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RISK PREFERENCES ARE NOT TIME PREFERENCES: DISCOUNTED EXPECTED UTILITY WITH A DISPROPORTIONATE PREFERENCE FOR CERTAINTY

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ABSTRACT

Risk and time are intertwined. The present is known while the future is inherently risky. Discounted expected utility provides a simple, coherent structure for analyzing decisions in intertemporal, uncertain environments. However, we document robust violations of discounted expected utility, inconsistent with both prospect theory probability weighting and models with preferences for the resolution of uncertainty. We find that we can organize our data with surprising precision if we allow for a disproportionate preference for certainty. These results have potentially important implications for understanding dynamically inconsistent preferences.

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1 Introduction

Research on decision making under uncertainty has a long tradition. A core of tools designed to explore risky decisions has evolved, from Savage's (1954) axioms and the expected utility (EU) framework.[1] There are, however, a number of well-documented departures from EU such as the Allais (1953) common consequence and common ratio paradoxes. An organizing principle behind the body of violations of expected utility is that they seem to arise as so-called 'boundary effects' where certainty and uncertainty are combined. Camerer (1992), Harless and Camerer (1994) and Starmer (2000) indicate that violations of expected utility are notably less prevalent when all choices are uncertain.

Certainty and uncertainty are combined in intertemporal decisions. The present is known, while the future is inherently risky. The discounted expected utility (DEU) model is the standard approach to addressing decision-making in such contexts.

There are noted difficulties with the DEU model related to the timing of the resolution of uncertainty. Preferences on income streams induced from preferences on consumption streams that follow the EU axioms may depend on the timing of the resolution of income uncertainty and will not generally have an expected utility formulation (Markowitz, 1959; Mossin, 1969; Spence and Zeckhauser, 1972; Machina, 1984). Kreps and Porteus (1978), Chew and Epstein (1989), and Epstein and Zin (1989) use this observation to motivate utility models with preferences for the temporal resolution of uncertainty.

There is a distinction between these developments and the evidence presented in this paper. We document violations of expected utility in a setting where uncertainty is resolved immediately, before further consumption decisions are made.[2] The preference

[1] Ellingsen (1994) provides a thorough history of the developments building towards expected utility theory and its cardinal representation.

[2] The only evidence of intertemporal violations of EU we are aware of are Baucells and Heukamp (2009) and Gneezy, List and Wu (2006) who show that temporal delay can generate behavior akin to the classic common ratio effect and that the so-called 'uncertainty effect' is present for hypothetical

models of Kreps and Porteus (1978) and Chew and Epstein (1989) and the primary model classes of Epstein and Zin (1989) "...conform with expected utility theory when ranking timeless gambles, i.e., those in which uncertainty is resolved before further consumption takes place" (Epstein and Zin, 1989, p. 948). As such, in our experiment these models will be equivalent to DEU.[3]

An implication of the DEU model is that intertemporal allocations should depend *only* on relative intertemporal risk. For example, if sooner consumption will be realized 50% of the time and later consumption will be realized 50% of the time, intertemporal allocations should be identical to a situation where all consumption is risk-free. This is simply an intertemporal statement of the common ratio property of expected utility.

In an experiment with 80 undergraduate subjects at the University of California, San Diego, we test intertemporal common ratio predictions using Convex Time Budgets (CTBs) under varying risk conditions (Andreoni and Sprenger, 2009). In CTBs, individuals are asked to allocate a budget of experimental tokens to sooner and later payments. CTB allocation decisions are equivalent to intertemporal optimization subject to a linear budget constraint.

We implement CTBs in two baseline risk conditions: 1) A risk-free condition where all payments, both sooner and later, will be paid 100% of the time; and 2) a risky condition where, independently, sooner and later payments will be paid only 50% of the time. All uncertainty was resolved immediately after the allocation decisions were made, for both sooner and later payments. Under the standard DEU model, CTB allocations in the two conditions should yield identical choices. The pattern of results we find clearly violates DEU, and correspondingly resolution-timing preferences, and is further inconsistent with non-EU concepts such as probability weighting (Kahneman

intertemporal decisions, respectively.

[3]Not all of the classes of recursive utility models discussed in Epstein and Zin (1989) will reduce to expected utility when all uncertainty is resolved immediately. The weighted utility class (Class 3) corresponding to the models of Dekel (1986) and Chew (1989) can accomodate expected utility violations even without a preference for sooner or later resolution of uncertainty.

and Tversky, 1979; Tversky and Kahneman, 1992; Tversky and Fox, 1995) or temporally dependent probability weighting (Halevy, 2008). We document substantial DEU violations at both the group and individual level. Indeed, 85% of subjects are found to violate common ratio predictions and do so in more than 80% of opportunities. In estimations of utility parameters, aggregate discounting is found to be around 30% per year, and is virtually identical in both the all-safe and all-risky conditions. However, other utility parameters, such as utility function curvature, are found to differ significantly. Taken at face value, the estimates indicate a disproportionate preference for certainty.

To explore this result in greater detail, we examine four additional experimental conditions with differential risk, but common ratios of probabilities. In the first such condition the sooner payment is paid 100% of the time while the later payment is paid only 80% of the time. This is compared to a common ratio counterpart where the sooner payment is paid 50% of the time while the later payment is paid only 40% of the time. We document violations of the DEU common ratio prediction suggestive of a disproportionate preference for certainty. We mirror this design with conditions where the later payment has the higher probability of payment and again document a disproportionate preference for certainty. The data are organized systematically at both the group and individual level. Subjects who violate common-ratio predictions in the baseline 100%-100% and 50%-50% conditions are more likely to violate in the four additional conditions.

Our results are remarkably in line with the initial intuition for the Allais paradox and have implications for intertemporal decision theory. Allais (1953, p. 530) argued that when two options are far from certain, individuals act effectively as expected utility maximizers, while when one option is certain and another is uncertain a disproportionate preference for certainty prevails. Such an argument may help to explain the frequent experimental finding of present-biased preferences (Frederick, Loewenstein and O'Donoghue, 2002). That is, certainty, not intrinsic temptation, may lead present payments to be disproportionately preferred. This view has been argued previously in prior explorations of present-bias (Halevy, 2008), and is implied in the recognized dynamic inconsistency of non-expected utility models (Green, 1987; Machina, 1989). However, our results provide evidence of a different mechanism. Our results point towards so-called u-v preferences as in the models of Neilson (1992), Schmidt (1998), and Diecidue, Schmidt and Wakker (2004). Such models deliver a representation with standard expected utility $u(\cdot)$ away from certainty, and utility $v(\cdot)$ for certainty, potentially with $u(\cdot) \neq v(\cdot)$ and the disproportionate preference $v(x) > u(x)$ for $x > 0$.[4]

The paper proceeds as follows: Section 2 presents a conceptual development of u-v preferences and discounted expected utility, building to a testable hypothesis of decision making in uncertain and certain situations. Section 3 describes our experimental design. Section 4 presents results and Section 5 is a discussion and conclusion.

2 Conceptual Background

We begin by discussing u-v preferences (Neilson, 1992; Schmidt, 1998; Diecidue et al., 2004). Let $v(c)$ be some utility function for certain consumption and $u(c)$ be a utility function for uncertain consumption, assumed to be separable and linearly additive over probabilistic states. Note that the u-v model nests standard expected utility when $u(\cdot) \equiv v(\cdot)$, yet can accommodate a disproportionate preference for certainty $v(c) > u(c)$ for $c > 0$. Hence, standard expected utility is a special case of u-v preferences with an assumption of interchangeability for $u(\cdot)$ and $v(\cdot)$.

Assumption: *Interchangeability.* Individuals evaluate consumption, c, obtained under certainty and uncertainty in an identical manner, that is $u(c) \equiv v(c)$.

[4]For a discussion of the early history of u-v preferences, see Schoemaker (1982).

When utility is time separable, interchangeability gives rise to the standard DEU model,

$$U = \sum_{k=0}^{T} \delta^{t+k} E[v(c_{t+k})],$$

Simplify to assume two periods, t and $t+k$, and that consumption at time t will be c_t with probability p_1 and zero otherwise, while consumption at time $t+k$ will be c_{t+k} with probability p_2 and zero otherwise. Under the standard construction, utility is

$$p_1 \delta^t v(c_t) + p_2 \delta^{t+k} v(c_{t+k}) + ((1-p_1)\delta^t + (1-p_2)\delta^{t+k})v(0).$$

Suppose an individual maximizes utility subject to the future value budget constraint

$$(1+r)c_t + c_{t+k} = m,$$

yielding the marginal condition

$$\frac{v'(c_t)}{\delta^k v'(c_{t+k})} = (1+r)\frac{p_2}{p_1}.$$

The tangency condition, in combination with the budget constraint, yields a solution

$$c_t = c_t^*(p_1/p_2; k, 1+r, m).$$

A key observation in this construction is that intertemporal allocations will depend *only* on the relative risk, p_1/p_2, and not on p_1 or p_2 separately. If $p_1/p_2 = 1$, for $p_1 = p_2 < 1$, then behavior should be identical to a risk-free situation, $p_1 = p_2 = 1$. This is a critical and testable implication of the DEU model.

Hypothesis: For any (p_1, p_2) and (p_1', p_2') where $p_1/p_2 = p_1'/p_2'$, $c_t^*(p_1/p_2; k, 1+r, m) = c_t^*(p_1'/p_2'; k, 1+r, m)$.

This hypothesis is simply an intertemporal statement of the common ratio property of expected utility.[5] However, it is important to understand the degree to which this common ratio hypothesis hinges upon interchangeability. If $u(c) \neq v(c)$, then there is no reason to expect $c_t^*(p_1/p_2; k, 1+r, m) = c_t^*(1/1, k, 1+r, m)$ when $p_1 = p_2 < 1$. This is because the marginal conditions in the two situations will generally be satisfied at different allocation levels.[6]

There exist important utility formulations such as those developed by Kreps and Porteus (1978), Chew and Epstein (1989), and Epstein and Zin (1989) where the common ratio prediction does not hold. Behavior need not be identical if the uncertainty of p_1 and p_2 are resolved at different points in time, and individuals have preferences over the timing of the resolution of uncertainty. Our experimental design will focus on cases where all uncertainty is resolved immediately, before any payments are received. The utility formulations of Kreps and Porteus (1978) and Chew and Epstein (1989), and the primary classes discussed by Epstein and Zin (1989) will reduce to standard expected utility. That is, when "... attention is restricted to choice problems/temporal lotteries where all uncertainty resolves at t = 0, there is a single 'mixing' of prizes and one gets the payoff vector [EU] approach" (Kreps and Porteus, 1978, p. 199).

In our later exposition it will be notationally convenient to use θ to indicate the *risk adjusted gross interest rate*:

$$\theta = (1+r)\frac{p_2}{p_1}$$

[5]If individuals face background risk compounded with the objective probabilities, the common ratio prediction is maintained. This is true even if background risk differs across time periods.

[6]In the risky situation the marginal condition will be $u'(c_t)/\delta^k u'(c_{t+k}) = (1+r)p_2/p_1 = (1+r)$, while in the risk-free situation the condition will be: $v'(c_t')/\delta^k v'(c_{t+k}') = (1+r)$. And $c_t' = c_t; c_{t+k}' = c_{t+k}$ only if the marginal utility functions $u'(\cdot)$ and $v'(\cdot)$ are equal. Though this may occur with $u(\cdot) \neq v(\cdot)$, it generally will not. Additionally, there is no reason to expect $c_t^*(p_1/p_2; k, 1+r, m) = c_t^*(p_1'/1, k, 1+r, m)$ when $p_1/p_2 = p_1'$ and $p_2' = 1$ or $c_t^*(p_1/p_2; k, 1+r, m) = c_t^*(1/p_2', k, 1+r, m)$ when $p_1/p_2 = 1/p_2'$ and $p_1' = 1$.

such that the tangency can be written as:

$$\frac{v'(c_t)}{\delta^k v'(c_{t+k})} = \theta$$

Provided that $v'(\cdot) > 0, v''(\cdot) < 0$, c_t^* will be increasing in p_1/p_2 and decreasing in $1+r$. As such, c_t^* will be decreasing in θ. In addition, for a given θ, c_t^* will be decreasing in $1 + r$. An increase in the interest rate will both raise the relative price of sooner consumption and reduce the available consumption set.

3 Experimental Design

In order to explore the evaluation of uncertain and certain intertemporal consumption, an experiment using Convex Time Budgets (CTB) (Andreoni and Sprenger, 2009) under varying risk conditions was conducted at the Univeristy of California, San Diego in April of 2009. In each CTB decision, subjects were given a budget of experimental tokens to be allocated across a sooner payment, paid at time t, and a later payment, paid at time $t + k$, $k > 0$. Two basic CTB environments consisting of 7 allocation decisions each were implemented under six different risk conditions. This generated a total of 84 experimental decisions for each subject.

3.1 CTB Design Features

Sooner payments in each decision were always seven days from the experiment date ($t = 7$ days). We chose this 'front-end-delay' to avoid any direct impact of immediacy on decisions, including resolution timing effects, and to help eliminate differential transactions costs across sooner and later payments.[7] In one of the basic CTB environments, later payments were delayed 28 days ($k = 28$) and in the other, later payments

[7]See below for the recruitment and payment efforts that allowed sooner payments to be implemented in the same manner as later payments. For discussions of front-end-delays in time preference experiments see Coller and Williams (1999); Harrison, Lau, Rutstrom and Williams (2005).

were delayed 56 days ($k = 56$). The choice of t and k were set to avoid holidays, school vacation days and final examination week. Payments were scheduled to arrive on the same day of the week (t and k are both multiples of 7) to avoid differential weekday effects.

In each CTB decision, subjects were given a budget of 100 tokens. Tokens allocated to the sooner date had a value of a_t while tokens allocated to the later date had a value of a_{t+k}. In all cases, a_{t+k} was \$0.20 per token and a_t varied from \$0.20 to \$0.14 per token. Note that $a_{t+k}/a_t = (1 + r)$, the gross interest rate over k days, and $(1 + r)^{1/k} - 1$ gives the standardized daily *net* interest rate. Daily net interest rates in the experiment varied considerably across the basic budgets, from 0 to 1.3 percent, implying annual interest rates of between 0 and 2100 percent (compounded quarterly). Table 1 shows the token values, gross interest rates, standardized daily interest rates and corresponding annual interest rates for the basic CTB budgets.

Table 1: Basic Convex Time Budget Decisions

t (start date)	k (delay)	Token Budget	a_t	a_{t+k}	$(1 + r)$	Daily Rate (%)	Annual Rate (%)
7	28	100	0.20	0.20	1.00	0	0
7	28	100	0.19	0.2	1.05	0.18	85.7
7	28	100	0.18	0.2	1.11	0.38	226.3
7	28	100	0.17	0.2	1.18	0.58	449.7
7	28	100	0.16	0.2	1.25	0.80	796.0
7	28	100	0.15	0.2	1.33	1.03	1323.4
7	28	100	0.14	0.2	1.43	1.28	2116.6
7	56	100	0.20	0.20	1.00	0	0
7	56	100	0.19	0.2	1.05	0.09	37.9
7	56	100	0.18	0.2	1.11	0.19	88.6
7	56	100	0.17	0.2	1.18	0.29	156.2
7	56	100	0.16	0.2	1.25	0.40	246.5
7	56	100	0.15	0.2	1.33	0.52	366.9
7	56	100	0.14	0.2	1.43	0.64	528.0

The basic CTB decisions described above were implemented in a total of six risk conditions. Let p_1 and p_2 be the probabilities that payment would be made for the sooner and later payments, respectively. The six conditions were $(p_1, p_2) \in$

$\{(1,1),(0.5,0.5),(1,0.8),(0.5,0.4),(0.8,1),(0.4,0.5)\}$. For all payments involving uncertainty, a ten-sided die was rolled immediately at the end of the experiment to determine whether the payment would be sent or not. Hence, p_1 and p_2 were immediately known, independent, and subjects were told that different random numbers would determine their sooner and later payments.[8]

The risk conditions have several features. To begin, the first and second conditions share a common ratio of $p_1/p_2 = 1$, the third and fourth conditions share a common ratio of $p_1/p_2 = 1.25$, and the fifth and sixth conditions share a common ratio of $p_1/p_2 = 0.8$. Discounted expected utility predicts identical behavior across each pair of conditions. Additionally, three of the risk conditions feature at least one certain payment, while the other three feature only uncertainty. If there exists a disproportionate preference for certainty, it should become apparent in cross-condition comparisons. For instance, for a given value of θ, subjects should disproportionately prefer the sooner payment when $(p_1, p_2) = (1, 0.8)$ and the later payment when $(p_1, p_2) = (0.8, 1)$. Lastly, across conditions the sooner payment goes from being relatively less risky, $p_1/p_2 = 1.25$, to relatively more risky, $p_1/p_2 = 0.8$. Following the discussion of Section 2, DEU maximizers should respond to changes in relative risk, allocating smaller amounts to sooner payments when relative risk is low.

3.2 Implementation and Protocol

One of the most challenging aspects of implementing any time discounting study is making all choices equivalent except for their timing. That is, transactions costs associated with receiving payments, including physical costs and confidence, must be equalized across all time periods. We took several unique steps in our subject recruitment process and our payment procedure in an attempt to equate transaction costs over time.

[8] See Appendix A.3 for the payment instructions provided to subjects.

3.2.1 Recruitment and Experimental Payments

In order to participate in the experiment, subjects were required to live on campus. All campus residents are provided with individual mailboxes at their dormitories to use for postal service and campus mail. Each mailbox is locked and individuals have keyed access 24 hours per day. We recruited 80 undergraduate students fitting this criterion.

All payments, both sooner and later, were placed in subjects' campus mailboxes by campus mail services, which allowed us to equate physical transaction costs across sooner and later payments. Subjects were fully informed of the method of payment.[9]

Several other measures were also taken to equate transaction costs. Upon beginning the experiment, subjects were told that they would receive a \$10 minimum payment for participating, to be received in two payments: \$5 sooner and \$5 later. All experimental earnings were added to these \$5 minimum payments. Two blank envelopes were provided. After receiving directions about the two minimum payments, subjects addressed the envelopes to themselves at their campus mailbox. At the end of the experiment, subjects wrote their payment amounts and dates on the inside flap of each envelope such that they would see the amounts written in their own handwriting when payments arrived. In sum, these measures serve to ensure that transaction costs, including banking convenience, likelihood of clerical error, and costs of remembering are equalized across time.

One choice for each subject was selected for payment by drawing a numbered card at random.[10] All experimental payments were made by personal check from Professor James Andreoni drawn on an account at the university credit union.[11] Subjects were

[9]See Appendix A.2 for the information provided to subjects.

[10]This randomization device introduces a compound lottery to the decision environment. Reduction of compound lotteries is assumed for expected utility and does not change the common ratio predictions. Subjects are told to treat each decision as if it were to determine their payments. See Appendix A.3 for text. In a sense, this encourages subjects to ignore the randomization device. As shown in Section 4, the results demonstrate behavior that is suggestive of individuals treating experimental certainty differently than other probabiltiies.

[11]Payment choice was guided by a separate survey of 249 undergraduate economics students eliciting payment preferences. Personal checks from Professor Andreoni, Amazon.com gift cards, PayPal transfers and the university stored value system TritonCash were each compared to cash payments.

informed that they could cash their checks (if they so desired) at the university credit union. They were also given the business card of Professor James Andreoni and told to call or email him if a payment did not arrive and that a payment would be hand-delivered immediately.

3.2.2 Instrument and Protocol

The experiment was done with paper and pencil. Upon entering the lab subjects were read an introduction with detailed information on the payment process and a sample decision with different payment dates, token values and payment risks than those used in the experiment.[12] Subjects were informed that they would work through 6 decision tasks. Each task consisted of 14 CTB decisions: seven with $t = 7,\ k = 28$ on one sheet and seven with $t = 7,\ k = 56$ on a second sheet. Each decision sheet featured a calendar, highlighting the experiment date, and the sooner and later payment dates, allowing subjects to visualize the payment dates and delay lengths.

Figure 1 shows a decision sheet. Identical instructions were read at the beginning of each task providing payment dates and the chance of being paid for each decision. Subjects were provided with a calculator and a calculation sheet transforming tokens to payment amounts at various token values.

Subjects were asked if they would prefer a twenty dollar payment made via each payment method or $\$X$ cash, where X was varied from 19 to 10. Personal checks were found to have the highest cash equivalent value. That is, the highest average value of $\$X$.

[12] See Appendix A.3 for introductory text, instructions and examples.

Figure 1: Sample Decision Sheet

2009 Calendar

S	M	T	W	Th	F	S
April						
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		
May						
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30
31						
June						
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

IN EACH ROW ALLOCATE 100 TOKENS BETWEEN

	PAYMENT A (1 week from today)				AND	PAYMENT B (4 weeks later)			
	Date A: April 8, 2009 Chance A Sent: 40%					Date B: May 6, 2009 Chance B Sent: 50%			
No.	A Tokens		Rate A $ per token	Date A	&	B Tokens		Rate B $ per token	Date B
1.	______	tokens at	$.20 each	on April 8	&	______	tokens at	$.20 each	on May 6
2.	______	tokens at	$.19 each	on April 8	&	______	tokens at	$.20 each	on May 6
3.	______	tokens at	$.18 each	on April 8	&	______	tokens at	$.20 each	on May 6
4.	______	tokens at	$.17 each	on April 8	&	______	tokens at	$.20 each	on May 6
5.	______	tokens at	$.16 each	on April 8	&	______	tokens at	$.20 each	on May 6
6.	______	tokens at	$.15 each	on April 8	&	______	tokens at	$.20 each	on May 6
7.	______	tokens at	$.14 each	on April 8	&	______	tokens at	$.20 each	on May 6

PLEASE MAKE SURE A + B TOKENS = 100 IN EACH ROW!

Four sessions were conducted over two days. Two orders of risk conditions were implemented to examine order effects.[13] Each day consisted of an early session (12 p.m.) and a late session (2 p.m.). The early session on the first day and the late session on the second day share a common order as do the late session on the first day and the early session on the second day. No identifiable order or session effects were found (see Section 4.1).

4 Results

The results are presented in two sub-sections. First, we examine behavior in the two baseline conditions: $(p_1, p_2) = (1, 1)$ and $(p_1, p_2) = (0.5, 0.5)$. We document violations of the DEU model's common ratio prediction at both aggregate and individual levels and show a pattern of results that is generally incompatible with various probability weighting concepts. In estimates of utility parameters, we show a clear difference between the utility functions for certain and uncertain outcomes, indicating a disproportionate preference for certainty. Second, we explore behavior in four further conditions where common ratios maintain but only one payment is certain. Subjects exhibit a disproportionate preference for certainty when it is available, but behave consistently with expected utility maximization away from certainty.

4.1 Behavior Under Certainty and Uncertainty

Section 2 provided a testable hypothesis for behavior across certain and uncertain intertemporal settings. For a given (p_1, p_2), if $p_1 = p_2 < 1$ then behavior should be identical to a similarly dated risk-free prospect, $(p_1 = p_2 = 1)$, at all gross interest rates,

[13] In one order, (p_1, p_2) followed the sequence $(1, 1), (1, 0.8), (0.8, 1), (0.5, 0.5), (0.5, 0.4), (0.4, 0.5)$, while in the second it followed $(0.5, 0.5), (0.5, 0.4), (0.4, 0.5), (1, 1), (1, 0.8), (0.8, 1)$. This, of course, does not exhaust the possible order effects, but the strength of the results suggests that order is unlikely to qualitatively affect the findings.

$1+r$, and all delay lengths, k.[14] Figure 2 graphs aggregate behavior for the conditions $(p_1, p_2) = (1, 1)$ (blue diamonds) and $(p_1, p_2) = (0.5, 0.5)$ (red squares) across the experimentally varied gross interest rates and delay lengths. The mean earlier choice of c_t is graphed along with error bars corresponding to 95 percent confidence intervals (+/− 1.96 standard errors).

Under the DEU model, behavior should be identical across the two conditions. We find strong evidence to the contrary. In a hypothesis test of equality across the two conditions, the overall difference is found to be highly significant: $F_{14,79} = 6.07$, $p < .001$.[15]

The data follow an interesting pattern. Behavior in both $(p_1, p_2) = (1, 1)$ and $(0.5, 0.5)$ conditions respect increasing interest rates. Allocations to sooner payments decrease as interest rates rise. At the lowest interest rate, c_t allocations are substantially higher in the $(1, 1)$ condition. However, as the gross interest rate increases, $(1, 1)$ allocations drop steeply, crossing over the graph of the $(0.5, 0.5)$ condition.[16] This cross-over in behavior is in clear violation of discounted expected utility and all models that reduce to discounted expected utility when uncertainty is immediately resolved. Though this is suggestive evidence against interchangeability, we must first consider possible alternative explanations. Principal among these is Prospect Theory and, in particular, non-linear probability weighting (Kahneman and Tversky, 1979; Tversky and Kahneman, 1992; Tversky and Fox, 1995).

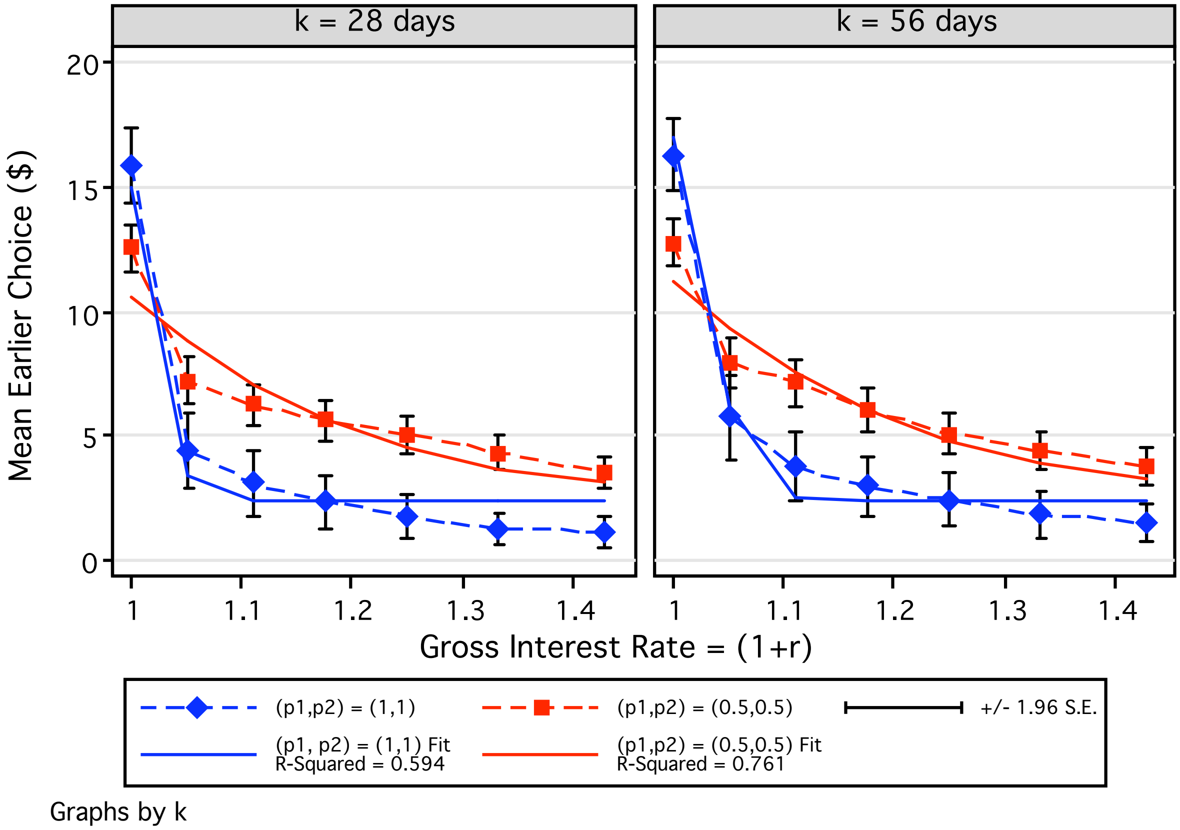
Probability weighting states that individuals 'edit' probabilities internally via a weighting function, $\pi(p)$. Though $\pi(p)$ may take a variety of forms, it is often argued

[14] We ignore m because the experimental budget was held constant across all choices.

[15] Test statistic generated from non-parametric OLS regression of choice on indicators for interest rate (7 levels), delay length (2 levels), risk condition (2 levels) and all interactions with clustered standard errors. F-statistic corresponds to null hypothesis that all risk condition terms have zero slopes. See Appendix Table A1 for regression.

[16] Indeed, in the $(1, 1)$ condition, 80.7 percent of allocations are at one or the other budget corners while only 26.1 percent are corner solutions in the $(0.5, 0.5)$ condition. We interpret the corner solutions in the $(1, 1)$ condition as evidence consistent with separability. See Andreoni and Sprenger (2009) for a full discussion of censoring issues in CTBs. The difference in allocations across conditions is obtained for all sessions and for all orders indicating no presence of order or day effects.

Figure 2: Aggregate Behavior Under Certainty and Uncertainty



Note: The figure presents aggregate behavior for $N = 80$ subjects under two conditions: $(p_1, p_2) = (1, 1)$, i.e. no risk, in blue; and $(p_1, p_2) = (0.5, 0.5)$, i.e. 50% chance sooner payment would be sent *and* 50% chance later payment would be sent, in red. $t = 7$ *days* in all cases, $k \in \{28, 56\}$ *days*. Error bars represent 95% confidence intervals, taken as $+/-1.96$ standard errors of the mean. Test of H_0 : Equality across conditions: $F_{14,79} = 6.07$, $p < .001$.

to be monotonically increasing in the interval $[0, 1]$, with an inverted S-shaped, such that low probabilities are up-weighted and high probabilities are down-weighted (Wu and Gonzalez, 1996; Prelec, 1998; Gonzalez and Wu, 1999). Probability weighting of this or any form is unable to explain the phenomena observed in Figure 2. If $p_1 = p_2$, then necessarily $\pi(p_1) = \pi(p_2)$, and $\pi(p_1)/\pi(p_2) = 1$ as before. As in the DEU model, probability weighting predicts behavior to be identical across our experimental conditions.

Another potential explanation is that probabilities are weighted by their temporal proximity (Halevy, 2008). Under this formulation, subjective probabilities are arrived at through some temporally dependent function $g(p, t) : [0, 1] \times \Re^+ \rightarrow [0, 1]$ where t represents the time at which payments will be made. Provided freedom to pick the functional form of $g(\cdot)$ one could easily arrive at differences between the ratios $g(1, t)/g(1, t + k)$ and $g(0.5, t)/g(0.5, t + k)$.[17]

These differences lead to a *new* risk adjusted interest rate similar to the θ defined in Section 2,

$$\tilde{\theta}_{p_1,p_2} \equiv \frac{g(p_2, t + k)}{g(p_1, t)}(1 + r).$$

Note that either $\tilde{\theta}_{1,1} > \tilde{\theta}_{0.5,0.5}$ for all $(1+r)$ or $\tilde{\theta}_{1,1} < \tilde{\theta}_{0.5,0.5}$ for all $(1+r)$, depending on the form of $g(\cdot)$ chosen. Once one obtains a prediction as to the relationship between $\tilde{\theta}_{1,1}$ and $\tilde{\theta}_{0.5,0.5}$, it must hold for all gross interest rates. As such, one should never observe the cross-over in behavior where for one gross interest rate c_t allocations are higher when $(p_1, p_2) = (1, 1)$ and for another gross interest rate c_t allocations are higher when $(p_1, p_2) = (0.5, 0.5)$. The cross-over that is observed in our data, therefore, is not consistent with temporally dependent probability weighting of the form proposed by Halevy (2008).

The aggregate violations of the DEU model documented above are also supported in the individual data. Out of 14 opportunities to violate the DEU common ratio prediction, individuals do so an average of 9.68 ($s.d. = 5.50$) times. Only fifteen percent of subjects (12 of 80) commit zero violations of expected utility. For the 85 percent of

[17] Halevy (2008) gives the example of $g(p, t) = g(p^t)$ with $g(0) = 0; g(1) = 1$. In this case:

$$\frac{g(1, t)}{g(1, t + k)} = \frac{g(1^t)}{g(1^{t+k})} = 1 \neq \frac{g(0.5, t)}{g(0.5, t + k)} = \frac{g(0.5^t)}{g(0.5^{t+k})}$$

provided $g(\cdot)$ does not take on identical values at 0.5^t and 0.5^{t+k}. If one further assumes $g(\cdot)$ is strictly monotonic and differentiable such that $\frac{\partial g}{\partial p} > 0$, then

$$\frac{g(1, t)}{g(1, t + k)} = \frac{g(1^t)}{g(1^{t+k})} = 1 < \frac{g(0.5, t)}{g(0.5, t + k)} = \frac{g(0.5^t)}{g(0.5^{t+k})}.$$

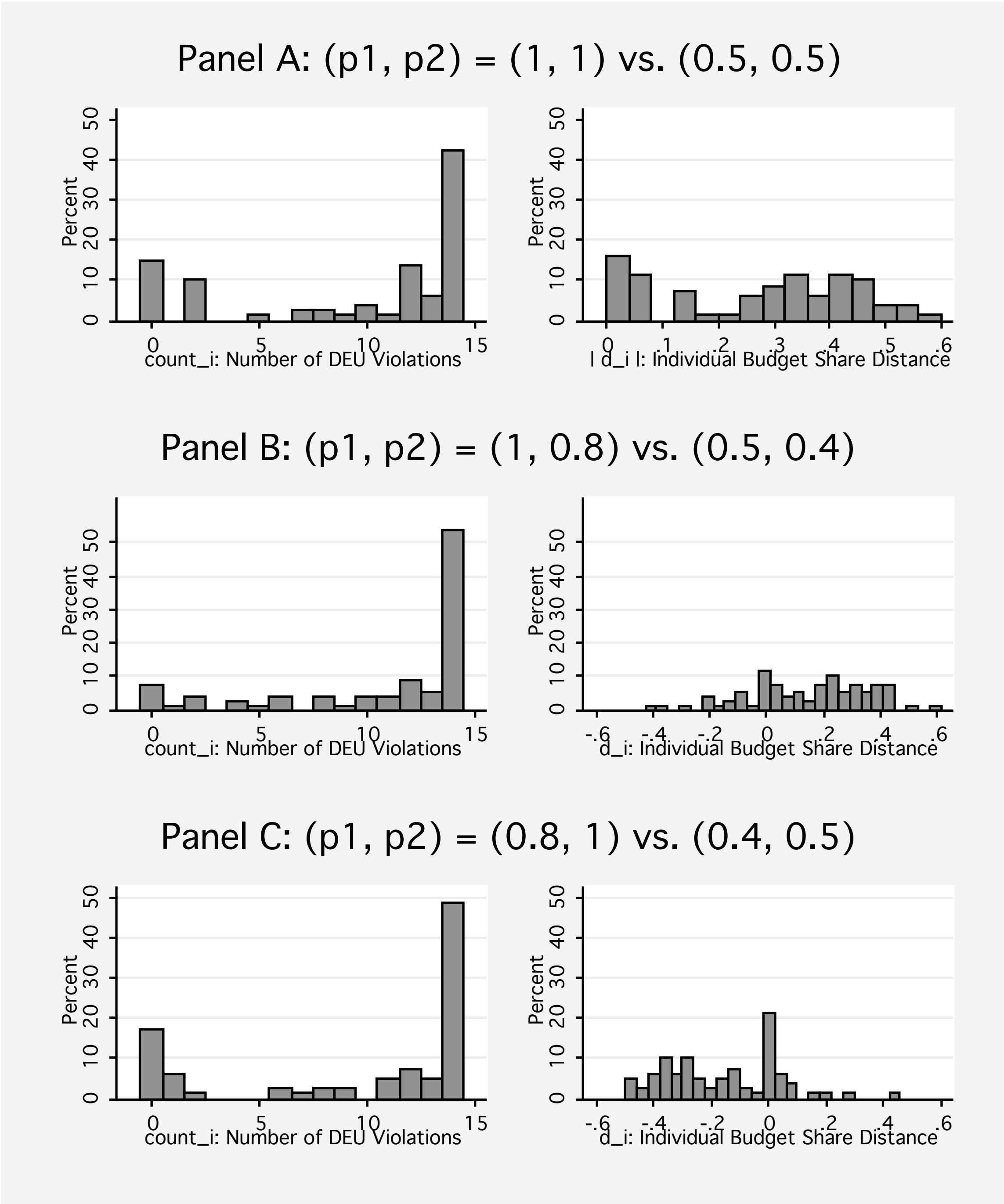
subjects who do violate expected utility, they do so in more than 80% of opportunities, an average of 11.38 ($s.d.$ = 3.99) times. Figure 3, Panel A presents a histogram of $count_i$, each individual's number of DEU violations across conditions $(p_1, p_2) = (1, 1)$ and $(0.5, 0.5)$. More than 40% of subjects violate common ratio predictions in all 14 opportunities. This may be a strict measure of violation as it requires identical allocation across risk conditions. As a complementary measure, we also present a histogram of $|d_i|$, the individual average budget share difference between risk conditions. For each individual and each CTB, we calculate the budget share of the sooner payment, $(1 + r)c_t/m$. The average of each individual's 14 budget share differences between common-ratio conditions is the measure d_i. Here we consider the absolute value as the difference may be positive in some cases and negative in others, following the aggregate results.[18] The mean value of $|d_i|$ is 0.27 ($s.d.$ = 0.18), indicating that individual DEU violations are substantial, around 27% of the budget share. Indeed 63.8% of the sample (51/80) exhibit $|d_i| > 0.2$, indicating that violations are not just the product of random response error.

4.1.1 Estimating Risk-Dependent Preferences

The observed data in the cases of $(p_1, p_2) = (1, 1)$ and $(p_1, p_2) = (0.5, 0.5)$ are inconsistent with the DEU model at both individual and aggregate levels and are difficult to reconcile with notions of probability weighting. In this section we proceed with structural estimation of intertemporal preferences in hopes of more clearly understanding the phenomenon. Given structural assumptions, the design allows us to estimate utility parameters, following the methodology outlined in Andreoni and Sprenger (2009). We

[18] That is, the absolute value of each of the 14 differences is obtained prior to computing the average. When computing d_i across comparisons $(p_1, p_2) = (1, 0.8)$ vs. $(p_1, p_2) = (0.5, 0.4)$ and $(p_1, p_2) = (0.8, 1)$ and $(p_1, p_2) = (0.4, 0.5)$, the first budget share is subtracted from the second budget share to have a directional difference. A disproportionate preference for certainty would be exhibited by a positive d_i across $(p_1, p_2) = (1, 0.8)$ vs. $(p_1, p_2) = (0.5, 0.4)$ and a negative d_i across $(p_1, p_2) = (0.8, 1)$ and $(p_1, p_2) = (0.4, 0.5)$.

Figure 3: Individual Behavior Under Certainty and Uncertainty



Note: The figure presents individual violation of DEU across three common ratio comparisons. The variable $count_i$ is a count of each individual's common ratio violations and, d_i is each individual's budget share difference between common ratio conditions.

assume an exponentially discounted CRRA utility function,

$$U = p_1 \delta^t (c_t - \omega)^\alpha + p_2 \delta^{t+k} (c_{t+k} - \omega)^\alpha,$$

where δ represents exponential discounting, α represents utility function curvature and ω is a background parameter that could be interpreted as a Stone-Geary minima.[19] We posit an exponential discounting function because for timing and transaction cost reasons no present payments were provided. This precludes direct analysis of present-biased or quasi-hyperbolic time preferences (Strotz, 1956; Phelps and Pollak, 1968; Laibson, 1997; O'Donoghue and Rabin, 1999). Under this formulation, the DEU solution function, c_t^*, can be written as

$$c_t^*(p_1/p_2, t, k, 1+r, m) = \frac{[1 - (\frac{p_2}{p_1}(1+r)\delta^k)^{\frac{1}{\alpha-1}}]}{[1 + (1+r)(\frac{p_2}{p_1}(1+r)\delta^k)^{\frac{1}{\alpha-1}}]}\omega + \frac{[(\frac{p_2}{p_1}(1+r)\delta^k)^{\frac{1}{\alpha-1}}]}{[1 + (1+r)(\frac{p_2}{p_1}(1+r)\delta^k)^{\frac{1}{\alpha-1}}]}m,$$

or

$$c_t^*(\theta, t, k, 1+r, m) = \frac{[1 - (\theta\delta^k)^{\frac{1}{\alpha-1}}]}{[1 + (1+r)(\theta\delta^k)^{\frac{1}{\alpha-1}}]}\omega + \frac{[(\theta\delta^k)^{\frac{1}{\alpha-1}}]}{[1 + (1+r)(\theta\delta^k)^{\frac{1}{\alpha-1}}]}m. \qquad (1)$$

We estimate the parameters of this function via non-linear least squares with standard errors clustered on the individual level to obtain $\hat{\alpha}$, $\hat{\delta}$, and $\hat{\omega}$. An estimate of the annual discount rate is generated as $1/\hat{\delta}^{365} - 1$, with corresponding standard error obtained via the delta method.

Table 2 presents discounting and curvature parameters estimated from the two conditions $(p_1, p_2) = (1, 1)$ and $(p_1, p_2) = (0.5, 0.5)$. In column (1), we estimate a baseline model where discounting, curvature, and background parameters are restricted

[19] The ω terms could be also be interpreted as intertemporal reference points or background consumption. Frequently in the time preference literature, the simplification $\omega = 0$ is imposed or ω is interpreted as *minus* background consumption (Andersen, Harrison, Lau and Rutstrom, 2008) and calculated from an external data source. In Andreoni and Sprenger (2009) we provide methodology for estimating the background parameters and employ this methodology here. Detailed discussions of sensitivity and censored data issues are provided in Andreoni and Sprenger (2009) who show that accounting for censoring issues has little influence on estimates.

to be equal across the two risk conditions. The aggregate discount rate is estimated to be around 27% per year and aggregate curvature is estimated to be 0.98. The background parameter, $\hat{\omega}$ is estimated to be 3.61.

Table 2: Discounting and Curvature Parameter Estimates

	(1)	(2)	(3)	(4)	(5)	(6)
$\hat{\alpha}$	0.982		0.984			
	(0.002)		(0.002)			
$\hat{\alpha}_{(1,1)}$		0.987		0.987	0.988	0.988
		(0.002)		(0.002)	(0.002)	(0.002)
$\hat{\alpha}_{(0.5,0.5)}$		0.950		0.951	0.885	0.883
		(0.008)		(0.008)	(0.017)	(0.017)
Rate	0.274			0.285		0.284
	(0.035)			(0.036)		(0.037)
$\text{Rate}_{(1,1)}$		0.281	0.276		0.282	
		(0.036)	(0.039)		(0.036)	
$\text{Rate}_{(0.5,0.5)}$		0.321	0.269		0.315	
		(0.059)	(0.033)		(0.088)	
$\hat{\omega}$	3.608				2.417	2.414
	(0.339)				(0.418)	(0.418)
$\hat{\omega}_{(1,1)}$		2.281	2.106	2.285		
		(0.440)	(0.439)	(0.439)		
$\hat{\omega}_{(0.5,0.5)}$		4.397	5.260	4.427		
		(0.321)	(0.376)	(0.324)		
H_0: Equality		$F_{3,79} = 16.12$	$F_{2,79} = 30.47$	$F_{2,79} = 23.24$	$F_{2,79} = 37.97$	$F_{1,79} = 38.09$
		$(p < 0.01)$	$(p < 0.01)$	$(p < 0.01)$	$(p < 0.01)$	$(p < 0.01)$
R^2	0.642	0.675	0.672	0.675	0.673	0.673
N	2240	2240	2240	2240	2240	2240
Clusters	80	80	80	80	80	80

Notes: NLS solution function estimators. Subscripts refer to (p_1, p_2) condition. Column (1) imposes the interchangeability, $v(\cdot) = u(\cdot)$. Column (2) allows different curvature, discounting and background parameters in each (p_1, p_2) condition. Column (3) restricts curvature to be equal across conditions. Column (4) restricts discounting to be equal across conditions. Column (5) restricts the background parameter ω to be equal across conditions. Column (6) restricts the background parameter ω and discounting to be equal across conditions. Clustered standard errors in parentheses. F statistics correspond to hypothesis tests of equality of parameters across conditions. Rate: Annual discount rate calculated as $(1/\hat{\delta})^{365} - 1$, standard errors calculated via the delta method.

In column (2), we estimate separate discounting, curvature and background parameters for the two risk conditions. That is, we estimate a certain $v(\cdot)$ and an uncertain

$u(\cdot)$. Discounting is found to be similar across the conditions, around 30% per year ($F_{1,79} = 0.69,\ p = 0.41$).[20] In the certain condition, $(p_1, p_2) = (1, 1)$, we find almost linear utility while in the uncertain condition, $(p_1, p_2) = (0.5, 0.5)$, we estimate utility to be significantly more concave ($F_{1,79} = 24.09,\ p < 0.01$). In the certain condition, $(p_1, p_2) = (1, 1)$, we estimate a background parameter $\hat{\omega}_{1,1}$ of 2.28 while in the uncertain condition the background parameter is significantly higher at 4.40 ($F_{1,79} = 25.53,\ p < 0.01$). A hypothesis test of equal utility parameter estimates across conditions is rejected ($F_{3,79} = 16.12,\ p < 0.01$).

In Table 2, columns (3) through (6) we estimate utility parameters with various imposed restrictions. In column (3), we restrict curvature to be equal across conditions and obtain very similar discounting estimates, but a larger difference in estimated background parameters. In column (4), we restrict discounting to be equal across conditions and obtain a result almost identical to column (2). In column (5), we restrict background parameters to be equal and obtain very similar discounting estimates, but a larger difference in curvature. This finding is repeated in column (6) where discounting is restricted to be the same. Across specifications, hypothesis tests of equality of utility parameters are rejected. To illustrate how well these estimates fit the data, Figure 2 also displays solid lines with predicted behavior from the most restricted regression, column (6). The general pattern of aggregate responses is well matched.[21]

Taken together, these results suggest substantial differences between certain and uncertain utility parameters. The direction of the results is towards a larger back-

[20]For comparison, using similar methodology without uncertainty Andreoni and Sprenger (2009) find aggregate discount rate between 25-35% and aggregate curvature of around 0.92. These discount rates are lower than generally found in the time preference literature (Frederick et al., 2002). Notable exceptions of similarly low or lower discount rates include Coller and Williams (1999), Harrison, Lau and Williams (2002), and Harrison et al. (2005) which all assume linear utility, and Andersen et al. (2008), which accounts for utility function curvature with Holt and Laury (2002) risk measures.

[21]Figure 2 additionally reports separate R^2 values for the two conditions: $R^2_{1,1} = 0.594$; $R^2_{0.5,0.5} = 0.761$, indicating that the solution function estimation approach does an adequate job of fitting the aggregate data. For comparison a simple linear regression of c_t on the levels of interest rates, delay lengths and their interaction in each condition would produce $\tilde{R}^2$ values of $\tilde{R}^2_{1,1} = 0.443$; $\tilde{R}^2_{0.5,0.5} = 0.346$. The least restricted regression, Column (2) creates very similar predicted values with R^2 values of 0.595 and 0.766.

ground parameter, ω, and a smaller curvature parameter, α, in the uncertain $(p_1, p_2) = (0.5, 0.5)$ condition relative to the certain $(p_1, p_2) = (1, 1)$. Given that ω enters negatively into the utility function, these results point to a disproportionate preference for certainty. For the payment values of the experiment, around \$20, $v(c)$ with certainty will be greater than $u(c)$ with uncertainty.

4.2 Behavior with Differential Risk

In this sub-section we explore disproportionate preferences for certainty in four conditions with differential risk. First, we discuss DEU violations in common ratio situations where only one payment is certain as in the original Allais paradox. Second, we examine our three experimental conditions where all payments are uncertain and document behavior consistent with discounted expected utility.

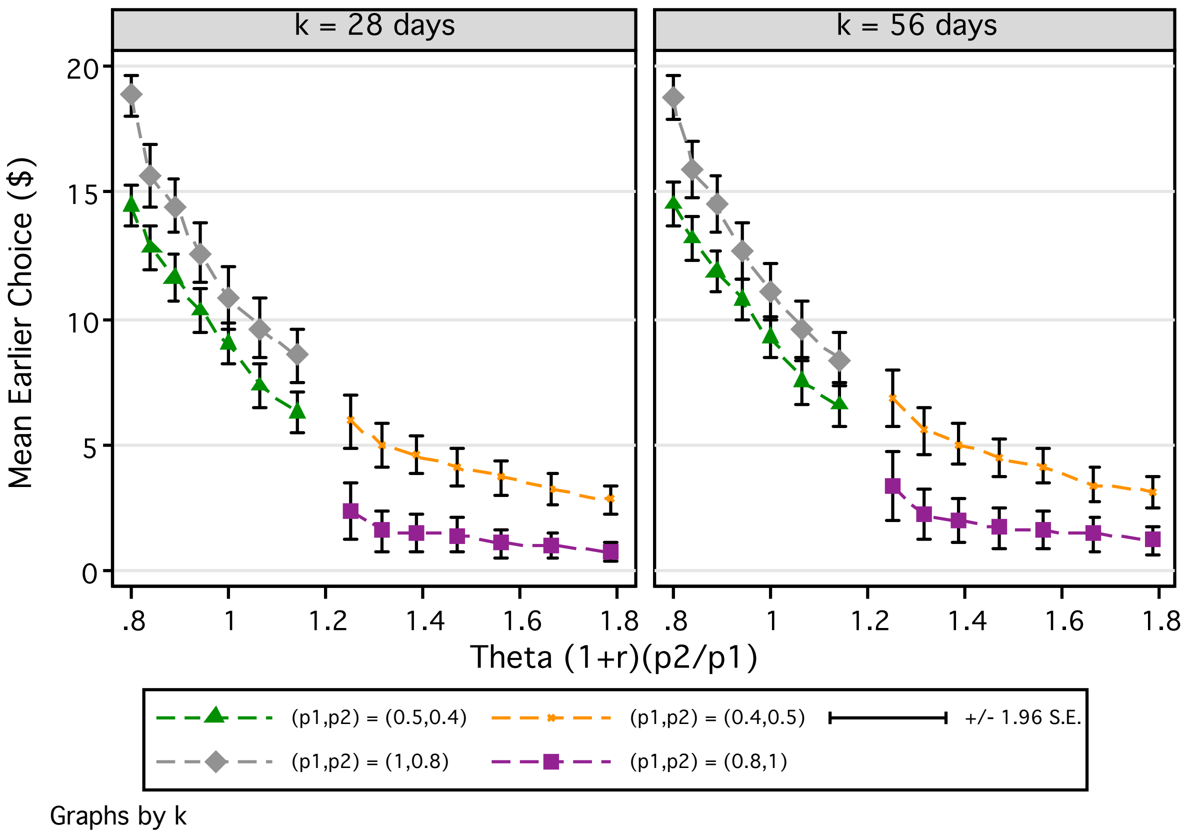
4.2.1 A Disproportionate Preference for Certainty

Figure 4 compares behavior in four conditions with differential risk but common ratios of probabilities. Condition $(p_1, p_2) = (1, 0.8)$ (gray diamonds) is compared to $(p_1, p_2) = (0.5, 0.4)$ (green triangles), and condition $(p_1, p_2) = (0.8, 1)$ (yellow circles) is compared to $(p_1, p_2) = (0.4, 0.5)$ (purple squares). The DEU model predicts equal allocations across conditions with common ratios. Interestingly, subjects show a disproportionate preference for certainty when it is available, regardless of whether the certain payment is sooner or later. Hypotheses of equal allocations across conditions are rejected in both cases.[22]

Figure 3, Panels B and C demonstrate that the individual behavior is organized in a similar manner. Individual violations of common ratio predictions are substantial.

[22]For equality across $(p_1, p_2) = (1, 0.8)$ and $(p_1, p_2) = (0.5, 0.4)$ $F_{14,79} = 7.69$, $p < .001$ and for equality across $(p_1, p_2) = (0.8, 1)$ and $(p_1, p_2) = (0.4, 0.5)$ $F_{14,79} = 5.46$, $p < .001$. Test statistics generated from non-parametric OLS regression of choice on indicators for interest rate (7 levels), delay length (2 levels), risk condition (2 levels) and all interactions with clustered standard errors. F-statistic corresponds to null hypothesis that all risk condition terms have zero slopes. See Appendix Table A1 for regression.

Figure 4: A Disproportionate Preference for Certainty



Note: The figure presents aggregate behavior for $N = 80$ subjects under four conditions: $(p_1, p_2) = (1, 0.8)$, $(p_1, p_2) = (0.5, 0.4)$, $(p_1, p_2) = (0.8, 1)$ and $(p_1, p_2) = (0.4, 0.5)$. Error bars represent 95% confidence intervals, taken as $+/-1.96$ standard errors of the mean. The first and second conditions share a common ratio as do the third and fourth. Test of H_0 : Equality across conditions $(p_1, p_2) = (1, 0.8)$ and $(p_1, p_2) = (0.5, 0.4)$: $F_{14,79} = 7.69$, $p < .001$. Test of H_0 : Equality across conditions $(p_1, p_2) = (0.8, 1)$ and $(p_1, p_2) = (0.4, 0.5)$: $F_{14,79} = 5.46$, $p < .001$.

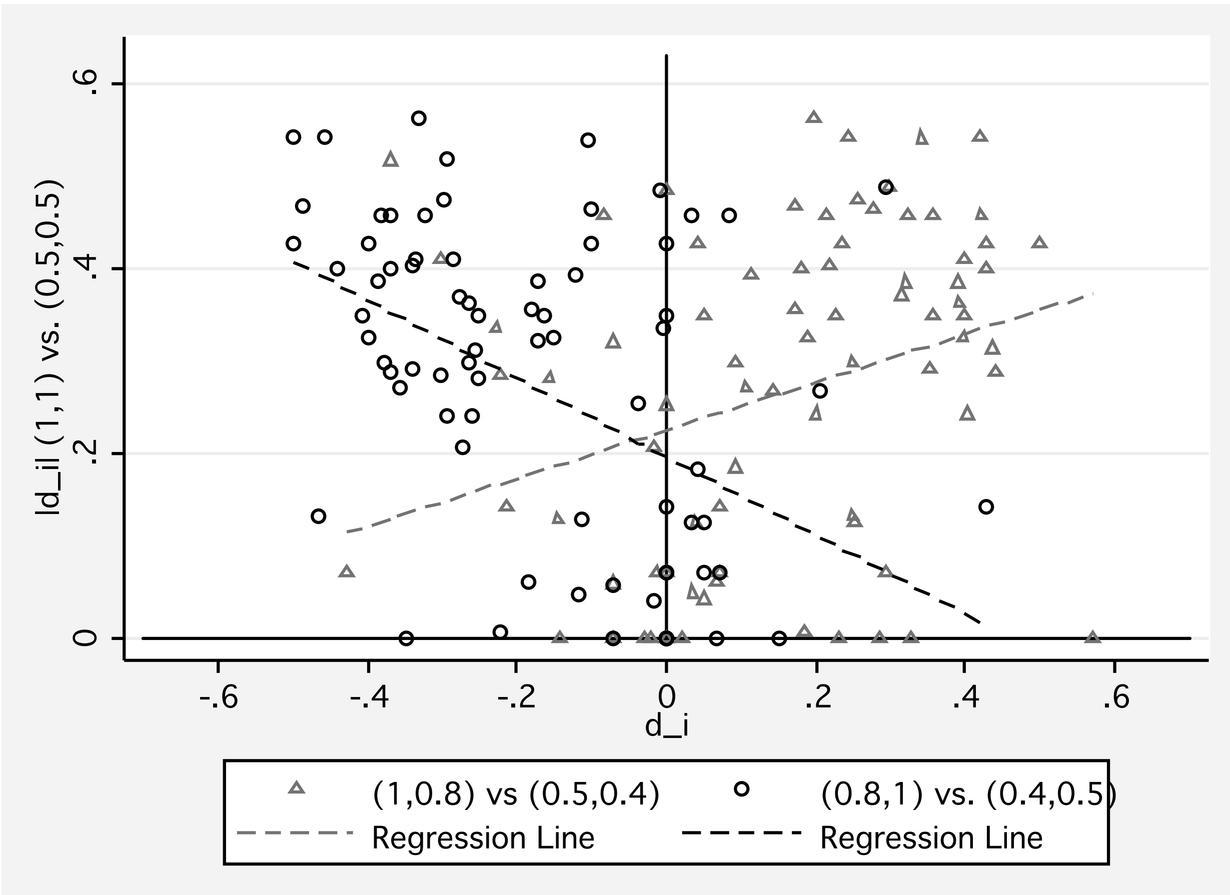
When certainty is sooner, across conditions $(p_1, p_2) = (1, 0.8)$ and $(p_1, p_2) = (0.5, 0.4)$, subjects commit an average of 10.90 ($s.d. = 4.67$) common ratio violations in 14 opportunities and only 7.5% of subjects commit zero violations. The average distance in budget shares, d_i, is 0.150 ($s.d. = 0.214$), which is significantly greater than zero ($t_{79} = 6.24$, $p < 0.01$), and in the direction of disproportionately preferring the certain sooner payment. When certainty is later across conditions $(p_1, p_2) = (0.8, 1)$ and $(p_1, p_2) = (0.4, 0.5)$, subjects make an average of 9.68 ($s.d. = 5.74$) common ratio violations and 17.5% of subjects make no violations at all, similar to Panel A. The average distance in budget share, d_i, is -0.161 ($s.d. = 0.198$), which is significantly less than zero ($t_{79} = 7.27,\ p < 0.01$), and in the direction of disproportionately preferring the certain later payment.

Importantly, violations of discounted expected utility correlate across experimental comparisons. Figure 5 plots budget share differences, d_i, across common-ratio comparisons. The difference $|d_i|$ from condition $(p_1, p_2) = (1, 1)$ vs. $(p_1, p_2) = (0.5, 0.5)$ is on the vertical axis while d_i across the alternate comparisons is on the horizontal axis. Common ratio violations correlate highly across experimental conditions. The more an individual violates DEU across conditions $(p_1, p_2) = (1, 1)$ and $(p_1, p_2) = (0.5, 0.5)$ predicts how much he or she will demonstrate a disproportionate preference for certainty when it is sooner in $(p_1, p_2) = (1, 0.8)$ vs. $(p_1, p_2) = (0.5, 0.4)$, ($\rho = 0.31,\ p < 0.01$), and when it is later in $(p_1, p_2) = (0.8, 1)$ vs. $(p_1, p_2) = (0.4, 0.5)$, ($\rho = -0.47,\ p < 0.01$). Table 3 presents a correlation table for the number of violations $count_i$, and the budget proportion differences d_i, across comparisons and shows significant individual correlation across all conditions and across all measures for DEU violation behavior. This individual data is strikingly supportive of the a u-v interpretation.

4.2.2 When All Choices Are Uncertain

Figure 6 presents aggregate behavior from three risky situtations: $(p_1, p_2) = (0.5, 0.5)$ (red diamonds); $(p_1, p_2) = (0.5, 0.4)$ (green squares); and $(p_1, p_2) = (0.4, 0.5)$ (orange triangles) over the experimentally varied values of θ and delay length. The mean earlier choice of c_t is graphed along with error bars corresponding to 95 percent confidence intervals. We also plot predicted behavior based on uncertain utility function estimated in Table 2, column (6). These out-of-sample predictions are plotted as solid lines in green and orange. The solid red line corresponds to the model fit for $(p_1, p_2) = (0.5, 0.5)$, as in Figure 2.

Figure 5: Violation Behavior Across Conditions



Note: The figure presents the correlations of the budget share difference, d_i, across common ratio comparisons. $|d_i|$ across conditions $(p_1, p_2) = (1, 1)$ and $(p_1, p_2) = (0.5, 0.5)$ is on the vertical axis. d_i across the alternate comparisons is on the horizontal axis. Regression lines are provided. Corresponding correlation coefficients are $\rho = 0.31$, $(p < 0.01)$ for the triangular points $(p_1, p_2) = (1, 0.8)$ vs $(p_1, p_2) = (0.5, 0.4)$ and $\rho = -0.47$, $(p < 0.01)$ for the circular points $(p_1, p_2) = (0.8, 1)$ vs $(p_1, p_2) = (0.4, 0.5)$. See Table 3 for more details.

We highlight two dimensions of Figure 6. First, the theoretical predictions are 1) that c_t should be declining in θ; and 2) that if two decisions have identical θ then c_t should be higher in the condition with the lower interest rate.[23] These features are observed in the data. Allocations of c_t decline with θ and, where overlap of θ exists c_t

[23]Under the DEU-based solution function established in (4.1.1), c_t should be monotonically decreasing in θ. Additionally, if $\theta = \theta'$ and $1 + r \neq 1 + r'$ then behavior should be identical up to a scaling factor related to the interest rates $1 + r$ and $1 + r'$. c_t should be slightly higher in the lower interest rate condition due to income effects.

Table 3: Individual DEU Violation Correlation Table

		$count_i$	$count_i$	$count_i$	$\|d_i\|$	d_i	d_i
		$(1,1)$ vs. $(0.5,0.5)$	$(1,0.8)$ vs. $(0.5,0.4)$	$(0.8,1)$ vs. $(0.4,0.5)$	$(1,1)$ vs. $(0.5,0.5)$	$(1,0.8)$ vs. $(0.5,0.4)$	$(0.8,1)$ vs. $(0.4,0.5)$
$count_i$	$(1,1)$ vs. $(0.5,0.5)$	1					
$count_i$	$(1,0.8)$ vs. $(0.5,0.4)$	0.56 ***	1				
$count_i$	$(0.8,1)$ vs. $(0.4,0.5)$	0.71 ***	0.72 ***	1			
$\|d_i\|$	$(1,1)$ vs. $(0.5,0.5)$	0.84 ***	0.40 ***	0.52 ***	1		
d_i	$(1,0.8)$ vs. $(0.5,0.4)$	0.31 ***	0.34 ***	0.28 **	0.31 ***	1	
d_i	$(0.8,1)$ vs. $(0.4,0.5)$	-0.55 ***	-0.412 ***	-0.61 ***	-0.47 ***	-0.34 ***	1

Notes: Pairwise correlations with 80 observations. The variable $count_i$ is a count of each individual's common ratio violations and, d_i is each individual's budget share difference between common ratio conditions. *Level of significance*: $*p < 0.1$, $**p < 0.05$, $***p < 0.01$.

is generally higher for lower gross interest rates.[24] Second, out of sample predictions match actual aggregate behavior. Indeed, the out-of-sample calculated R^2 values are high: 0.878 for $(p_1, p_2) = (0.5, 0.4)$ and 0.580 for $(p_1, p_2) = (0.4, 0.5)$.[25]

The results are surprisingly consistent with the DEU model. Indeed, when the data from the $(p_1, p_2) = (0.5, 0.4)$, $(p_1, p_2) = (0.5, 0.5)$ and $(p_1, p_2) = (0.4, 0.5)$ conditions

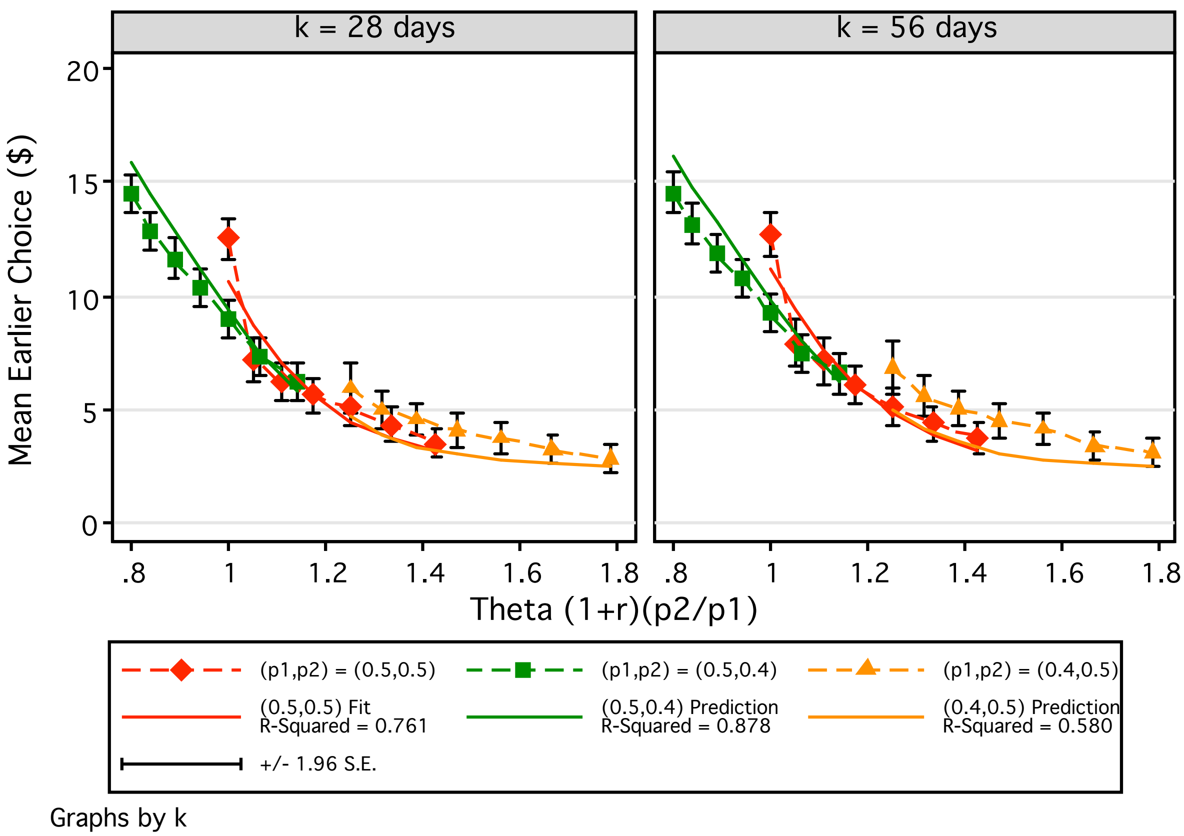
[24]This pattern of allocations is obtained for all sessions and for all orders indicating no presence of order or day effects.

[25]By comparison, making similar out of sample predictions using utility estimates from $(p_1, p_2) = (1, 1)$ yields predictions that diverge dramatically from actual behavior (see Appendix Figure A1) and lowers R^2 values to 0.767 and 0.462, respectively. This suggests that accounting for differential utility function curvature in risky situations allows for an improvement of fit on the order of 15-25%.

are used to estimate the uncertain utility function, the results are in line with those of Table 2, column (6). Discounting and $\hat{\omega}$ are virtually unchanged and the uncertain α parameter is estimated to be 0.834 ($s.e. = 0.020$).

Figure 6 demonstrates that in situations where all payments are risky, utility parameters measured under uncertainty describe behavior extremely well. Though subjects have a disproportionate preference for certainty when it is available, they trade off relative risk and interest rates like expected utility maximizers away from certainty.

Figure 6: Aggregate Behavior Under Uncertainty



Note: The figure presents aggregate behavior for $N = 80$ subjects under three conditions: $(p_1, p_2) = (0.5, 0.5)$, i.e. equal risk, in red; $(p_1, p_2) = (0.5, 0.4)$, i.e. more risk later, in green; and $(p_1, p_2) = (0.4, 0.5)$, i.e. more risk sooner, in orange. Error bars represent 95% confidence intervals, taken as $+/- 1.96$ standard errors of the mean. Solid lines correspond to predicted behavior using utility estimates from $(p_1, p_2) = (0.5, 0.5)$ as estimated in Table 2, column (6).

5 Discussion and Conclusion

Intertemporal decision-making involves a combination of certainty and uncertainty. In an experiment using Convex Time Budgets (Andreoni and Sprenger, 2009) under varying risk conditions, we document violations of discounted expected utility. Our findings indicate that certain and uncertain consumption are evaluated very differently. Subjects exhibit a disproportionate preference for certainty when it is available, but behave approximately as discounted expected utility maximizers away from certainty. We interpret our findings as being consistent with both prior research on expected utility violations and the intuition of the Allais Paradox (Allais, 1953). Allais (1953, p. 530) argued that when two options are far from certain, individuals act effectively as discounted expected utility maximizers, while when one option is certain and another is uncertain a disproportionate preference for certainty prevails.

Demonstrating a difference between certain and uncertain utility has substantial implications for intertemporal decision theory. In particular, we consider present bias. Present bias has been frequently documented (Frederick et al., 2002) and is argued to be a dynamically inconsistent discounting phenomenon generated by diminishing impatience through time. Our results suggest that present-bias may have an alternate source. If individuals exhibit a disproportionate preference for certainty when it is available, then present, certain consumption will be disproportionately favored over future, uncertain consumption. When only uncertain future consumption is considered, individuals act as expected utility maximizers and apparent preference reversals are generated.

Other research has discussed the possibility that certainty plays a role in the generating present bias (Halevy, 2008). Additionally such a notion is implicit in the recognized dynamic inconsistency of non-expected utility models (Green, 1987; Machina, 1989) and could be thought of as preferring immediate resolution of uncertainty (Kreps and Porteus, 1978; Chew and Epstein, 1989; Epstein and Zin, 1989). Our results point in a new direction: that certainty, per se, is disproportionately preferred. This view is captured in the u-v preference models of Neilson (1992), Schmidt (1998), and Diecidue et al. (2004) and may help researchers to understand how and why present bias and other discounting phenomena are manifested.

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A Appendix

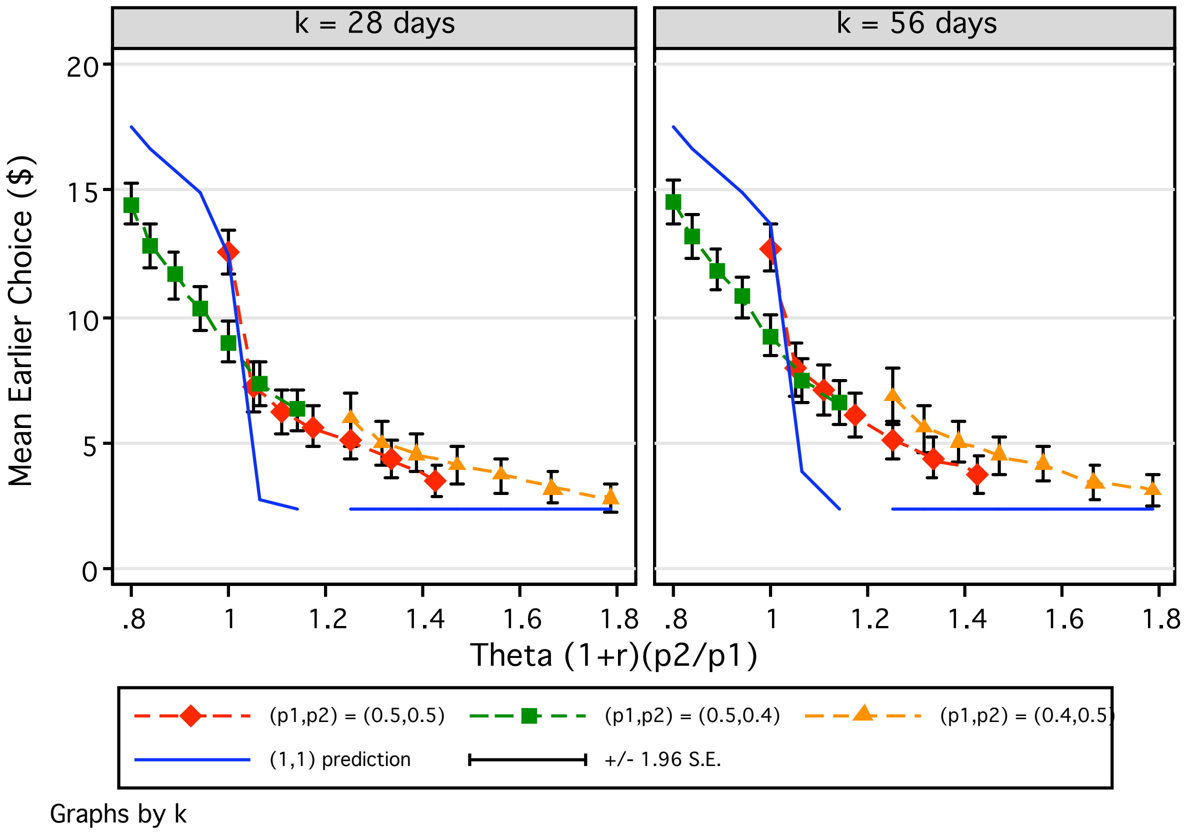
A.1 Appendix Tables and Figures

Table A1: Non-Parametric Estimates of DEU Violations

	Comparison		
	$(p_1,p_2)=(1,1)$ vs. $(0.5,0.5)$	$(p_1,p_2)=(1,0.8)$ vs. $(0.5,0.4)$	$(p_1,p_2)=(0.8,1)$ vs. $(0.4,0.5)$
Dependent Variable:		c_t Allocations	
Risk Conditions			
Condition $(p_1,p_2)=(1,1)$	3.350***		
	(0.772)		
Condition $(p_1,p_2)=(1,0.8)$		4.418***	
		(0.558)	
Condition $(p_1,p_2)=(0.8,1)$			-3.537***
			(0.684)
Interest Rate x Delay Length Categories			
$(1+r,k)=(1.00,28)$	-	-	-
$(1+r,k)=(1.05,28)$	-5.318***	-1.651***	-0.967*
	(0.829)	(0.316)	(0.452)
$(1+r,k)=(1.11,28)$	-6.294***	-2.818***	-1.382**
	(0.812)	(0.434)	(0.454)
$(1+r,k)=(1.18,28)$	-6.921***	-4.140***	-1.851***
	(0.780)	(0.490)	(0.455)
$(1+r,k)=(1.25,28)$	-7.438***	-5.449***	-2.222***
	(0.755)	(0.544)	(0.488)
$(1+r,k)=(1.33,28)$	-8.187***	-7.139***	-2.742***
	(0.721)	(0.668)	(0.496)
$(1+r,k)=(1.43,28)$	-9.039***	-8.164***	-3.126***
	(0.677)	(0.658)	(0.503)
$(1+r,k)=(1.00,56)$	0.193	0.073	0.873*
	(0.192)	(0.211)	(0.395)
$(1+r,k)=(1.05,56)$	-4.600***	-1.290***	-0.352
	(0.791)	(0.336)	(0.442)
$(1+r,k)=(1.11,56)$	-5.409***	-2.582***	-0.923
	(0.805)	(0.331)	(0.515)
$(1+r,k)=(1.18,56)$	-6.462***	-3.685***	-1.451**
	(0.796)	(0.480)	(0.513)
$(1+r,k)=(1.25,56)$	-7.436***	-5.227***	-1.812***
	(0.758)	(0.544)	(0.512)
$(1+r,k)=(1.33,56)$	-8.118***	-6.979***	-2.532***
	(0.740)	(0.652)	(0.493)
$(1+r,k)=(1.43,56)$	-8.775***	-7.882***	-2.833***
	(0.713)	(0.656)	(0.477)
Risk Condition Interactions: Relevant Risk Condition x			
$(1+r,k)=(1.05,28)$	-6.148***	-1.544*	0.134
	(1.111)	(0.602)	(0.421)
$(1+r,k)=(1.11,28)$	-6.493***	-1.574**	0.498
	(1.048)	(0.573)	(0.446)
$(1+r,k)=(1.18,28)$	-6.597***	-2.131**	0.849
	(0.981)	(0.708)	(0.463)
$(1+r,k)=(1.25,28)$	-6.666***	-2.584**	0.920
	(0.971)	(0.762)	(0.576)
$(1+r,k)=(1.33,28)$	-6.425***	-2.136**	1.319*
	(0.917)	(0.764)	(0.601)
$(1+r,k)=(1.43,28)$	-5.683***	-2.170**	1.443*
	(0.880)	(0.728)	(0.623)
$(1+r,k)=(1.00,56)$	0.192	-0.180	0.107
	(0.450)	(0.243)	(0.602)
$(1+r,k)=(1.05,56)$	-5.540***	-1.646**	0.156
	(1.088)	(0.616)	(0.557)
$(1+r,k)=(1.11,56)$	-6.734***	-1.781**	0.511
	(1.093)	(0.588)	(0.521)
$(1+r,k)=(1.18,56)$	-6.450***	-2.471***	0.747
	(1.040)	(0.719)	(0.644)
$(1+r,k)=(1.25,56)$	-6.006***	-2.576***	0.994
	(0.975)	(0.714)	(0.636)
$(1+r,k)=(1.33,56)$	-5.911***	-2.286**	1.604**
	(0.974)	(0.781)	(0.587)
$(1+r,k)=(1.43,56)$	-5.574***	-2.618***	1.639*
	(0.936)	(0.702)	(0.654)
Constant (Omitted Category)	12.537***	14.455***	5.950***
	(0.464)	(0.424)	(0.554)
H_0: Zero Condition Slopes	$F_{14,79}=6.07$	$F_{14,79}=7.69$	$F_{14,79}=5.46$
	($p<0.01$)	($p<0.01$)	($p<0.01$)
# Observations	2240	2240	2240
# Clusters	80	80	80
R^2	0.429	0.360	0.173

Notes: Clustered standard errors in parentheses. $F_{14,79}$ statistics correspond to hypothesis tests of zero slopes for risk condition regressor and 13 risk condition interactions.

Figure A1: Aggregate Behavior Under Uncertainty with Predictions Based on Certainty



Note: The figure presents aggregate behavior for $N = 80$ subjects under three conditions: 1) $(p_1, p_2) = (0.5, 0.5)$, i.e. equal risk, in red; 2) $(p_1, p_2) = (0.5, 0.4)$, i.e. more risk later, in green; and 3) $(p_1, p_2) = (0.4, 0.5)$, i.e. more risk sooner, in orange. Error bars represent 95% confidence intervals, taken as $+/-1.96$ standard errors of the mean. Blue solid lines correspond to predicted behavior using certain utility estimates from $(p_1, p_2) = (1, 1)$ as estimated in Table 2, column (6).

A.2 Welcome Text

Welcome and thank you for participating.

Eligibility for this study: To be in this study, you need to meet these criteria. You must have a campus mailing address of the form:

YOUR NAME
9450 GILMAN DR 92(MAILBOX NUMBER)
LA JOLLA CA 92092-(MAILBOX NUMBER)

Your mailbox must be a valid way for you to receive mail from now through the end of the Spring Quarter.

You must be willing to provide your name, campus mail box, email address, and student PID. This information will only be seen by Professor Andreoni and his assistants. After payment has been sent, this information will be destroyed. Your identity will not be a part of any subsequent data analysis.

You must be willing to receive your payment for this study by check, written to you by Professor James Andreoni, Director of the UCSD Economics Laboratory. The checks will be drawn on the USE Credit Union on campus. You may deposit or cash your check wherever you like. If you wish, you can cash your checks for free at the USE Credit Union any weekday from 9:00 am to 5:00 pm with valid identification (drivers license, passport, etc.).

The checks will be delivered to you at your campus mailbox at a date to be determined by your decisions in this study, and by chance. The latest you could receive payment is the last week of classes in the Spring Quarter.

If you do not meet all of these criteria, please inform us of this now.

A.3 Instruction and Examples Script

Earning Money:

To begin, you will be given a $10 minimum payment. You will receive this payment in two payments of $5 each. The two $5 minimum payments will come to you at two different times. These times will be determined in the way described below. Whatever you earn from the study today will be added to these minimum payments.

In this study, you will make 84 choices over how to allocate money between two points in time, one time is 'earlier' and one is 'later'. Both the earlier and later times will vary across decisions. This means you could be receiving payments as early as one week from today, and as late as the last week of classes in the Spring Quarter, or possibly other dates in between.

It is important to note that the payments in this study involve chance. There is a chance that your earlier payment, your later payment or both will not be sent at all. For each decision, you will be fully informed of the chance involved for the sooner and later payments. Whether or not your payments will be sent will be determined at the END of the experiment today. If, by chance, one of your payments is not sent, you will receive only the $5 minimum payment.

Once all 84 decisions have been made, we will randomly select one of the 84 decisions as the decision-that-counts. This will be done in three stages. First, we will pick a number from 1 to 84 at random to determine which is the decision-that-counts and the corresponding sooner and later payment dates. Then we will pick a second number at random from 1 to 10 to determine if the sooner payment will be sent. Then we will pick a third number at random from 1 to 10 to determine if the later payment will be sent. We will use the decision-that-counts to determine your actual earnings. Note, since all decisions are equally likely to be chosen, you should make each decision as if it will be the decision-that-counts. When calculating your earnings from the decision-that-counts, we will add to your earnings the two $5 minimum payments.

Thus, you will always get paid at least \$5 at the chosen earlier time, and at least \$5 at the chosen later time.

IMPORTANT: All payments you receive will arrive to your campus mailbox. On the scheduled day of payment, a check will be placed for delivery in campus mail services by Professor Andreoni and his assistants. Campus mail services guarantees delivery of 100% of your payments by the following day.

As a reminder to you, the day before you are scheduled to receive one of your payments, we will send you an e-mail notifying you that the payment is coming. On your table is a business card for Professor Andreoni with his contact information. Please keep this in a safe place. If one of your payments is not received you should immediately contact Professor Andreoni, and we will hand-deliver payment to you.

Your Identity:

In order to receive payment, we will need to collect the following pieces of information from you: name, campus mail box, email address, and student PID. This information will only be seen by Professor Andreoni and his assistants. After all payments have been sent, this information will be destroyed. Your identity will not be a part of subsequent data analysis.

On your desk are two envelopes: one for the sooner payment and one for the later payment. Please take the time now to address them to yourself at your campus mail box.

How it Works:

In each decision you are asked to divide 100 tokens between two payments at two different dates: Payment A (which is sooner) and Payment B (which is later). Tokens will be exchanged for money. The tokens you allocate to Payment B (later) will always be worth at least as much as the tokens you allocate to Payment A (sooner). The process is best described by an example. Please examine the sample sheet in you packet marked SAMPLE.

The sample sheet provided is similar to the type of decision sheet you will fill out in the study. The sample sheet shows the choice to allocate 100 tokens between Payment A on April 17th and Payment B on May 1st. Note that today's date is highlighted in yellow on the calendar on the left hand side. The earlier date (April 17th) is marked in green and the later date (May 1st) is marked in blue. The earlier and later dates will always be marked green and blue in each decision you make. The dates are also indicated in the table on the right.

In this decision, each token you allocate to April 17th is worth \$0.10, while each token you allocate to May 1st is worth \$0.15. So, if you allocate all 100 tokens to April 17th, you would earn 100x\$0.10 = \$10 (+ \$5 minimum payment) on this date and nothing on May 1st (+ \$5 minimum payment). If you allocate all 100 tokens to May 1st, you would earn 100x\$0.15 = \$15 (+ \$5 minimum payment) on this date and nothing on April 17th (+ \$5 minimum payment). You may also choose to allocate some tokens to the earlier date and some to the later date. For instance, if you allocate 62 tokens to April 17th and 38 tokens to May 1st, then on April 17th you would earn 62x\$0.10 = \$6.20 (+ \$5 minimum payment) and on May 1st you would earn 38x\$0.15 = \$5.70 (+ \$5 minimum payment). In your packet is a Payoff Table showing some of the token-dollar exchange at all relevant token exchange rates.

REMINDER: Please make sure that the total tokens you allocate between Payment A and Payment B sum to exactly 100 tokens. Feel free to use the calculator provided in making your allocations and making sure your total tokens add to exactly 100 in each row.

Chance of Receiving Payments:

Each decision sheet also lists the chances that each payment is sent. In this example there is a 70% chance that Payment A will actually be sent and a 30% chance that Payment B will actually be sent. In each decision we will inform you of the chance that the payments will be sent. If this decision were chosen as the decision-that-counts we would determine the actual payments by throwing two ten sided die, one for Payment A and one for Payment B.

EXAMPLE: Let's consider the person who chose to allocate 62 tokens to April 17th and 38 tokens to May 1st. If this were the decision-that-counts we would then throw a ten-sided die for Payment A. If the die landed on 1,2,3,4,5,6,or 7, the person's Payment A would be sent and she would receive \$6.20 (+ \$5 minimum payment) on April 17th. If the die landed 8,9, or 10, the payment would not be sent and she would receive only the \$5 minimum payment on April 17th. Then we would throw a second ten-sided die for Payment B. If the die landed 1,2, or 3, the person's Payment B would be sent and she would receive \$5.70 (+ \$5 minimum payment) on May 1st. If the die landed 4,5,6,7,8,9, or 10, the payment would not be sent and she would receive only the \$5 minimum payment on May 1st.

Things to Remember:

- You will always be allocating exactly 100 tokens.
- Tokens you allocate to Payment A (sooner) and Payment B (later) will be exchanged for money at different rates. The tokens you allocate to Payment B will always be worth at least as much as those you allocate to Payment A.
- Payment A and Payment B will have varying degrees of chance. You will be fully informed of the chances.
- On each decision sheet you will be asked 7 questions. For each decision you will allocate 100 tokens. Allocate exactly 100 tokens for each decision row, no more,

no less.

- At the end of the study a random number will be drawn to determine which is the decision-that-counts. Because each question is equally likely, you should treat each decision as if it were the one that determines your payments. Two more random numbers will be drawn by throwing two ten sided die to determine whether or not the payments you chose will actually be sent.
- You will get an e-mail reminder the day before your payment is scheduled to arrive.
- Your payment, by check, will be sent by campus mail to the mailbox number you provide.
- Campus mail guarantees 100% on-time delivery.
- You have received the business card for Professor James Andreoni. Keep this card in a safe place and contact Prof. Andreoni immediately if one of your payments is not received.