exponential discounting, as explained in Appendix B.

2.5 Procedures

A total of 122 student subjects participated in the experiment at the research laboratory of the School of Economics at The University of Sydney between 6 and 13 May 2014. The mean age of the subjects was 20.4 years, and 55.7% were males. Subjects were recruited using ORSEE (Greiner, 2004). To ensure that subjects would still be at the university when payments were sent, students already in their final semester of study were not eligible to participate. Each session ran for approximately 75 minutes including instruction and payment, and the average subject payment was $45.2 (approximately USD 42.0 or EUR 28.5), inclusive of the $10 show-up fee described below. A total of 12 sessions were conducted, and the order of presentation of the time-preference choice lists was varied between sessions.[19] Each choice list consisted of ten decisions, and thus each subject made 70 choices in total. The experiment was conducted by pen-and-paper.

At the end of the session, one of the 70 decisions was drawn randomly and independently for each subject, and the subject was paid according to the choice they had made in that decision. Following the procedure introduced by Andreoni and Sprenger (2012a), each subject received a show-up fee of $10, which was split into two equal installments of $5 and paid by check on the sooner and later payment dates corresponding to the decision selected to count for payment. The payments chosen by the subject were added to these two checks. Since the subject would always have to bank two checks, this procedure ensured that there was no convenience benefit from choosing a more unbalanced payoff vector in order to amass payment on a single date. If one of the ten risk-preference choices was selected to count for payment, the realization of the chosen lottery was paid in cash at the end of the session, however the show-up fee was still paid in two checks of $5, sent one and sixteen weeks after the experiment. This ensured that any wealth effect attributable to the show-up fee would be the same for both the risk and time preference choices.[20]

The procedures also incorporated several other measures introduced by Andreoni and Sprenger (2012a), as adapted by Cheung (in press), to enhance the credibility of payment and minimize the background risk of receiving payment in the future. Firstly, all checks were drawn on the campus branch of the National

[18] Obviously, while there is considerable variation in the back-end delay, this is perfectly correlated with the interest rate.

[19] The full text of the instructions for one of the orders may be found in Appendix D, available online. There were four different orders in total, enumerated in Appendix A.3. Within each order, the first four choice lists were a different permutation of CA, C'A, AB' and AB, and the risk preference task was always presented last.

[20] Sixteen weeks represents the median of the (non-degenerate) later payment dates used in the time-preference choice lists.

Australia Bank and mailed by Australia Post guaranteed Express Post. Australia Post guarantees next-day delivery for articles mailed by Express Post, at a cost of $6 per envelope. Since every subject addressed their own envelopes prior to making their choices, they could observe that the experimenter was prepared to pay $6 to mail a check to the value of as little as $5 by Express Post. This imparted a high level of credibility to the payments.[21] At the end of the session, each subject wrote their own payment amounts and dates on the inside of each envelope, and was given a copy of the receipt form showing these amounts and dates, as well as the business card of the experimenter to contact in the event of a payment not arriving as expected.

3 Results

3.1 Utility curvature under risk

I begin by examining the curvature of the Bernoulli utility function under risk. The primary purposes of this analysis are to provide a benchmark against which to compare the curvature of utility elicited over time, and to verify that the observed levels of risk aversion are comparable to what has been found in other studies. Figure 4 reports the percentage of subjects who choose the safer Option A in each row of the risk-preference choice list. This indicates that the majority of subjects continue to choose the safer lottery until at least the sixth row, providing a first indication of considerable risk aversion in the data.[22]

To formalize this observation, I estimate structural models of risk preference building upon well-established procedures described by Harrison and Rutström (2008) and Andersen et al. (2014, Appendix E). I assume a constant relative risk aversion (CRRA) functional form for utility:

$$u(x) = \frac{x^{1-\alpha}}{1-\alpha} \tag{5}$$

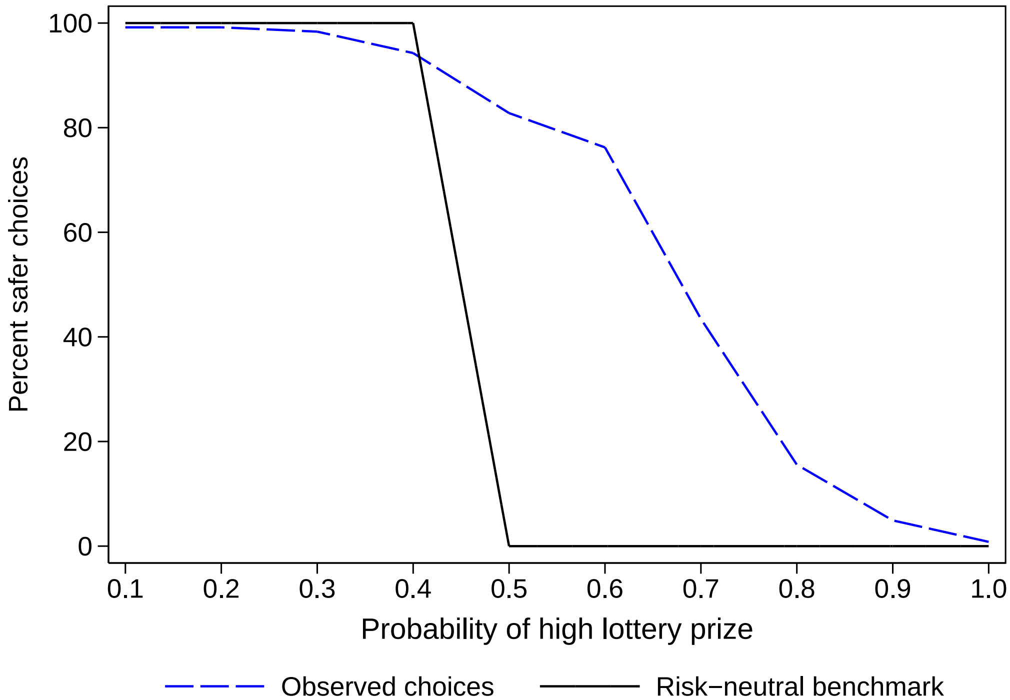
such that $\alpha = 0$ corresponds to linear utility, while $\alpha > 0$ implies concave utility. I begin with the benchmark case of expected utility, $w(p) = p$, but later consider specifications that allow non-linear probability weighting. Given some candidate value of α (and a probability weighting parameter γ), the expected utility (or rank-dependent utility) of each lottery is calculated. Then, adopting a "Fechner" error specification, the probability that Option B is chosen is modeled as:

$$\Pr(B) = \Lambda\left(\left(RDU_B - RDU_A\right)/\mu\right) \tag{6}$$

[21] In the post-experiment questionnaire, all but two subjects reported trusting that they would be paid as stated in the instructions.

[22] There was one subject who made a dominated choice by choosing Option A in the final row of the choice list. There were four subjects who "reswitched" by choosing Option A after previously choosing Option B; one of these was also the subject who made the dominated choice. Each of these subjects re-switched exactly one time. One advantage of estimating a structural model that allows for noisy decision making, as I do below, is that it is not necessary to exclude such observations from the data. Nonetheless, I check the robustness of all results to the inclusion or omission of these subjects. Unless otherwise indicated, the significance of all results reported in this section are robust to omitting the data of these four subjects. Details are available upon request.

Figure 4: Choice behavior in the risk preference task



where $\Lambda(\cdot)$ is the cumulative logistic distribution function and μ is a structural "noise" parameter which is jointly estimated with the utility curvature (and probability weighting) parameters. As μ goes to zero, the lottery with the larger *RDU* is chosen deterministically, while as μ goes to infinity, the choice probability goes to one-half such that choices are essentially random.[23] The parameters α, γ (where applicable), and μ are estimated to maximize the likelihood of the observed choices using Stata 13.1, with robust standard errors clustered at the level of individual subjects.

Model (1) in Table 1 reports estimates for the benchmark expected utility specification assuming CRRA utility. The point estimate of the CRRA coefficient is 0.547, with a 95% confidence interval between 0.477 and 0.618. This estimate implies substantial concavity of the utility function, and sits comfortably within the range of previously-reported estimates using similar experimental designs and estimation procedures.[24]

However, as discussed in Section 2.1, risk aversion in HL-style tasks may be driven by curvature of the

[23] Andersen et al. (2014) adopt a "contextual" error model, in which the utility difference in equation 6 is divided through by the difference between the maximum and minimum utilities over all prizes within a given choice, thereby ensuring that the normalized difference lies in the unit interval. This specification was proposed by Wilcox (2011) to generalize the relation "more risk averse" to stochastic choice under risk. However in the present experiment design there is only a single choice list for risk, such that all choices involve the same set of prizes, and so this contextual adjustment is redundant.

[24] For example, Harrison and Rutström (2008, Table 8) report their "preferred" estimates of an expected utility with CRRA specification for three data sets, using similar estimation techniques to those adopted here. For the original data of Hey and Orme (1994), the CRRA estimate is 0.61 (standard error 0.03), while in their replication of the same design it is 0.53 (standard error 0.05). For the data of Holt and Laury (2005), the estimate is 0.76 (standard error 0.04). More recently in a field setting, Andersen et al. (2014) report an estimate of 0.65 (standard error 0.038) in a model employing the Wilcox (2011) contextual error specification.

Table 1: Estimates of utility curvature and probability weighting, from choices under risk

	Specification	Weighting function	Restrictions on γ	Restriction at linearity	Utility curvature (CRRA) α				Probability weighting γ				LL
					Coef	se	95% CI		Coef	se	95% CI		
(1)	Expected utility	$w(p) = p$	n/a	n/a	0.547	0.036	0.477	0.618	n/a	n/a	n/a	n/a	–342.938
(2)	Power	$w(p) = p^{\gamma}$	$\gamma \geq 1$	$\gamma = 1$	0.155	0.121	–0.083	0.392	1.657	0.245	1.178	2.136	–340.071
(3)	Gul	$w(p) = \frac{p}{1+(1-p)\gamma}$	$\gamma \geq 0$	$\gamma = 0$	0.206	0.095	0.020	0.393	0.787	0.281	0.237	1.337	–339.867
(4)	Tversky-Kahneman	$w(p) = \frac{p^{\gamma}}{\left[p^{\gamma}+(1-p)^{\gamma}\right]^{1/\gamma}}$	$0.279 < \gamma \leq 1$	$\gamma = 1$	0.396	0.066	0.266	0.526	0.771	0.057	0.659	0.883	–340.930
(5)	Karmarkar	$w(p) = \frac{p^{\gamma}}{p^{\gamma}+(1-p)^{\gamma}}$	$0 < \gamma \leq 1$	$\gamma = 1$	0.455	0.048	0.361	0.548	0.745	0.097	0.554	0.936	–341.250
(6)	Prelec-I	$w(p) = \exp\left[-(-\ln p)^{\gamma}\right]$	$0 < \gamma \leq 1$	$\gamma = 1$	0.378	0.051	0.278	0.479	0.730	0.064	0.604	0.855	–340.522

Notes: All models are estimated from 1,220 observations on 122 subjects, with robust standard errors clustered at the level of individual subjects. Each model also includes a Fechner "noise" parameter μ to model decision errors in the risk preference choices. Estimates of this parameter have been omitted for reasons of space; details are available upon request.

utility function, and/or by non-linear probability weighting. Therefore, just as assuming linear utility may cause estimates of the discount rate to be biased in the context of time, assuming linear probability weighting may cause estimates of the utility function to be biased in the context of risk. Indeed, a recent working paper by Drichoutis and Lusk (2014) claims that the risk aversion observed in HL tasks may be *solely* a product of probability weighting as opposed to utility curvature – in their estimates of a rank-dependent specification with CRRA utility they find significant evidence of non-linear probability weighting, while their estimates of the CRRA coefficient do not differ significantly from zero. While this finding is arguably at odds with other existing literature,[25] it does highlight the importance of allowing for probability weighting in choice under risk when comparing the curvature of utility elicited under risk and over time.

Given that the risk-preference component of the experiment only involved a single choice list, it will only be possible to estimate single-parameter specifications of the probability weighting function, and even these estimates are only identified off functional form.[26] Therefore, to examine the robustness of the results to the form of the probability weighting function, I report estimates for each of the single-parameter weighting functions described in a recent survey by Fehr-Duda and Epper (2012, Section 3.6.1). Clearly, the purpose of this exercise is not to arbitrate between these alternative specifications, and it is only incidentally to assess the role of probability weighting in the observed choice behavior. Rather, the purpose is to permit an evaluation of the robustness of the comparison between utility elicited under risk and over time to the assumed form of probability weighting. These estimates are reported as Models (2) through (6) in Table 1. In the interest of parsimony in notation, I refer to the single probability-weighting parameter as γ throughout, although its interpretation naturally varies from one specification to the next. The exact specification of each weighting function is shown in the second column of the table, while the fourth column shows the parameter restriction at which the weighting function collapses to linearity.

The results of the rank-dependent models in Table 1 clearly indicate a role for probability weighting in the risk aversion observed in the experiment. In each of the specifications, the estimated weighting function differs significantly from linearity. Moreover, the point estimates of the CRRA coefficient are each lower than the corresponding estimate under expected utility. Broadly speaking, the convex-shaped weighting functions in Models (2) and (3) yield smaller and less precise estimates of utility curvature, while the "inverse-S" shaped specifications in Models (4) through (6) yield larger and more precise estimates. In all but one of the rank-dependent specifications, the estimated curvature of the utility function differs significantly from linearity, contrary to the recent findings of Drichoutis and Lusk (2014).[27] Thus, in short, the

[25] For example, in their re-analysis of the original data of Holt and Laury (2005), Harrison and Rutström (2008, Table 8) estimate the same rank-dependent specification – with CRRA utility and a Tversky and Kahneman (1992) probability weighting function – preferred by Drichoutis and Lusk. In this specification, Harrison and Rutström do not find significant evidence of non-linear probability weighting, while their point estimate of the CRRA coefficient is actually (insignificantly) larger than in their corresponding expected utility specification. In a representative sample of adult Danes, Andersen et al. (2014) find evidence of probability weighting but conclude that the bulk of aversion to risk derives from concavity of the utility function.

[26] Note that the results of Drichoutis and Lusk (2014), discussed above, were also estimated from single choice lists.

[27] The exception is the power weighting function in Model (2), for which the precision of the CRRA estimate is particularly poor, while the estimated noise parameter (not shown in Table 1) is particularly large. Moreover, this is the one model for which the results are not robust to omitting the four subjects who make non-monotonic choices. When these subjects are dropped, the CRRA estimate jumps from 0.155 to 0.315, which differs significantly from zero with a p-value of 0.029 (details available upon request).

weight of evidence in Table 1 indicates substantial concavity of the Bernoulli utility function under risk, even after allowing for the possibility of non-linear probability weighting.

3.2 Utility curvature and discounting over time

Turning to behavior in the time-preference tasks, Figure 5 reports the percentage of sooner choices as a function of the back-end delay, separately for the pooled CA/C'A and AB'/AB choice lists. Appendix C.1, available online, reports separate figures for each of the six individual time-preference choice lists. Several observations are evident from these figures. Firstly, there are a number of subjects who always choose larger-later even at the longest back-end delay and hence lowest interest rate. In total, there are 15 subjects who choose larger-later in all 60 time preference decisions. These subjects behave *as if* they have linear utility with a discount rate of less than 25.46%, however it cannot be observed whether they would exhibit non-linear utility at lower interest rates. Secondly, the proportion of sooner choices declines smoothly as the back-end delay falls and the interest rate increases. This suggests that most subjects understood the underlying trade-off entailed in waiting a longer or shorter length of time for a given-sized increase in undiscounted payoffs. Thirdly, however, there are also a small number of subjects who make dominated choices by choosing the smaller-sooner option in the final row of a choice list.[28]

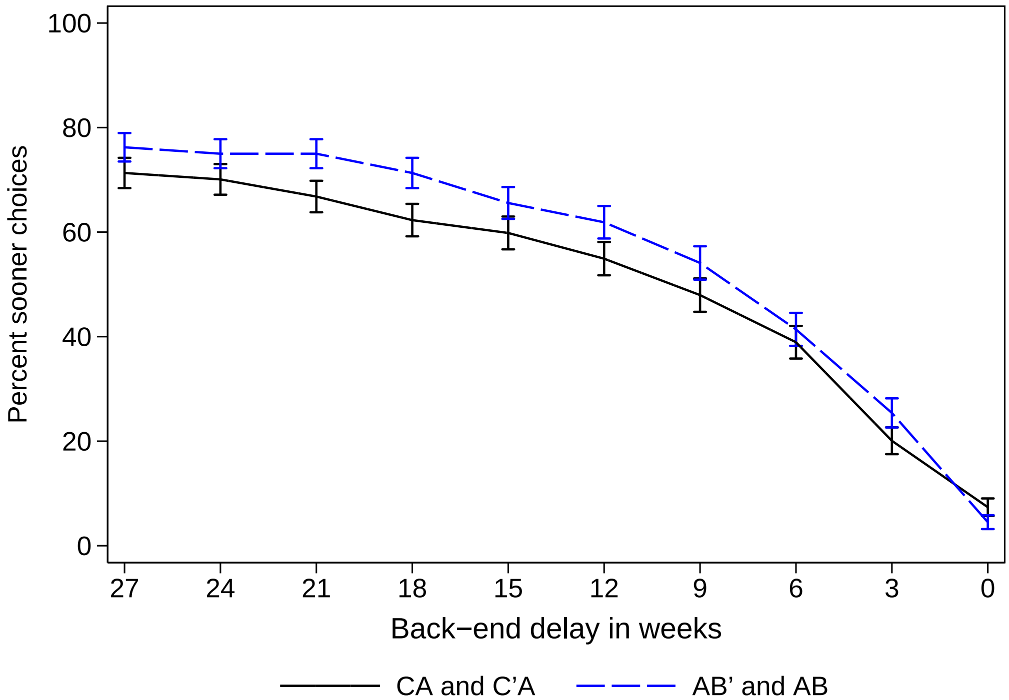
Under linear utility a subject is predicted to make the same choices in all six choice lists, while departures from linearity are expressed as differences in behavior across lists. In particular, a subject with concave utility prefers to smooth payoffs over time, and thus makes more sooner choices in the AB'/AB choice lists (in which the smaller-sooner payoff vector is more balanced) than in the CA/C'A lists (in which the larger-later option is more balanced). The CB/C'B' choice lists represent an intermediate situation where both the sooner and later options are similarly unbalanced; in this case, concave utility does not favor either one.

Figure 5 confirms that there is a small, but clearly discernible shift in choices in the direction predicted by concave utility. At every back-end delay except zero (where the sooner choice is dominated), subjects make more sooner choices in AB'/AB than in CA/C'A. To illustrate the magnitude of these differences, the error bars in the figure represent $\pm$ one standard error of the mean for a binomial proportion. Table 2 presents an analysis of the number of sooner choices that subjects make in each type of choice list. In the full sample, the average subject makes a total of 11 sooner choices in the combined AB'/AB choice lists,

The power weighting function is also not recommended by Fehr-Duda and Epper (2012, p. 578), who remark that "its popularity is a mystery to us, as it is neither subproportional anywhere, which would be necessary to capture general common ratio violations, nor can it accommodate the special case of the certainty effect, which in our view is a minimum requirement".

[28]There are 17 subjects who made dominated choices in one or more of the time-preference choice lists. Of these, six made a single dominated choice, eight made two, and three made more than two. While the incidence of dominated choices is greater than in the risk-preference task, this may be explained in part by the fact that the cost of making a dominated choice is substantially smaller. In the risk-preference task, the cost of making a dominated choice is $\$38-\$20=\$18$ paid at the conclusion of the session. In the corresponding AB time-preference choice list, the cost is $(\$1+\$38)-(\$17+\$20)=\$2$ in one week's time. There are 26 subjects who reswitched by choosing smaller-sooner after previously choosing larger-later within a given choice list. Of these, 13 reswitched once, seven did so twice, and six did so more than two times in total over six choice lists. Overall, there are 30 subjects who made at least one dominated and/or non-monotonic choice. In the subsequent structural preference models, I demonstrate that the estimated utility curvature and discount rate parameters do not differ significantly for these 30 subjects.

Figure 5: Choice behavior in the time preference tasks



Note: Error bars represent ± one standard error of the mean for a binomial proportion.

compared to 10 in the CA/C'A lists. This difference is highly significant in a Wilcoxon signed-rank test. Moreover, subjects make an intermediate number of sooner choices in the CB/C'B' lists, and this also differs significantly from the number chosen in AB'/AB.[29] The lower panel of the table confirms that these findings are not driven by subjects who make dominated or non-monotonic choices: the same patterns are observed when all subjects who make one or more such choices are excluded from the analysis. This evidence of a systematic preference for the more balanced payoff vector A, consistent with a preference to smooth payoffs over time, does not rely on any assumptions on the functional form of utility.

I next turn to structural estimation of utility and discounting parameters, adopting similar procedures to Section 3.1 and Andersen et al. (2014). I assume a CRRA form for the instantaneous utility function:

$$v(x) = \frac{x^{1-\theta}}{1-\theta} \tag{7}$$

and an exponential form for the discount function:

[29]As discussed in Section 2.3, concave utility may also motivate differences in behavior between AB' and AB, or between CA and C'A. However, no significant differences were found in Wilcoxon signed-rank tests. Details are available upon request.

Table 2: Number of sooner choices per subject

A. Full sample ($N = 122$)				
	mean	sd		Signed-rank p
CA/C'A	9.99	6.37	CA/C'A vs. CB/C'B'	0.2937
CB/C'B'	10.56	6.51	CA/C'A vs. AB'/AB	0.0006 ***
AB'/AB	11.01	6.42	CB/C'B' vs. AB'/AB	0.0274 **
B. Restricted sample ($N = 92$)				
	mean	sd		Signed-rank p
CA/C'A	9.78	6.73	CA/C'A vs. CB/C'B'	0.2960
CB/C'B'	10.40	6.83	CA/C'A vs. AB'/AB	0.0036 ***
AB'/AB	10.72	6.81	CB/C'B' vs. AB'/AB	0.0592 *

Notes: Restricted sample excludes 30 subjects who make dominated or non-monotonic choices.
* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$.

$$D(t) = \frac{1}{(1+\rho)^{\frac{t}{52}}} \tag{8}$$

where θ measures the curvature of instantaneous utility and ρ is the annual discount rate. Given candidate values of θ and ρ, the discounted utility of each alternative is evaluated as:

$$DU = \frac{1}{(1+\rho)^{\frac{t}{52}}} \cdot \frac{x_t^{1-\theta}}{1-\theta} + \frac{1}{(1+\rho)^{\frac{t+k}{52}}} \cdot \frac{x_{t+k}^{1-\theta}}{1-\theta} \tag{9}$$

The probability that the alternative presented as Option B is chosen is modeled as:

$$\Pr(B) = \Lambda\left(\left(DU_B - DU_A\right)/\sigma\right) \tag{10}$$

where σ is a structural noise parameter that is jointly estimated with the utility and discounting parameters. It is important to note that this estimation framework is essentially identical to that of Andersen et al. (2014, Appendix E), except that information on utility curvature is inferred directly from choices over time instead of a separate risk preference task, so it is not necessary to invoke the equivalence of the Bernoulli utility function for risk and the instantaneous utility function for time. The parameters θ, ρ, and σ are estimated by maximum likelihood in Stata 13.1, with robust standard errors clustered at the level of individual subjects.

Table 3: Estimates of utility curvature and discount rates, from choices over time

A. Assuming linear utility	(1)				(2)				(3)				(4)			
	Coef	se	95% CI		Coef	se	95% CI		Coef	se	95% CI		Coef	se	95% CI	
Annual discount rate ρ	0.667	0.085	0.500	0.835	0.506	0.136	0.240	0.771	0.940	0.117	0.710	1.169	0.905	0.255	0.405	1.404
Order 1B					–0.036	0.161	–0.351	0.279					–0.088	0.276	–0.629	0.453
Order 2A					0.246	0.222	–0.188	0.681					0.513	0.418	–0.306	1.331
Order 2B					0.053	0.178	–0.296	0.402					–0.180	0.272	–0.714	0.354
Dominated/Reswitched					0.090	0.133	–0.171	0.351					–0.256	0.198	–0.643	0.131
Expect to Move					0.413	0.257	–0.090	0.915					0.599	0.400	–0.184	1.383
Decision "noise" σ	1.539	0.110	1.324	1.754	1.492	0.111	1.274	1.709	1.463	0.115	1.238	1.688	1.368	0.107	1.158	1.578
LL		–4,443.712				–4,364.788				–3,561.084				–3,432.740		
B. Allowing non-linear utility	(1)				(2)				(3)				(4)			
	Coef	se	95% CI		Coef	se	95% CI		Coef	se	95% CI		Coef	se	95% CI	
Utility curvature (CRRA) θ	0.014	0.006	0.002	0.025	0.019	0.011	–0.002	0.040	0.016	0.007	0.003	0.030	0.024	0.013	–0.001	0.050
Order 1B					–0.027	0.014	–0.055	0.001					–0.033	0.017	–0.066	0.001
Order 2A					–0.012	0.017	–0.046	0.021					–0.018	0.023	–0.062	0.027
Order 2B					–0.013	0.016	–0.044	0.018					–0.019	0.018	–0.054	0.016
Dominated/Reswitched					0.027	0.017	–0.006	0.060					0.027	0.016	–0.005	0.059
Expect to Move					0.005	0.015	–0.025	0.035					0.003	0.020	–0.037	0.042
Annual discount rate ρ	0.649	0.082	0.488	0.810	0.488	0.133	0.228	0.748	0.907	0.112	0.687	1.126	0.872	0.250	0.382	1.362
Order 1B					–0.023	0.158	–0.333	0.287					–0.078	0.270	–0.607	0.450
Order 2A					0.245	0.218	–0.183	0.672					0.499	0.412	–0.308	1.307
Order 2B					0.065	0.179	–0.286	0.415					–0.168	0.273	–0.703	0.367
Dominated/Reswitched					0.075	0.130	–0.180	0.329					–0.254	0.190	–0.627	0.119
Expect to Move					0.395	0.249	–0.093	0.884					0.567	0.388	–0.193	1.327
Decision "noise" σ	1.453	0.105	1.247	1.660	1.404	0.108	1.194	1.615	1.366	0.110	1.150	1.581	1.278	0.105	1.073	1.483
LL		–4,437.196				–4,349.558				–3,553.386				–3,414.843		

Notes: Models (1) and (2) are estimated from 7,320 observations on 122 subjects. Models (3) and (4) are estimated from 6,420 observations on 107 subjects, omitting the data of 15 subjects who always choose the larger-later alternative. All models are estimated with robust standard errors clustered at the level of individual subjects.

Panel A in Table 3 reports estimates assuming linear utility, i.e. $\theta = 0$. Model (1) is a homogeneous preference specification, using the data of all 122 subjects. The estimated annual discount rate in this model is 66.7%. While this is higher than prevailing market interest rates, it is certainly not extreme by the standards of the discounting literature.[30] Model (2) adds controls for order effects, subjects who made one or more dominated or non-monotonic choices, and subjects who reported in the post-experiment questionnaire that they expect to move address within the next seven months.[31] In this specification, the discount rate is estimated as a linear function of dummies for each of these covariates. The results reveal no significant evidence of any order effects, and no significant difference in the aggregate discounting behavior of subjects who made dominated or non-monotonic choices. The coefficient on subjects who expect to move is sizable at 41.3% but not statistically significant, indicating heterogeneity in the behavior of these subjects.

Panel B in Table 3 reports estimates that allow for non-linear utility, in which the discount rate is jointly estimated with the curvature of utility. In the discussion of extensions in Section 3.3 below, I will refer to the specification in column (1) of Panel B as the "baseline". In this model, the point estimate of θ is 0.014 which is positive and significant ($p = 0.016$), indicating concave utility. This is consistent with the non-parametric analysis in Table 2. However this estimate is an order of magnitude smaller than the estimates of α from the risk-preference task in Table 1. Because the estimated curvature of instantaneous utility is modest, the effect of correcting for this concavity upon the discount rate is mild: the estimate of ρ falls from 66.7% in Panel A to 64.9% in Panel B. When the additional covariates are added in model (2), the estimate of utility curvature ceases to be statistically significant, although the point estimate is in fact larger than in model (1). Again, none of the covariates have any significant effect upon the estimates of either θ or ρ, and the effect of correcting for non-linear utility upon the estimated discount rate is again modest.[32]

Recall that the sample includes 15 subjects who choose larger-later in all 60 decisions. While these subjects behave as if they have linear utility, it is unclear whether they would display concave utility at lower interest rates. To assess the sensitivity of the finding of near-linear utility to the inclusion of these subjects, models (3) and (4) in Table 3 report estimates in which they are omitted. Since it is precisely the most patient subjects who are excluded, it is unsurprising to see a substantial increase in the estimated discount rate. Of greater interest is the effect on the estimated curvature of utility, and the impact of correcting for this

[30]See Frederick et al. (2002) for a review of early literature. Among more recent studies, Takeuchi (2011) imputes an annual discount rate of 726% in a design that theoretically controls for non-linear utility, while Benhabib et al. (2010) report annual discount rates on the order of 472%. However, both of these studies do not employ a front-end delay. Laury et al. (2012) is an example of a modern study using student subjects and a front-end delay design. Their dollar discount rate task (Task D) is a standard time-preference choice list in the manner of Coller and Williams (1999). From this task, they estimate an annual discount rate of 55.5% assuming linear utility, which is comparable to the estimate reported here.

[31]There were 29 subjects who reported expecting to move, although it is likely that many expected to do so at the very end of seven months, at the conclusion of the school year. Subjects who moved address were able to email the experimenter to arrange for their check to be redirected. Nonetheless, if subjects have doubts about receiving future payment in the event of moving, this may bias them toward favoring sooner payment independent of their time preference.

[32]To evaluate the magnitude of the estimated structural noise parameter σ, it may be compared to the corresponding parameter μ from the risk preference task. For example, the estimated noise parameter for the expected utility model is 0.758, while for the rank-dependent Tversky-Kahneman model it is 0.900 (not shown in Table 1, details available upon request). These are smaller than the corresponding estimates in Table 3. One interpretation is that subjects may have found the time preference tasks to be cognitively more challenging. However, it should also be noted that the time preference models are estimated from a larger number of choices per subject, and this alone may be expected to add some noise to the data.

curvature upon the estimated discount rate. In these respects, the key findings of the full-sample models are confirmed. While the point estimates of utility curvature in models (3) and (4) are indeed slightly larger, they remain substantially smaller than the estimates from the risk-preference task. The resulting effect of joint estimation is to lower the estimated annual discount rate by 3.3 percentage points.

Thus in short, the results of the time preference tasks confirm that there is indeed significant concavity of the instantaneous utility function for time, which may be detected from choices over bundles of time-dated payoffs. This concavity is evident in both a non-parametric analysis, as well as in structural estimates of preference parameters. However, it is substantially less than the curvature of the Bernoulli utility function for risk, as observed from analogously-constructed choices over bundles of state-contingent payoffs.

3.3 Extensions

3.3.1 Background consumption

It has been assumed thus far that the argument of utility is simply the value of the payoff itself. Suppose, however, that subjects also derive utility from some exogenous quantity of background consumption ω, and payoffs from the experiment are integrated with ω such that utility is evaluated as $v(\omega + x)$.[33] Moreover, suppose that ω is the same at both t and $t+k$ – a reasonable assumption considering that all subjects will still be students at university on every future payment date. Then in terms of Figure 3, the effect of increasing background consumption is to shift the consumption vectors to the north-east, in parallel to the 45-degree diagonal. As a result, bundles such as B and C – which are highly unequal in payoff terms – are less unequal in terms of final consumption. Therefore, insofar as subjects display a systematic preference to smooth *payoffs* over time, this represents an even stronger desire to smooth *consumption*.[34] The effect of ignoring background consumption will thus be to understate the value of the instantaneous curvature parameter θ.

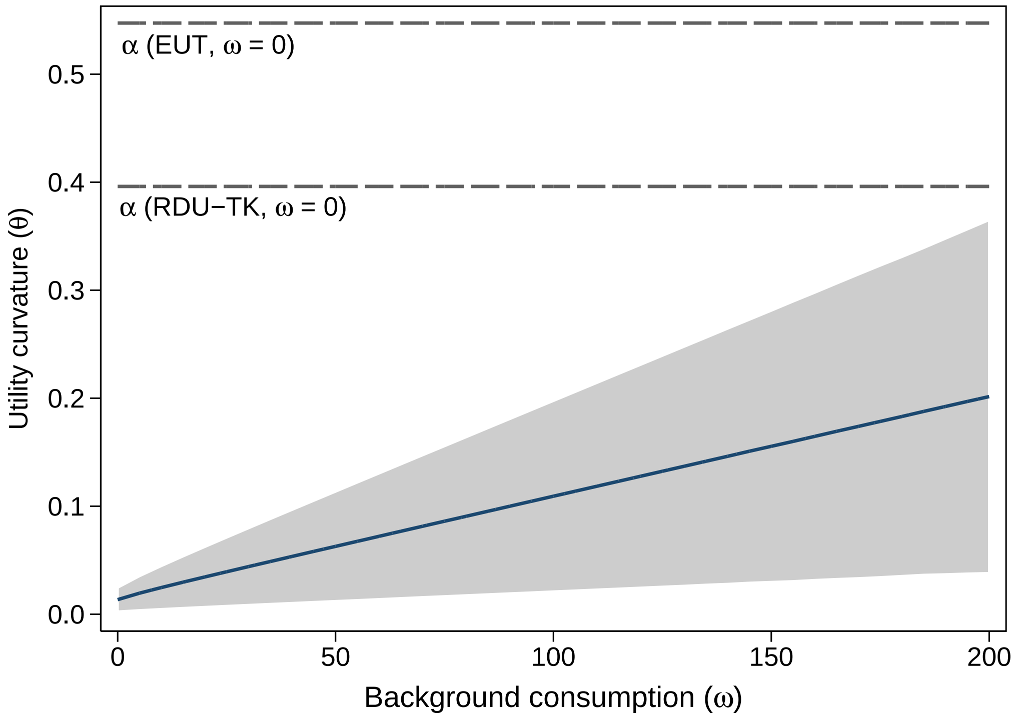
To examine the impact of the background consumption assumption on the estimated curvature of instantaneous utility, Figure 6 illustrates the effect of parametrically varying the assumed exogenous value of ω upon the point estimate and 95% confidence interval for θ in the baseline model from Table 3. The figure confirms that the estimate of θ increases with increasing values of ω. The likelihood of the model is maximized at $\omega = \$29$, where the point estimate of θ is 0.043 with a 95% confidence interval between 0.008 and 0.078, while the estimated discount rate is virtually identical to that reported in Table 3. Figure 6 shows that even at quite large values of ω the estimates of θ remain substantially smaller than the estimates of the risk curvature parameter α at $\omega = 0$.[35] The dashed horizontal lines depict the point estimates of α from models

[33] See Andersen et al. (2008) and Andreoni and Sprenger (2012a) for related discussions of this issue.

[34] Irrespective of the value of ω, any given pattern of choices in the experiment will always be explained by the same amount of "absolute risk aversion". However, as the argument of the utility function is inflated by increasing values of ω, these same choices represent increasing amounts of "relative risk aversion" – where the quotation marks are to point out that all choices are in fact over deterministic bundles of payment over time.

[35] In the post-experiment questionnaire, subjects were asked to report how much they spent on everyday expenses (excluding housing and studies) in a typical week. The mean response was \$78, the median was \$60, and the 95th percentile value was \$200.

Figure 6: Effect of background consumption upon estimates of utility curvature in choices over time



(1) and (4) of Table 1 assuming nil background consumption. Of course, these estimates would themselves be inflated as increasing values of ω are added to the payoffs. Therefore, in short, background consumption cannot explain the differences in the curvature of utility elicited under risk and over time.

3.3.2 Individual estimation

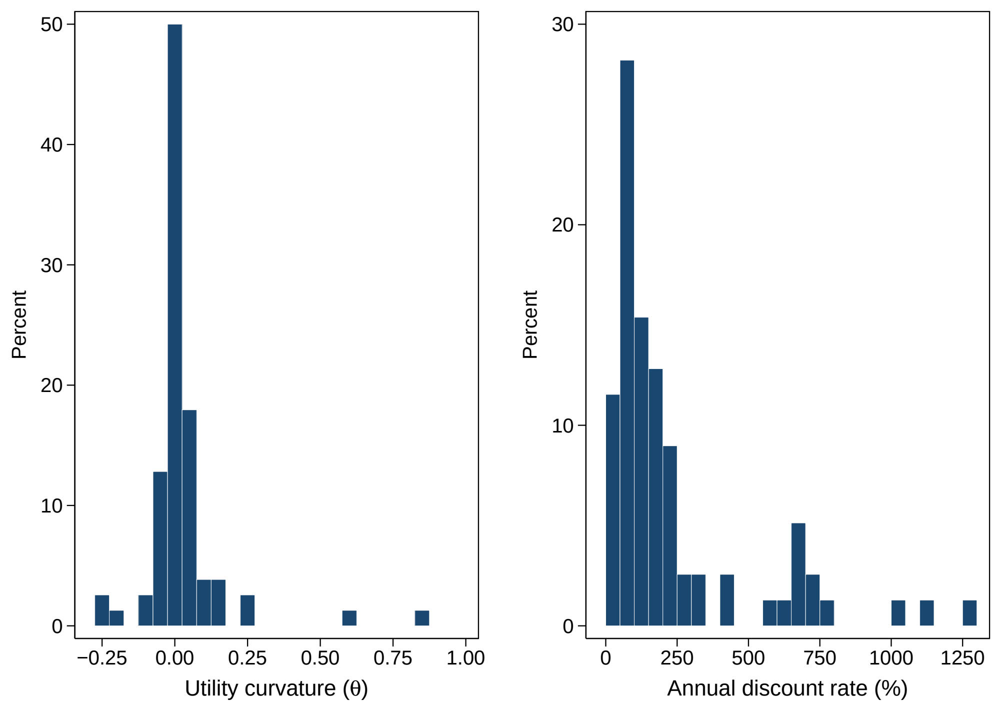
Up to this point, the analysis has focused on models in which a single set of preference parameters is estimated to fit the choices of all subjects. To what extent is the main finding – of limited concavity of instantaneous utility – qualified by allowing for individual heterogeneity in behavior? To address this question, I estimate the baseline model from Table 3, assuming nil background consumption, at the level of individual subjects. Clearly, the model cannot be estimated for 15 subjects who always choose larger-later. I am able to estimate the model for 79 of the remaining 107 subjects. Table 4 reports summary statistics of the distribution of individual parameter estimates of θ and ρ, while 7 reports histograms of the distributions.

The results indicate that there is indeed variation in the parameter estimates, however the distributions are consistent with the aggregate results. Both the mean and median of the individual utility curvature estimates are slightly positive, and the mass of the distribution is clearly concentrated around (and to the right of) zero. There are some subjects who have negative point estimates of θ implying slightly convex utility, but only five of the estimates are smaller than –0.1. On the other hand, only four subjects have point estimates larger

Table 4: Individual-level estimates of utility curvature and discount rates, from choices over time

	N	mean	sd	Percentiles min	5th	25th	median	75th	95th	max
θ	79	0.005	0.233	–1.642	–0.193	–0.018	0.004	0.037	0.230	0.867
ρ	79	2.682	4.135	0.240	0.333	0.723	1.334	2.400	10.318	30.513

Figure 7: Individual-level estimates of utility curvature and discount rates, from choices over time



Note: Individual estimates for 79 subjects. Left panel omits one subject with an estimated utility curvature parameter of –1.642. Right panel omits one subject with an estimated annual discount rate of 3,051%.

than 0.2. Supposing that the individual estimates of θ were to also characterize subjects' attitudes toward risk under expected utility, then only nine of the 79 subjects would be predicted to make five or more safe lottery choices in the risk preference task. In fact, 70 out of 79 actually make five or more safe choices, again illustrating how the curvature of utility exhibited over time is less pronounced than under risk.[36]

[36]For the annual discount rate ρ, both the mean and median of the distribution of individual estimates are somewhat larger than the estimates in Table 3. This partly reflects the composition of the subset of subjects for which I am able to estimate the model individually. When I re-estimate the baseline representative agent model using only this subset, the point estimate of ρ is 110.7% with a 95% confidence interval between 87.9% and 133.6%. However the point estimate of θ is 0.015 with a 95% confidence interval between 0.004 and 0.030, and this is very similar to the estimates in Table 3.

4 Conclusion

In this paper, I have introduced a novel method to elicit the curvature of instantaneous utility, jointly with the discount function, directly from choices over bundles of time-dated payoffs. Owing to a lack of suitable measurement techniques, relatively little is known about the shape of the utility function outside the domain of risk. This has made it difficult to evaluate the assumption – frequently invoked in both theoretical and empirical literatures – that a single utility function characterizes preferences both under risk and over time.

The approach that I adopt builds upon design and estimation principles that are well-established in the experimental economics literature. The Holt and Laury (2002) design is a very well-known and popular elicitation procedure for risk preference, and moreover it is often used as the risk-preference instrument in studies which, following Andersen et al. (2008), assume the equivalence of utility under risk and over time for the purpose of jointly estimating risk and time preferences. By transposing the HL design from state-payoff space into time-dated payoff space, I am able to retain the joint estimation apparatus developed by Andersen et al. (2008, 2014), with the important distinction that the curvature of utility is inferred directly from choices over time. This makes it possible to compare the estimated curvature of utility under risk and over time within a unified design and estimation framework.

The results confirm firstly that the instantaneous utility function is indeed significantly concave. This reaffirms the underlying theoretical concern raised by Frederick et al. (2002) regarding the confounding influence of utility curvature upon estimates of the discount rate, which has motivated the development of the joint estimation approach as well as alternative strategies such as those of Takeuchi (2011) and Laury et al. (2012). However, whereas each of those approaches assume that a single utility function is used to evaluate payoffs both under risk and over time, I find the curvature of instantaneous utility elicited from choices over time to be substantially less than the curvature of Bernoulli utility elicited from choices under risk, with the estimated CRRA coefficient being roughly an order of magnitude smaller. This is consistent with the results of recent studies by Abdellaoui et al. (2013) and Andreoni and Sprenger (2012a), who also find limited concavity of utility over time. It follows that just as assuming linear utility may cause estimates of discount rates to be biased, so too may assuming the equivalence of utility for risk and time. Indeed, whereas Andersen et al. (2008) find a substantial effect of correcting for risk-elicited utility curvature, I find the effect of correcting for time-elicited curvature to be no more than a few percentage points.

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Appendices: For online publication only

A Details of experiment design

A.1 Parameters of the risk preference choice list

Row	Option A				Option B				EV_A	EV_B	CRRA at indifference
	x_b	$1-p_g$	x_g	p_g	x_b	$1-p_g$	x_g	p_g			
1	17	0.9	20	0.1	1	0.9	38	0.1	17.3	4.7	–1.936
2	17	0.8	20	0.2	1	0.8	38	0.2	17.6	8.4	–1.095
3	17	0.7	20	0.3	1	0.7	38	0.3	17.9	12.1	–0.594
4	17	0.6	20	0.4	1	0.6	38	0.4	18.2	15.8	–0.222
5	17	0.5	20	0.5	1	0.5	38	0.5	18.5	19.5	0.087
6	17	0.4	20	0.6	1	0.4	38	0.6	18.8	23.2	0.367
7	17	0.3	20	0.7	1	0.3	38	0.7	19.1	26.9	0.643
8	17	0.2	20	0.8	1	0.2	38	0.8	19.4	30.6	0.948
9	17	0.1	20	0.9	1	0.1	38	0.9	19.7	34.3	1.354
10	17	0.0	20	1.0	1	0.0	38	1.0	20.0	38.0	n/a

Note: Values in the final column are the value of the CRRA coefficient α for risk at which a subject is indifferent between Options A and B, assuming expected utility and zero background consumption. Values in the final three columns were not presented to subjects.

A.2 Parameters of the time preference choice lists

CA

Row	Option A				Option B				Annual Rate
	x_t	t	x_{t+k}	$t+k$	x_t	t	x_{t+k}	$t+k$	
1	33	1	2	28	17	1	20	28	25.46
2	33	1	2	25	17	1	20	25	29.07
3	33	1	2	22	17	1	20	22	33.86
4	33	1	2	19	17	1	20	19	40.53
5	33	1	2	16	17	1	20	16	50.43
6	33	1	2	13	17	1	20	13	66.59
7	33	1	2	10	17	1	20	10	97.49
8	33	1	2	7	17	1	20	7	177.54
9	33	1	2	4	17	1	20	4	670.27
10	33	1	2	1	17	1	20	1	∞

C'A

Row	Option A				Option B				Annual
	x_t	t	x_{t+k}	$t+k$	x_t	t	x_{t+k}	$t+k$	Rate
1	25	1	11	28	17	1	20	28	25.46
2	25	1	11	25	17	1	20	25	29.07
3	25	1	11	22	17	1	20	22	33.86
4	25	1	11	19	17	1	20	19	40.53
5	25	1	11	16	17	1	20	16	50.43
6	25	1	11	13	17	1	20	13	66.59
7	25	1	11	10	17	1	20	10	97.49
8	25	1	11	7	17	1	20	7	177.54
9	25	1	11	4	17	1	20	4	670.27
10	25	1	11	1	17	1	20	1	∞

AB'

Row	Option A				Option B				Annual
	x_t	t	x_{t+k}	$t+k$	x_t	t	x_{t+k}	$t+k$	Rate
1	17	1	20	28	9	1	29	28	25.46
2	17	1	20	25	9	1	29	25	29.07
3	17	1	20	22	9	1	29	22	33.86
4	17	1	20	19	9	1	29	19	40.53
5	17	1	20	16	9	1	29	16	50.43
6	17	1	20	13	9	1	29	13	66.59
7	17	1	20	10	9	1	29	10	97.49
8	17	1	20	7	9	1	29	7	177.54
9	17	1	20	4	9	1	29	4	670.27
10	17	1	20	1	9	1	29	1	∞

Note: Interest rates in final column of each table were not presented to subjects. Delay lengths are in weeks.

AB

Row	Option A				Option B				Annual
	x_t	t	x_{t+k}	$t+k$	x_t	t	x_{t+k}	$t+k$	Rate
1	17	1	20	28	1	1	38	28	25.46
2	17	1	20	25	1	1	38	25	29.07
3	17	1	20	22	1	1	38	22	33.86
4	17	1	20	19	1	1	38	19	40.53
5	17	1	20	16	1	1	38	16	50.43
6	17	1	20	13	1	1	38	13	66.59
7	17	1	20	10	1	1	38	10	97.49
8	17	1	20	7	1	1	38	7	177.54
9	17	1	20	4	1	1	38	4	670.27
10	17	1	20	1	1	1	38	1	∞

CB

Row	Option A				Option B				Annual
	x_t	t	x_{t+k}	$t+k$	x_t	t	x_{t+k}	$t+k$	Rate
1	33	1	2	28	1	1	38	28	25.46
2	33	1	2	25	1	1	38	25	29.07
3	33	1	2	22	1	1	38	22	33.86
4	33	1	2	19	1	1	38	19	40.53
5	33	1	2	16	1	1	38	16	50.43
6	33	1	2	13	1	1	38	13	66.59
7	33	1	2	10	1	1	38	10	97.49
8	33	1	2	7	1	1	38	7	177.54
9	33	1	2	4	1	1	38	4	670.27
10	33	1	2	1	1	1	38	1	∞

Note: Interest rates in final column of each table were not presented to subjects. Delay lengths are in weeks.

C'B'

Row	Option A x_t	t	x_{t+k}	$t+k$	Option B x_t	t	x_{t+k}	$t+k$	Annual Rate
1	25	1	11	28	9	1	29	28	25.46
2	25	1	11	25	9	1	29	25	29.07
3	25	1	11	22	9	1	29	22	33.86
4	25	1	11	19	9	1	29	19	40.53
5	25	1	11	16	9	1	29	16	50.43
6	25	1	11	13	9	1	29	13	66.59
7	25	1	11	10	9	1	29	10	97.49
8	25	1	11	7	9	1	29	7	177.54
9	25	1	11	4	9	1	29	4	670.27
10	25	1	11	1	9	1	29	1	∞

Note: Interest rates in final column of each table were not presented to subjects. Delay lengths are in weeks.

A.3 Order of presentation of choice lists

Decisions	1-10	11-20	21-30	31-40	41-50	51-60	61-70
Order 1A	AB	AB'	CA	C'A	CB	C'B'	Risk
Order 1B	AB'	AB	C'A	CA	C'B'	CB	Risk
Order 2A	CA	C'A	AB	AB'	CB	C'B'	Risk
Order 2B	C'A	CA	AB'	AB	C'B'	CB	Risk

Note: Choice lists were not described using these labels in the decision sheets presented to subjects.

B Implications of linear versus concave instantaneous utility

Assume an additively-separable intertemporal utility function of the form of equation 3 in the text. Let $\left(x_t^S, x_{t+k}^S\right)$ denote the smaller-sooner payoff vector presented as Option A, and let $\left(x_t^L, x_{t+k}^L\right)$ be the larger-later one presented as Option B. In rows 1 to 9 of each choice list, a subject chooses Option A (B) as:[37]

$$D(t)\,v\left(x_t^S\right) + D(t+k)\,v\left(x_{t+k}^S\right) \gtrless D(t)\,v\left(x_t^L\right) + D(t+k)\,v\left(x_{t+k}^L\right)$$

$$\frac{D(t)}{D(t+k)} \gtrless \frac{v\left(x_{t+k}^L\right) - v\left(x_{t+k}^S\right)}{v\left(x_t^S\right) - v\left(x_t^L\right)} \tag{11}$$

The quantity on the left of equation 11 represents the relative value of utility on date t compared to $t+k$. Moving down the rows of a choice list, as k falls toward 0 weeks, $D(t+k)$ increases toward $D(t)$ and so $D(t)/D(t+k)$ falls toward 1. The quantity on the right is the ratio of the utility gained at date $t+k$ to utility lost at date t when the subject chooses Option B over Option A. Within a given choice list, this term is constant because all payoffs are fixed. A subject's "switch point" from smaller-sooner to larger-later is thus defined by the value of k at which $D(t)/D(t+k)$ first falls below this fixed ratio of utility differences.

For the case of linear utility, the switch point is defined by:

$$\frac{D(t)}{D(t+k)} \gtrless \frac{x_{t+k}^L - x_{t+k}^S}{x_t^S - x_t^L} \tag{12}$$

where, by design of the experiment, the ratio of *payoff* differences is constant and equal to 1.125 in all choice lists. Thus, *a subject with linear* instantaneous *utility is predicted to switch from Option A to Option B at the same row (i.e. make the same number of sooner choices) in all time-preference choice lists.*

For the case of concave utility, for given-sized differences in the magnitudes of the payoffs, the utility difference in the numerator of equation 11 shrinks as the later payoffs are shifted further up the utility function, while the utility difference in the denominator grows as the sooner payoffs are shifted further down. For example, comparing switch points for the AB and CA choice lists, concave utility implies that:

$$\frac{v(38) - u(20)}{v(17) - u(1)} < \frac{v(20) - u(2)}{v(33) - u(17)}$$

since the numerator of the term on the left is smaller than that of the one on the right, while the denominator is larger. It follows that a subject with concave instantaneous utility is predicted to make a larger number of sooner choices in the AB choice list compared to the CA choice list.

[37] In row 10, $k = 0$ and $D(t)\,v\left(x_t^S + x_{t+k}^S\right) < D(t)\,v\left(x_t^L + x_{t+k}^L\right)$ such that the subject should always chooses Option B.

Note that *these predictions hold regardless of the shape of the discount function* $D(t)$, provided it satisfies the standard assumptions that $D(t) > 0$ and $D'(t) < 0$. For example, they hold not only for exponential discounting, but also for any conventional model of hyperbolic discounting (see Andersen et al. (2014) for a review), as well as the models of time-dependent probability weighting mentioned in the introduction.

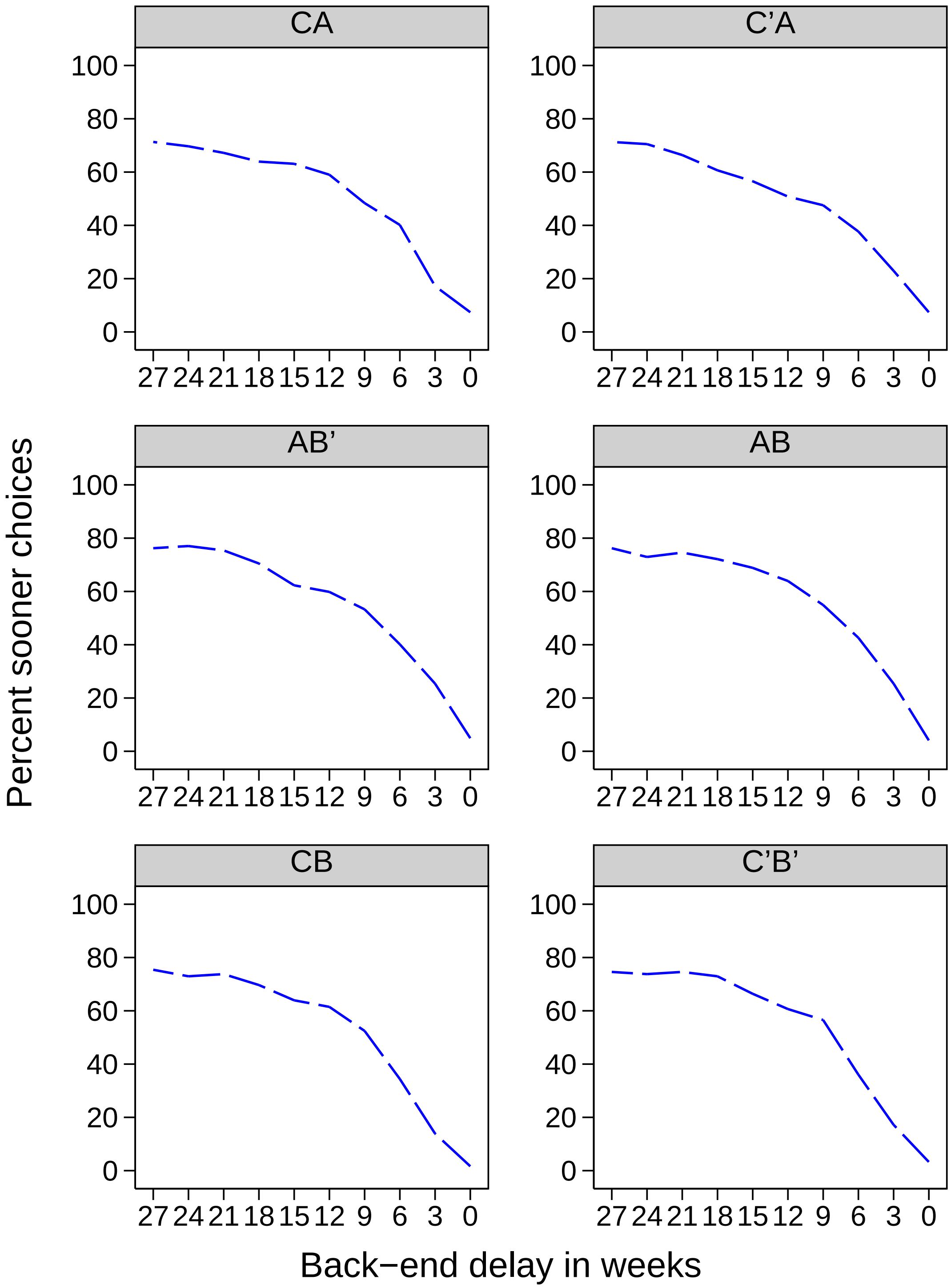
For choice situations where subjects face risks over multiple points in time, Andersen et al. (2011) and Cheung (in press) consider the possibility that the intertemporal utility function may not be additively separable, contrary to what is assumed in equation 3 in the text. The basic idea is that subjects may be averse not only to the atemporal risk that they face at a single point in time, but also to the intertemporal risk inherent in their overall payoff stream. A simple specification that captures this idea is to replace equation 3 by:

$$IU(x_t, t; x_{t+k}, t+k) = V\left[D(t) \cdot v(x_t) + D(t+k) \cdot v(x_{t+k})\right] \tag{13}$$

where $V(\cdot)$ is an increasing concave function (cf. equation 12 in Andersen et al. (2011), and equation 2 in Cheung (in press)). However, in the time preference experiment in this paper, subjects only ever faced choices in which all payments on both dates were sent with certainty, such that there was only a single possible realization of intertemporal utility and choices could not be affected by intertemporal risk aversion. That is, $IU\left(x_t^S, t; x_{t+k}^S, t+k\right) \gtrless IU\left(x_t^L, t; x_{t+k}^L, t+k\right)$ as $DU\left(x_t^S, t; x_{t+k}^S, t+k\right) \gtrless DU\left(x_t^L, t; x_{t+k}^L, t+k\right)$, and so the switch point defined by equation 11 remains unchanged. Similarly, by standard textbook arguments for increasing monotonic transformations, the slope of an indifference curve for the intertemporal utility function in equation 13 is identical to that of the additive specification, as given by equation 4 in the text, since terms involving $V'(\cdot)$ cancel out.

C Supplementary analyses

C.1 Choice behavior in the time preference tasks, by choice list



D Experiment instructions (Order 1A)

ELIGIBILITY TO PARTICIPATE

Welcome to today's session, and thank you for coming here on time. Please do not talk to the other participants while the session is in progress. Mobile phones must also be turned off. If you have a question at any time, please raise your hand, and someone will come to assist you in private.

IN THIS STUDY, YOU WILL RECEIVE SOME OR ALL OF YOUR EARNINGS IN THE FUTURE.

Therefore, to be eligible to participate, you must be willing to receive payments by cheque, to be written to you by Dr Stephen Cheung, a Lecturer in the School of Economics. These cheques will be drawn on the University of Sydney branch of the National Australia Bank.

You will receive two cheques. The first cheque will arrive one week from today. The second cheque will arrive between one and twenty-eight weeks from today. You will be fully informed of the amount of each cheque before you leave the lab at the end of this session. There is also a chance that you may receive some payment in cash at the end of the session.

Cheques will be delivered by Express Post, to your own nominated mailing address in Sydney. Australia Post guarantees next business day delivery for mail sent by Express Post to addresses within the Sydney metropolitan region.

Therefore to take part in this study, you must be willing to provide your mailing address in Sydney. This will only be seen by Dr Cheung and his assistants. After payment has been sent, your address will no longer be retained and your identity will not be a part of the subsequent data analysis.

Finally, you must be willing to stay for the full duration of today's session, and to comply with the instructions of the experimenter; otherwise you will not receive any payment at all.

If you do not agree to all of these points, please raise your hand now.

**IF YOU AGREE, PLEASE TURN OVER THIS PAGE TO SIGN THE CONSENT FORM,
AND HAND IT IN WHEN ASKED TO DO SO.**

GENERAL INFORMATION AND EARNINGS

In this study you will make a total of 70 decisions involving amounts of money that differ with respect to the dates on which the money will be received, or the chances of receiving the money.

In each of these decisions you will be presented with two alternatives, labelled “Option A” and “Option B”, and you will be asked to indicate which of the two options you would prefer to receive.

Afterwards, we will ask you to complete a brief questionnaire about yourself. Both your choices and your responses to the questionnaire will be anonymous and not linked to your identity in any way.

At the end of the session, one of the 70 decisions will be randomly selected by drawing a numbered ball from the bingo cage at the front of the lab. We will do this separately for each participant. Your earnings will be determined by the choice that you made – Option A or Option B – for that decision.

You will also receive a participation fee of $10.00 in return for submitting valid responses for all 70 decisions, as well as every item of the questionnaire.

Your participation fee will be paid by cheque, in two equal instalments of $5 each. The first cheque will arrive one week from today. The second cheque will arrive between one and twenty-eight weeks from today. In particular:

- **If the decision randomly selected as the one that counts is one of Decisions 1 through 60,** then your earnings from the choice that you made will be added to your two cheques of $5 each, and sent to you on the dates indicated as part of that decision.
- **If the decision randomly selected as the one that counts is one of Decisions 61 through 70,** then your earnings from the choice that you made will be paid to you in cash at the end of the session. In this case, you would still receive two cheques of $5 each: the first would be sent one week from today, and the second would be sent sixteen weeks from today.

The selection of the decision that counts is entirely random, and your choices have no influence over whether you receive payment in the form of cash as well as cheque. What your choices do affect are the amounts of money you receive, in the event that a decision is chosen to count for payment. You will always receive two cheques by mail, and the value of each cheque will always be at least $5.

The decisions are not designed to test you – the only correct answers are the ones you really think are best for you. Since every decision has an equal chance to be selected as the one that determines your earnings, you should consider each one carefully, treating it as if it may be the one that counts.

One business day before each payment date, your cheque will dispatched for delivery by Express Post. Australia Post guarantees next business day delivery for mail sent by Express Post to addresses within the Sydney metropolitan region.

Attached to your Participation Information Statement is Dr Cheung’s business card. Please keep this in a safe place. If you do not receive a cheque on the designated date, please contact Dr Cheung.

On your desk are two envelopes: one for each of your two cheques. Please take the time now to address these to yourself at your own mailing address in Sydney.

DECISION TABLES 1 TO 6 (Decisions 1 to 60)

Decision Tables 1 to 6 each show ten choices between two options labelled "A" and "B". Each decision involves a choice between receiving different amounts of money on two different dates, which will be clearly indicated for each decision. You will make 60 of these choices in total.

For example: In Decision 1, Option A pays $17 in 1 week from today, **and** it also pays $20 in 28 weeks from today. Option B pays $1 in 1 week from today, **and** it also pays $38 in 28 weeks from today.

The other decisions in Decision Table 1 are similar, except that as you move down the table, the date of the second payment in each option becomes sooner. In fact, for Decision 10 in the bottom row, both payments will arrive on the same date in one week from today. So in Decision 10, your choice is between $17 **and** $20 in Option A, or $1 **and** $38 in Option B, all arriving one week from today.

Decision Tables 2 to 6 also have the same format. It is only the amounts of money in Option A and Option B that change from one table to the next.

For each decision, you are asked to choose either Option A or Option B by marking an "X" in the appropriate box.

You may choose A for some decisions and B for others, and you may make your choices in any order.

Please note that the decision sheets will be double-sided, and that you should complete all decisions on both the front and back of each page.

If one of these decisions is randomly selected as the one that counts for payment, then your earnings will be determined by the choice that you made – either Option A or Option B – for that decision.

These earnings would be added to the two instalments of your participation fee, and mailed to you by cheque on the two dates indicated as part of that decision.

For example: Suppose that one of the choices in Decision Table 1 is selected to count for payment.

- Then, if you chose Option A, $17 would be added to the first instalment of your participation fee and sent to you on the first date. **In addition,** $20 would also be added to the second instalment of your participation fee and sent to you on the second date.
- Otherwise, if you chose Option B, $1 would be added to the first instalment of your participation fee and sent to you on the first date. **In addition,** $38 would also be added to the second instalment of your participation fee and sent to you on the second date.

At the time you make each choice, you will not know if it will be selected for payment. Since each choice is equally likely to be selected, you should treat each one as if it may be the one that counts.

PLEASE DO NOT BEGIN MAKING YOUR DECISIONS UNTIL YOU ARE INSTRUCTED TO DO SO.

DECISION TABLE 7 (Decisions 61 to 70)

Decision Table 7 shows ten choices between two options labelled “A” and “B”. These choices involve different chances to receive different amounts of money at the end of today’s session.

We will use a ten-sided die to determine these chances; the faces are numbered from 1 to 10 (the “0” face of the die will serve as 10).

For example: In Decision 61, Option A pays $20 if the roll of the ten-sided die is 1, and it pays $17 if the roll is 2 to 10. Option B pays $38 if the roll of the die is 1, and it pays $1 if the roll is 2 to 10.

The other decisions are similar, except that as you move down the table, the chances of the higher payment in each option increase. In fact, for Decision 70 in the bottom row, the die will not be needed since each option pays the higher payoff for sure, so your choice here is between $20 or $38.

For each decision row, you are asked to choose either Option A or Option B by marking an “X” in the appropriate box.

You may choose A for some decisions and B for others, and you may make your choices in any order.

If one of these decisions is randomly selected as the one that counts for payment, then we will roll the ten-sided die to determine your earnings according to the choice that you made – either Option A or Option B – for that decision.

This amount would be paid to you in cash at the end of today’s session. In this case, you would still receive your participation fee by cheque in two instalments of $5 each: the first would be sent one week from today, and the second would be sent sixteen weeks from today.

At the time you make each choice, you will not know if it will be selected for payment. Since each choice is equally likely to be selected, you should treat each one as if it may be the one that counts.

PLEASE DO NOT BEGIN MAKING YOUR DECISIONS UNTIL YOU ARE INSTRUCTED TO DO SO.