Time-inconsistent Risk Preferences in a Laboratory Experiment

K. Jeremy Ko and Zhijian (James) Huang *

December 15, 2008

Abstract

We conducted an experiment to explore the time-consistency of risk preferences in a multi-period betting game. Specifically, subjects planned their contingent betting decisions in advance then played the game dynamically later to determine whether their respective decisions matched. We found that subjects took more risk than planned in their initial bet and after losses. In addition, this increased risk was associated with an increase in breakeven mental accounting. Our findings indicate that immediacy of outcomes can lead to impulsive risk-taking behavior and highlight the importance of precommitment to long-term financial planning.

JEL Classification: C91; D81; G14

Key Words: Experimental economics; Time inconsistency; Decision making; Risk preference; Mental accounting; Behavioral finance

*Ko is from Smeal College of Business, Pennsylvania State University. Huang is from Lubar School of Business, University of Wisconsin-Milwaukee. We thank Jennifer Bender, Philip O'Connor, seminar participants at the Growth of Gambling and Prediction Markets Conference, Eastern Finance Association 2007 Conference, Frontiers of Finance 2007 Conference and Penn State University for their valuable comments. All errors are our own. Please address correspondence to: Zhijian (James) Huang, Lubar Hall S430E, University of Wisconsin-Milwaukee, Milwaukee, WI 53201, huang6@uwm.edu (e-mail), Phone: 414-229-4235, Fax: 414-229-6957.

1 Introduction

There is a substantial literature in psychology and economics that studies time-inconsistent discounting or preferences for consumption over time. The basic conclusion of this work is that people generally prefer immediate to delayed consumption but that this preference reverses when this decision is translated into the future. There have since been several attempts to explore time-inconsistency in the other dimension of investment preferences, i.e., risk-preferences. Most of these studies conclude that people take more risk in investment decisions made for the future than for today. These decisions, however, involve the abstract choice between binary options and do not simulate actual portfolio allocation decisions over time.[1] The only results thusfar regarding temporal consistency of portfolio allocations exist in the experimental literature on myopic loss-aversion. Subjects in these studies have been found to take more risk in positive-return gambles when decisions are made less frequently consistent with the loss-aversion component of prospect theory. Hence, people are dynamically inconsistent when comparing subjects who commit to a risky allocation for several periods versus those who reallocate each period.[2] These studies do not, however, make a direct comparison of projected future decisions for all periods and contingent states with decisions made dynamically.

Our experiment addresses this particular issue of temporal consistency in portfolio allocation decisions. Specifically, we examine whether precommitted contingent behavior is consistent with dynamic behavior in a multi-period betting game. In other words, do subjects behave as they project they will in such a game, and does their inconsistency depend on gains and losses? In our experiment, we asked subjects to plan out all of their contingent betting decisions in an initial session (the plan session) then had them actually play the game dynamically in a second session (the play session) one week later to see if these decisions matched their initial plan.

We were able to articulate a few simple findings. First, the majority of subjects in our experiment were time-inconsistent; specifically, 72% of subjects bet differently than they had planned in their actual game play. Second, subjects on average took more risk than

[1] Keren and Roelofsma (1995) and Onculer (2000) produce this finding for hypothetical gambles while Noussair and Wu (2006) do so with actual economic stakes.

[2] See Thaler, et al. (1997) and Gneezy and Potters (2003).

they had planned in their initial bet as well as after a loss where this increase was more significant when the loss was more recent. Finally, the increase in risk-taking is associated with an increase in the degree of break-even mental accounting, i.e., the desire to return to one's original level of wealth. Our results stand in contrast to the aforementioned findings that risk-aversion is greater for immediate than future decisions. This discrepancy indicates that temporal inconsistency differs in actual portfolio contexts than for the abstract binary decision frames used in many studies. We finally show that a number of frameworks designed to explain time inconsistent preferences fail to explain our results. There is some indication, however, that prospect theory may be consistent our findings. Unfortunately, this framework does not unambiguously specify preferences in a dynamic setting as pointed out in Barberis and Xiong (2008) and needs to be further developed to fully establish this connection.

The neuroeconomic study of McClure, et al. (2004) is particularly illuminating with regard to our results. These authors examine neural activity when people are presented with immediate versus delayed riskless intertemporal choices. Their main finding is that the brain's limbic system, which is associated with impulsive behaviors, is preferentially activated for immediate rewards but not delayed ones. This neural pattern is likely to be driving the observed behavior in our own experiment as well. Namely, the immediacy of outcomes during the play session causes subjects to be driven by emotional impulses such as excitement and regret, which causes them to bet more and chase their previous wealth levels more aggressively than they had planned. Kuhnen and Knutson (2008) also find that arousing emotional states such as excitement increase risk-taking in a related study. Our findings are significant because they indicate that immediacy can lead to impulsive investment behaviors such as excessive risk-taking and by-products of mental accounting like the disposition effect as documented by Odean (1998) and others. They also highlight the need for precommitments in the form of long-term financial planning or novel products such as lifecycle mutual funds in order to mute impulsive investment behavior.

The remainder of this paper is organized as follows. Section 2 describes the design of our experiment, and section 3 discusses our major results. Section 4 tries to relate our results to some existing theoretical frameworks. Section 5 concludes.

2 Experimental Design

Our experiment consisted of two sessions, the plan session and the play session, each conducted one week apart. In both sessions, subjects made decisions for a three-round betting game where they could make fair double-or-nothing bets on the outcomes of the spin of a wheel, which was numbered from 1 to 100. In each of the three rounds, they decided how much to bet with the constraint that their bet not exceed their available funds. They could also decide whether to bet on odd or even numbers on the wheel. Subjects were initially given 100 units or $10 for the first bet the game, and available funds in any subsequent round were simply the previous funds plus (minus) the profit (loss) from the previous bet. Experimental instructions were read from a script provided in the appendix.

In the first session, the plan session, subjects made all of their contingent betting decisions in advance. In other words, they chose their initial bet, their bets for the second round contingent on winning and losing the first bet, and their bets for the third round for every possible contingency of winning or losing the first two bets. Subjects, therefore, made seven betting decisions (i.e., how much to bet and on which set of numbers) for every node of the contingency tree for the three bets. We label these bets: bet 1 (the first round bet), bet 2w and bet 2l (the second round bets contingent on winning and losing the first bet, respectively), bet 3ww and bet 3ll (the third round bets contingent on winning and losing both prior bets, respectively), bet 3wl (the third round bet contingent on winning the first bet and losing the second bet). and bet 3lw (the third round bet contingent on losing the first bet and winning the second bet).

We also asked subjects their beliefs about their probability of winning to determine if their inferences were rational. All data for our experiment were collected by computer using the experimental economics program, Z-tree. Sample screenshots for our game are shown in figures 1 and 2. We instructed subjects in the plan session that they were making decisions for a game whose outcomes would be determined in a week. They were told that they would observe the outcomes from spinning the wheel and answer questions related to the experiment in the following week's session.

In the second session, the play session, subjects actually played the game dynamically. Specifically, they decided on their initial bet, and the wheel was then spun and outcomes

determined for this bet. The same procedure was then followed for the second bet and then for the third bet. Subjects viewed their decisions from the plan session, but were instructed that they were not required to adhere to this plan and were free to alter these decisions in any way. In order to prevent social influences from affecting preferences, communication between subjects was prohibited in both the plan and play sessions. As in the plan session, we polled subjects in the play session for their chance of winning each bet.

We should take a moment to discuss how subjects perceived the commitment value of their decisions in the plan session. We obviously wanted subjects to take their decisions seriously in this session without deceiving them and explicitly stating that their decisions were irreversible. In order to deal with this delicate issue, we simply did not mention that decisions could be reversed in the second session. There were only two subjects who asked us privately whether they would be allowed to change their betting decisions in the next session. We told these individuals that that they may or may not be allowed to change their decisions, but that they should take their plan decisions seriously and think of them as final. None of our results change if we exclude these subjects from our analysis. In addition, we conducted a control treatment where plan decisions were made and outcomes determined in a single session. Plans decisions in this treatment were statistically indistinguishable from those in our two session treatments, indicating that subjects did indeed take these decisions seriously. These results are available upon request.

Our subjects consisted of 121 undergraduate finance majors recruited from a finance course at Penn State University. These students were compensated with their earnings from the experiment (the initial $10 plus (minus) any profits (losses) from the three rounds of betting) in addition to a fixed amount of extra credit for their participation in both sessions.

3 Results

The goal of our analysis is to study the change in risk-taking between the plan and play sessions at various nodes of the game's contingency tree. To this end, we employ three different measures to quantify the risk characteristics of bets.

The first measure is simply the dollar amount of the bet, and the second is its portfolio weight or the proportion of wealth bet, which takes on a missing value if the subject had zero

wealth at that node. Our third measure captures whether or not subjects may be engaging in "break-even" mental accounting as in Thaler and Johnson (1990) and trying to return to their original wealth of $10. This measure is an indicator variable equal to one if their maximum wealth in the next period is greater than or equal to $10 and zero otherwise. This variable takes on a missing value if the subject's funds are greater than or equal to $10 or less than $5. In the former case, the subject's maximum wealth will always be at least $10 in the next period. In the latter case, the subject can not achieve wealth of $10 in the next period with our double-or-nothing bets.[3]

There are several reasons why differences in plan and play betting behavior may not reflect inconsistency between present and future risk-preferences on the part of subjects. One reason is that subjects may dynamically update their probabilities of outcomes during the game in the play session. Namely, subjects may improperly believe that the wheel is not fair and that past outcomes influence the odds of subsequent outcomes. This updating would not be reflected in our course game tree from the plan session, which only has win and loss contingencies and not individual numerical outcomes. To control for this possibility, we eliminated subjects from our data who reported any probability of winning not equal to 50% in any of their plan or play responses, of whom there were nine.

Another possibility is that subjects' preferences changed over the week between the plan and play sessions for rational reasons. An unexpected change in a subject's economic circumstances over the course of the week such as receiving a parking ticket, for example, might change his or her betting preferences in the game. For this reason, we asked our subjects in the exit interview whether they had experienced an unexpected change in economic circumstances over the past week that may have changed their betting behavior in the game. We eliminated subjects from the data who answered yes to this question, of whom there were five. We were left with 107 of 121 subjects in our sample after applying both filters.

[3]We do not include a measure where subjects' *minimum wealth* in the next period is at least $10 because there is no empirical evidence for such a tendency. Our measure is based on Thaler and Johnson's finding that people exhibit greater risk-taking after losses if given a chance to recover their initial wealth.

3.1 Average Bet Characteristics

We start in table 1 by reporting average bet characteristics for our three measures and average wealth at each node of the game tree. In all of our tables, we have removed subjects with zero wealth at each node because these subjects have no discretion over the amount of their bets. In addition, the portfolio weight and mental accounting take on missing values for zero wealth as mentioned previously. In our data, there is clearly some evidence of Thaler and Johnson's (1990) house money effect, whereby people take more risk after gains because they view betting these additional funds as "playing with the house's money." Namely, the average bet 3ww was greater in dollar terms than bet 2w which was greater than bet 1 for both the plan and play samples. The finding that subjects had a greater propensity to bet after wins may be confounded by the budget constraint in our game, i.e., subjects had more available funds to bet after gains. The same pattern holds, however, if we remove subjects without a binding budget constraint who bet less than their available funds.[4] In addition, around 5% of subjects for bets 1 and 2w and around 15% for bet 3ww bet all of their available funds. The fact that the budget constraint was more binding in the highest wealth node (bet 3ww) serves to weaken the appearance of the house money effect in our data since more subjects at this node would, in principle, like to bet more than their budget.

One can also see from table 1 that there were general increases in our risk-taking measures between plan and play sessions. In addition, a high percentage of subjects with wealth between \$5 and \$10 engaged in break-even mental accounting at the terminal nodes of the game in the play session. According to our measure, 100% of such subjects engaged in mental accounting for bets 3wl and 3lw while 83.3% did so for bet 3ll in this session. We study this increased risk-taking more carefully in the next sections by computing average bet changes across subjects while attempting to control for wealth differences between plan and play.

3.2 Average Bet Changes

77 of 107 subjects (72%) in our sample were time-inconsistent. Namely, the amount that these subjects bet in their actual play was different than in their plan at some point in the

[4] In the plan session, the average amounts of bet 1, bet 2w, and bet 3ww were 36.0, 57.8, and 78.2 units, respectively, for subjects who bet less than their available funds. In the play session, the average amounts of bet 1, bet 2w, and bet 3ww were 40.5, 56.1, and 87.0 units, respectively, for these subjects.

game. 33 of our 107 subjects changed their initial bet (bet 1) when they played the game, and the average change was significantly riskier.

In the next two sections, we discuss average changes in the second and third bets of the game. Changes in these second and third round bets, however, may not reflect time inconsistency in these bets if the subject alters his or her first bet. If subjects change their first bet, their wealth in the play session is different than planned at later nodes. Such subjects may change these later bets not because they improperly anticipate their preferences for these bets but rather because their preferences and constraints are dependent on the level or path of wealth in the game. In order to control for the prior path of wealth, we compute bet changes between plan and play at each node for two types of samples. In the "no prior change" samples, we compute the average bet change at each node for all subjects who have an outcome at that node in the play session and that have not changed any of their prior bets. Hence, their paths of wealth in plan and play are identical up to that point. We also compute changes at each node for all subjects in the total sample with an outcome at that node in order to increase the size of the sample and to characterize the behavior of subjects that have changed decisions at prior nodes.

- No Prior Change Samples

  Results for the no prior change samples are shown in table 2. In these samples, subjects bet significantly more than they had planned both in terms of dollars and portfolio weight immediately after a loss for bets 2l and 3wl. The average change in risk for bet 3ll is not statistically significant though we lack statistical power in this observation since there were only seven subjects at this node who had not changed their prior bets and with non-zero wealth. Only one subject in this sample changed this final bet, which became riskier than planned.

  This increase in risk-taking immediately after a loss is associated with an increase in the degree of break-even mental accounting. By our mental accounting measure, subjects on average took significantly more break-even bets than they had planned for bets 2l and 3wl.

- Total Sample

In the total sample, subjects on average took significantly more risk than they had planned in terms of their dollar bet not only immediately after a prior loss for bets 2l and 3wl nodes as before but also for bet 3lw as seen in table 3. The average increase in dollar risk for bet 3ll is again not statistically significant. In the total sample, this lack of statistical significance is probably due to the fact that subjects had less wealth on average when they actually played the game than in their plans for this bet (i.e., they bet more than planned and lose twice) as seen in table 1 and faced a budget constraint.

Subjects did, however, increase their risk-taking in bet 3ll in terms of portfolio weight. On average, subjects bet a greater proportion of their portfolio than they had planned at all nodes with a prior loss, i.e., bet 2l, bet 3wl, bet 3lw, and bet 3ll. There was a significant increase in mental accounting not only for bet 3wl as before but also for bet 3ll as a result of additional statistical power in our total sample. There is no longer a significant increase in mental accounting for bet 2l although our previous results but not for bet 2l. This lack of significance is not surprising given the fact that our measure is equal to 0.528 in the play session and 0.5 in the total sample, on average, in table 3. The significant increase bet 2l in the no prior change sample is probably a characteristic only of this particular subgroup. In the total sample, subjects apparently only had a heightened desire to break-even during the play session for their final bet immediately after a loss.

The greater significance of increases in risk in the whole sample as well as the no prior change samples at the bet 3wl node relative to the bet 3lw node probably reflects a short-term emotional impulse to increase risk and chase prior levels of wealth immediately after a loss. As a result, the average bets in the play session for these nodes was comparable even though the average wealth for bet 3wl was greater than that for bet 3lw as seen in table 1.

In summary, we were able to articulate a few simple findings in our analysis. First, the preponderance of subjects in our experiment were time-inconsistent and altered their bets when they played the game in spite of being able to see their planned betting strategy. Second, subjects bet more than they had planned in their initial bet and after a loss. In addition, this increase was more significant for more recent than more distant losses. Although we can not say definitively that these increased risks after losses were caused by increased

mental accounting, the associated increase in the breakeven betting leads us to believe that subjects may be more impulsively chasing prior levels of wealth in the play session. As mentioned previously, these results are consistent with the findings of McClure, et al. (2004) that people are more intensely driven by impulses such as greed and regret when faced with immediate payoffs.

4 Frameworks

We now consider whether our results can be understood within the context of a value-maximizing framework. First, any framework with a risk or loss-averse value function should feature some non-pecuniary benefit from betting in our game. Subjects would otherwise generally not participate in the game since our gambles offer zero expected return. Second, models with standard utility maximization over wealth contradict our results. Namely, they imply time-consistency between the plan and play sessions as long as the non-pecuniary benefit is not frame-dependent.

There are a number of alternative frameworks that potentially explain time-inconsistent behaviors. The first is that of projection bias developed by Loewenstein, et al. (2003) whereby people systematically underestimate future changes in preferences. This framework, unfortunately, does not fully explain our results. According to this theory, subjects should underestimate changes in betting behavior in response to gains and losses. Hence, subjects in plan session should not only underestimate their mental accounting in response to losses but also underestimate their increase in risk-taking as a result of the house money effect in response to gains. Though we find evidence of the former, we find no evidence of the latter. Namely, there is no significant difference between plan and play decisions after gains.

Another set of frameworks that potentially explain time-inconsistency are the non-expected utility models outlined in Raiffa (1968). For example, Baucells and Heukamp (2008) develop a model which explains the diminishing of the common ratio effect with time delay.[5] This predictions of this framework, unfortunately, run counter to our results. Namely, subjects

[5]The common ratio effect refers to the fact that most people who are indifferent between \$3000 for certain and an 80% chance of \$4000 would prefer an 8% chance of \$4000 over a 10% chance of \$3000 (Kahneman and Tversky, 1979). This violation of the independence axiom of expected utility was first documented by Allais (1953).

ought to place less value on certainty and bet more when rewards are delayed in the plan session whereas we find that they bet the same or less.

4.1 Prospect-Theory

We next turn our attention to prospect theory which can imply dynamic inconsistency when evaluated over different time horizons. As mentioned previously, such evidence has been found in the experimental studies of Thaler, et al. (1997), Gneezy and Potters (1997), and Gneezy, Kapteyn, and Potters (2003). The problem with this framework is that it was designed as a static model and does not unambiguously specify preferences in a dynamic setting. Barberis and Xiong (2008), for example, show how different dynamic rules in prospect theory can lead to dramatically different investment behaviors.

We conjecture that subjects will aggregate gains and losses across periods in the plan session as they are when making multi-period decisions in the aforementioned myopic loss-aversion studies. Hence, subjects' objective function in the plan session of our game would be:

$$\begin{aligned}
&\max_{\alpha.} \pi(0.125) \cdot [v(10+\alpha_1+\alpha_{2w}+\alpha_{3ww}) + v(10+\alpha_1+\alpha_{2w}-\alpha_{3ww}) + \\
&+v(10+\alpha_1-\alpha_{2w}+\alpha_{3wl}) + v(10+\alpha_1-\alpha_{2w}-\alpha_{3wl}) + v(10-\alpha_1+\alpha_{2l}+\alpha_{3lw}) + \\
&+v(10-\alpha_1+\alpha_{2l}-\alpha_{3lw}) + v(10-\alpha_1-\alpha_{2l}+\alpha_{3ll}) + v(10-\alpha_1-\alpha_{2l}-\alpha_{3ll})]
\end{aligned} \tag{1}$$

where α_1 corresponds to the dollar amount of bet 1, α_{2w} to the amount of bet 2w, etc. In addition, $v(\cdot)$ is a prospect-theoretic objective function evaluated over dollar outcomes of the eight final nodes of the game and $\pi(\cdot)$ is a prospect-theoretic probability weighting function. We assume that the subject's initial \$10 is integrated with subsequent profit and loss because segregating this initial wealth delivers counterfactual implications. Namely, bets 3lw and 3wl should be greater in the plan than in the play session by similar arguments to the ones that follow.[6]

Again as with previous studies, we conjecture that subjects' objective function is myopic in the play session in that it only includes gains and losses one period in the future.

[6] We use the original version of prospect theory in equation 1 for simplicity. Using the cumulative version of prospect theory would complicate our analysis without changing our arguments substantially.

Precisely defining this objective function is not trivial since prospect theory alone does not specify dynamic editing rules, i.e., when to integrate and when to segregate prior gains and losses from current ones.[7] Thaler and Johnson (1990), however, provide some guidance with their "quasi-hedonic editing" hypothesis which specifies that gains should be integrated with smaller losses but that all other gain and loss combinations should be segregated. Unfortunately, this framework is also a bit underdeveloped in that it does not precisely specify editing rules when more than one grouping of sequential profit outcomes can absorb losses. We can, however, construct rough arguments that this hypothesis may be consistent with our pattern of results. An objective function consistent with quasi-hedonic editing in the play session for bet 3wl over the relevant domain is:

$$\max_{\alpha_{3wl}} \pi(0.5)[v(10+\alpha_1^1-\alpha_{2w}^1)+v(\alpha_{3wl})]+\pi(0.5)v(10+\alpha_1^1-\alpha_{2w}^1-\alpha_{3wl}) \tag{2}$$

where a superscript of 1 denotes the equilibrium amounts of these bets in the play session. We have segregated the gain for bet 3wl from the prior net gain while integrating the loss for this bet from the prior net gain in accordance with the hypothesis. It is necessary to integrate gains starting with the initial \$10 in order to absorb losses for bets 2 and 3 since we have the house money effect in our data, i.e., $\alpha_1^1 < \alpha_{2w}^1$. The corresponding play session first-order condition for bet 3wl is:

$$v'(\alpha_{3wl}) = v'(10+\alpha_1^1-\alpha_{2w}^1-\alpha_{3wl}) \tag{3}$$

The plan session first-order condition for bet 3wl from equation 1 is:

$$v'(10+\alpha_1^0-\alpha_{2w}^0+\alpha_{3wl}) = v'(10+\alpha_1^0-\alpha_{2w}^0-\alpha_{3wl}) \tag{4}$$

where a superscript of 0 denotes the equilibrium amounts of these bets in the plan session. We first compare the marginal utilities on the left-hand sides of these equations. $v'(\alpha_{3wl}) > v'(10+\alpha_1^0-\alpha_{2w}^0+\alpha_{3wl})$ since $10+\alpha_1^0-\alpha_{2w}^0 > 0$ and $v'' < 0$ in this gain region. We next compare

[7] In the terminology of Read, et al. (1999), subjects bracket choices *narrowly* in the play session when these decisions are naturally isolated from one another. They bracket these decisions *broadly* in the plan session when they are grouped together. The concepts of editing and bracketing are highly related, and their differences are largely semantic for the purposes of our analysis.

the marginal disutilities on the right-hand sides of these equations. $v'(10+\alpha_1^1-\alpha_{2w}^1-\alpha_{3wl}) < v'(10+\alpha_1^0-\alpha_{2w}^0-\alpha_{3wl})$ for the preponderance of subjects since $\alpha_1^1-\alpha_{2w}^1 = -\$1.81 > \alpha_1^0-\alpha_{2w}^0 = -\$2.15$ from table 3. Hence, $\alpha_{3wl}^1 > \alpha_{3wl}^0$ in accord with our results since the marginal utility is higher and the marginal disutility is lower in equation 3 than in equation 4.

The fact that current gains are segregated from prior net gains with quasi-hedonic editing tends to make marginal utility higher in the play than in the plan session. This general tendency may help explain the propensity for subjects to take more risk in the play than in the plan session especially after losses. These arguments break down after gains because only a portion of the prior net gain may be required to absorb a subsequent loss. For example, the first two gains may be sufficient to absorb a loss for bet 3ww. It is consistent with the theory, therefore, that the marginal disutility for bet 3ww in the play session is $v'(\alpha_1^1 + \alpha_{2w}^1 - \alpha_{3ww})$ which is greater than that for the plan session of $v'(10 + \alpha_1^0 + \alpha_{2w}^0 - \alpha_{3ww})$. Hence, the argument above does not apply.

As mentioned, the problem with quasi-hedonic editing is that objective functions are ambiguous when more than one grouping of profit outcomes can absorb losses. For example, one could group $\alpha_1^1 - \alpha_{2w}^1 + \alpha_{3wl}$ together while segregating the initial \$10 in the first term of equation 2 in order to absorb the loss for bet 2. Fortunately, these alternative objective functions do not affect the comparison of marginal utility between plan and play session for bet 3wl. They do generate ambiguous conclusions for other nodes and in general, however.

Our preliminary analysis nonetheless hints that prospect theory operating over different horizons is possibly at work in our results. It also suggests the need for further development of the theory into dynamic settings in order to generate well-defined implications in our setting and others.

5 Conclusion

The findings in this paper are important because they tell us that immediacy between decision-making and outcomes may exacerbate impulsive investment behaviors such as excessive risk-taking and by-products of mental accounting documented in investment behavior such as the disposition effect. One implication of our research is that the level of detachment from outcomes in different decision frames will affect investment. For example, decisions

made through a broker are likely to be quite different than decisions made through a financial planner for reasons of framing alone. This research highlights the importance of not only long-term financial planning but also novel financial products such as lifecycle mutual funds with embedded precommitments to mute impulsive investment behavior. Our findings have relevance for mitigating psychological biases in self-managed retirement accounts, an issue of interest to policymakers in the debate on privatizing social security, for example.

Our paper opens the door for interesting paths of future research. For example, our experiment indicates the need for further development of prospect theory into dynamic settings. Another interesting line of research would be to determine whether this research has any implications for pricing in asset markets. An important aspect of our experiment is that it documents a fundamental violation of the Arrow-Debreu theorem. Namely, the static complete market of our plan session was not equivalent to the dynamically complete market of our play session. It would be interesting to study whether our findings have any implications for pricing and anomalies that can be confirmed in market data much as the literature on time-inconsistent discounting has attempted to develop implications for markets and asset prices.[8]

6 Appendix: Experimental Instructions

6.1 Plan Session

In this study, you will be playing a game of chance where you will bet on which numbers come up when we spin this wheel. The wheel is numbered 1 to 100, and it is entirely fair. Anyone who would like to spin the wheel at this point can feel free to do so. You will be playing fair double-or-nothing gambles with a 50% chance of winning and losing on either even or odd numbers on this wheel. We guarantee that this wheel is not rigged in any way for or against you. Our intention is not to rig the game in any way but rather to present you with fair gambles and see how you behave.

You will be given an initial amount to bet of 100 units which is equal to $10 so that 1 unit is equal to 10 cents. There will be three rounds of betting, and your available funds to

[8] Luttmer and Mariotti (2003), for example, study a model of asset prices in an exchange economy where time-inconsistent agents have hyperbolic discount functions.

bet will go up or down depending on how much you have won or lost in the previous rounds.

Today you will decide how you will be betting for next week. Specifically, you will decide the amount of your first bet and whether to bet on even or odd numbers. You will then decide on your second bet first if you win the first bet and then if you lose the first bet. You will then decide on your third bet depending on whether you've won or lost the first two bets. Next week you will spin the wheel, observe outcomes, and answer questions related to the game.

We will now start the game. It is essential to our study that you not communicate with your neighbors or look at their screens at any point. Please enter the amount of your first bet which must be less than your available funds and whether you want to bet on even or odd numbers. Also enter your chance of winning this bet in percentage terms. In other words, enter the probability that you think that you will win this particular bet. Next enter your second bet depending on whether you win or lose the first bet. Your available funds will go up or down depending on whether you've won or lost the bet. Finally, enter your third bet depending on whether you've won or lost the previous two bets.

6.2 Play Session

We will now play the betting game. It is essential to our study that you not communicate with your neighbors or look at their screens at any point. Please enter the amount of your first bet which must be less than your available funds of 100 units which is equal to $10. Also enter whether you want to bet on odd or even numbers. You do not have to stick to your plan (in front of you) from last week although you can if you like. Those decisions have no bearing on your earnings or outcomes for the game today. Finally, enter your chance of winning this bet, which is the probability in percentage terms that you think you will win this bet. At this point we would like to have a volunteer spin the wheel.

Now please enter the amount of your second bet which must be less than your available funds. Also enter whether you want to bet on odd or even numbers. Finally, enter your chance of winning this bet. We would again like to have a volunteer spin the wheel. This is your third and final bet. Please enter the amount of your third bet which must be less than your available funds. Also enter whether you want to bet on odd or even numbers. Finally,

enter your chance of winning this bet. We would again like to have a volunteer spin the wheel.

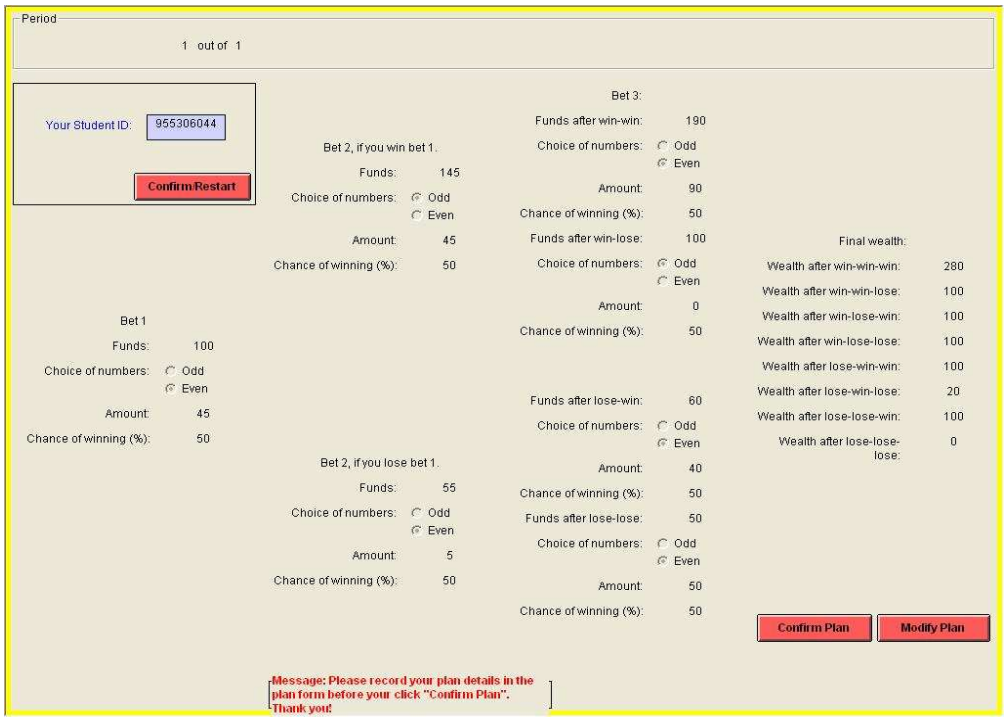

Figure 1: Screenshot for Plan Session

Figure 2: Screenshot for Play Session

Table 1: Average Bet Characteristics

Panel A lists the average bet characteristics and wealth at each node for the plan session whereas Panel B lists these figures for the play session. Bet 1, bet 2w, bet 2l, bet 3ww, bet 3wl, bet 3lw and bet 3ll are subsets including all players in that node of the game's event tree with available data. We summarize the average wealth, bet in terms of dollar amount, portfolio weight, and break-even mental accounting for each node of the game's event tree. The values for wealth and dollar bet are in the game unit of 10 cents. The values for mental accounting are 1 if the maximum wealth in the subsequent period (dollar bet + current wealth) is greater than or equal to the initial wealth of 100 and 0 otherwise. Subjects with zero wealth at a given node are removed.

Panel A:		Plan Session		
Subset	Wealth	Dollar Bet	Portfolio Weight	Mental Accounting
Bet 1	100	39.5514	39.5514%	NaN
(N)	(107)	(107)	(107)	(0)
Bet 2w	139.5514	63.8692	42.9473%	NaN
(N)	(107)	(107)	(107)	(0)
Bet 2l	64.0396	25.5446	45.7841%	0.5556
(N)	(101)	(101)	(101)	(90)
Bet 3ww	203.4206	111.0093	48.4597%	NaN
(N)	(107)	(107)	(107)	(0)
Bet 3wl	79.3922	38.3922	52.7958%	0.8382
(N)	(102)	(102)	(102)	(68)
Bet 3lw	89.5842	45.1584	53.2666%	0.9333
(N)	(101)	(101)	(101)	(45)
Bet 3ll	45.2093	25.9302	65.8234%	0.4773
(N)	(86)	(86)	(86)	(44)
Panel B:		Play Session		
Subset	Wealth	Dollar Bet	Portfolio Weight	Mental Accounting
Bet 1	100	44.9439	44.9439%	NaN
(N)	(107)	(107)	(107)	(0)
Bet 2w	144.8387	63.0161	41.5139%	NaN
(N)	(62)	(62)	(62)	(0)
Bet 2l	60.2683	31.2683	59.1032%	0.5278
(N)	(41)	(41)	(41)	(36)
Bet 3ww	209.2188	108.3125	47.5003%	NaN
(N)	(32)	(32)	(32)	(0)
Bet 3wl	77.7333	62.5667	84.2337%	1
(N)	(30)	(30)	(30)	(20)
Bet 3lw	92.5238	63.7143	70.7701%	1
(N)	(21)	(21)	(21)	(9)
Bet 3ll	39.625	29.25	85.1015%	0.8333
(N)	(16)	(16)	(16)	(6)

Table 2: Average Bet Changes for the No Prior Change Samples

This table presents average changes in bet characteristics across subjects for the "no prior change" samples, that is, subjects at each node who have not changed any of their prior bets. We present the number of total observations at each node (#Obs), average play bet (Play), average plan bet (Plan), and the mean change (Change) in bet between plan and play at the following nodes (subsets): bet 1, bet 2w, bet 2l, bet 3ww, bet 3wl, bet 3lw and bet 3ll are subsets with an outcome at that node in their game play and who have not changed any of their prior bets. We measure the change in three different measures: dollar amount in Panel A, portfolio weight in Panel B, and degree of break-even mental accounting in Panel C. We have eliminated subjects with zero wealth at each node. The statistical significance of the mean change is computed by bootstrapping from a trinomial distribution for the mental accounting measures, and is under the standard t-test for the other two measures.

Panel A				Dollar Amount	
Subset	N	Play	Plan	Change	p-Value
Bet 1	107	44.9439	39.5514	5.3925***	0.000662
Bet 2w	45	62.1556	65.9111	-3.7556	0.14273
Bet 2l	26	30.1154	24.1538	5.9615**	0.017258
Bet 3ww	20	119.45	122.45	-3	0.80413
Bet 3wl	10	56.5	32.6	23.9**	0.026541
Bet 3lw	9	57.2222	47.2222	10	0.48526
Bet 3ll	7	36.8571	34.7143	2.1429	0.35592
Panel B				Portfolio Weight	
Subset	N	Play	Plan	Change	p-Value
Bet 1	107	0.4494	0.3955	0.0539***	0.000662
Bet 2w	45	0.415	0.4353	-0.0203	0.23196
Bet 2l	26	0.5409	0.441	0.0999**	0.025634
Bet 3ww	20	0.5019	0.4867	0.0153	0.71794
Bet 3wl	10	0.8424	0.4899	0.3525**	0.024536
Bet 3lw	9	0.6702	0.5702	0.1	0.4999
Bet 3ll	7	0.8707	0.7993	0.0714	0.35592
Panel C				Mental Accounting	
Subset	N	Play	Plan	Change	p-Value
Bet 1	107	NaN	NaN	NaN	NaN
Bet 2w	45	NaN	NaN	NaN	NaN
Bet 2l	26	0.5833	0.4583	0.125**	0.02132
Bet 3ww	20	NaN	NaN	NaN	NaN
Bet 3wl	10	1	0.625	0.375**	0.02002
Bet 3lw	9	1	1	0	NaN
Bet 3ll	7	0.75	0.75	0	NaN

***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

Table 3: Average Bet Changes for the Total Sample

This table presents our basic time-inconsistency results for the total sample. We present the number of total observations (#Obs), play bet (Play), average plan bet (Plan), and the mean change (Change) in bet between plan and play at the following nodes (subsets): bet 1, bet 2w, bet 2l, bet 3ww, bet 3wl, bet 3lw and bet 3ll are subsets including subjects with an outcome at that node in their game play. We measure the change in three different measures: dollar amount in Panel A, portfolio weight in Panel B, and degree of break-even mental accounting in Panel C. We have eliminated subjects with zero wealth at each node. The statistical significance of the mean change is computed by bootstrapping from a trinomial distribution for the mental accounting measures, and is under the standard t-test for the other two measures.

Panel A				Dollar Amount	
Subset	N	Play	Plan	Change	p-Value
Bet 1	107	44.9439	39.5514	5.3925***	0.000662
Bet 2w	62	63.0161	61.0645	1.9516	0.62223
Bet 2l	41	31.2683	23.8049	7.4634***	0.000713
Bet 3ww	32	108.3125	97.6875	10.625	0.33673
Bet 3wl	30	62.5667	36.0667	26.5***	7.2e-005
Bet 3lw	21	63.7143	41.8571	21.8571**	0.018356
Bet 3ll	16	29.25	24.875	4.375	0.27598
Panel B				Portfolio Weight	
Subset	N	Play	Plan	Change	p-Value
Bet 1	107	0.4494	0.3955	0.0539***	0.000662
Bet 2w	62	0.4151	0.4155	-0.0004	0.98569
Bet 2l	41	0.591	0.4432	0.1478***	0.000667
Bet 3ww	32	0.475	0.4128	0.0622	0.1628
Bet 3wl	30	0.8423	0.5247	0.3177***	0.000339
Bet 3lw	21	0.7077	0.5079	0.1998**	0.018586
Bet 3ll	16	0.851	0.6634	0.1876**	0.035832
Panel C				Mental Accounting	
Subset	N	Play	Plan	Change	p-Value
Bet 1	107	NaN	NaN	NaN	NaN
Bet 2w	62	NaN	NaN	NaN	NaN
Bet 2l	41	0.5278	0.5	0.0278	0.33618
Bet 3ww	32	NaN	NaN	NaN	NaN
Bet 3wl	30	1	0.7826	0.2174**	0.01186
Bet 3lw	21	1	1	0	NaN
Bet 3ll	16	0.8333	0.375	0.4583**	0.0354

***, **, and * indicate statistical significance at the 1%, 5%, and 10% level, respectively.

References

[1] Maurice Allais. Le comportement de lhomme rationnel devant le risque: critique des postulats et axiomes de lcole amricaine. *Econometrica*, 21:503–546, 1953.

[2] Nicholas Barberis and Wei Xiong. What drives the disposition effect? an analysis of a long-standing preference-based explanation. *Journal of Finance, forthcoming*, 2008.

[3] Manel Baucells and Franz H. Heukamp. Probability and time tradeoff. *IESE Business School Working paper, Barcelona, Spain*, 2008.

[4] Uri Gneezy, Arie Kapteyn, and Jan Potters. Evaluation periods and asset prices in a market experiment. *The Journal of Finance*, 58(2):821–837, 2003.

[5] Uri Gneezy and Jan Potters. An experiment on risk taking and evaluation periods. *The Quarterly Journal of Economics*, 112(2):631–645, 1997.

[6] Daniel Kahneman and Amos Tversky. Prospect theory: An analysis of decision under risk. *Econometrica*, 47(2):263–291, 1979.

[7] Gideon Keren and Peter Roelofsma. Immediacy and certainty in intertemporal choice. *Organizational Behavior and Human Decision Processes*, 63(3):287–297, 1995.

[8] Camelia Kuhnen and Brian Knutson. The influence of affect on beliefs, preferences, and financial decisions. *Working Paper, Northwestern University, Evanston, IL*, 2008.

[9] George Loewenstein, Ted O'Donoghue, and Matthew Rabin. Projection bias in predicting future utility. *The Quarterly Journal of Economics*, 118(4):1209–1248, 2003.

[10] Erzo G. J. Luttmer and Thomas Mariotti. Subjective discounting in an exchange economy. *Journal of Political Economy*, 111(5):959–989, 2003.

[11] Mark J. Machina. Dynamic consistency and non-expected utility models of choice under uncertainty. *Journal of Economic Literature*, 27(4):1622–1668, 1989.

[12] Samuel M. McClure, David I. Laibson, George Loewenstein, and Jonathan D. Cohen. Separate neural systems value immediate and delayed monetary rewards. *Science*, 306(5695):503–507, 2004.

[13] Charles Noussair and Ping Wu. Risk tolerance in the present and the future: An experimental study. *Managerial and Decision Economics*, 27(6):401–412, 2006.

[14] Terrance Odean. Are investors reluctant to realize their losses? *Journal of Finance*, 53(5):1775–1798, 1998.

[15] Ayse Onculer. Intertemporal choice under uncertainty: A behavioral perspective. *Working Paper, INSEAD*, 2000.

[16] Howard Raiffa. *Decision Analysis: Introductory Lectures on Choices under Uncertainty.* Addison-Wesley, New York, 1968.

[17] Daniel Read, George Loewenstein, and Matthew Rabin. Choice bracketing. *Journal of Risk and Uncertainty*, 19(1-3):171–197, 1999.

[18] Richard H. Thaler and Eric J. Johnson. Gambling with the house money and trying to break even: The effects of prior outcomes on risky choice. *Management Science*, 36(6):643–660, 1990.

[19] Richard H. Thaler, Amos Tversky, Daniel Kahneman, and Alan Schwartz. The effect of myopia and loss aversion on risk taking: An experimental test. *The Quarterly Journal of Economics*, 112(2):647–661, 1997.