Lifecyle Retirement Planning: Experimental Evidence

John Duffy* Yue Li†

March 25, 2016

Abstract

We report on a series of economic decision-making experiments exploring how individuals make lifecycle consumption plans when they face various different deterministic endowment profiles over their lifetimes. In some treatments, subjects face a decline in their endowment income during a retirement phase while in other treatments endowment income is constant over all periods of life or subjects receive a single lump sum endowment only at the first period of their life. In all treatments, the present value of lifetime income is the same and so is the optimal consumption path. We find that, regardless of the endowment profile, subjects generally over-consume relative to the optimum in the early periods of life. Consequently, they accumulate too little wealth and so they under-consume relative to the optimum in later periods of life. We also find that consumption is excessively sensitive to endowment income and that there is a drop in consumption during the retirement phase of life regardless of whether or not there is a decline in the endowment received during those periods. Our lifecycle consumption findings thus mimic those found in studies using field data and so we argue that the laboratory provides an empirically relevant and controlled environment in which to study lifecycle consumption plans and retirement savings behavior and to assess the role of policy interventions. Finally, we develop a behavioral model of consumption behavior that is a hybrid of the Keynesian current-income approach and the forward-looking permanent income approach. We show that our hybrid behavioral model is able to explain several puzzling consumption/saving patterns found in the experiment.

Keywords: Lifecycle model, intertemporal choice, consumption, permanent income hypothesis, retirement planning, savings, behavioral and experimental economics.
JEL Codes: C91, D91, E21.

*Department of Economics, University of California, Irvine. Email: duffy@uci.edu.
†Department of Economics, University of Albany, SUNY, Email: yli49@albany.edu.

1 Introduction

Saving for retirement is one of the most important economic decisions that households face. Yet the available evidence suggests that households have performed poorly in preparing for this important task. Rhee (2013) estimates that 45 percent of working age (25-64) U.S. households do not own any retirement account assets, whether in an employer-sponsored 401(k) plan or an IRA. Among the 55 percent of working-age households with retirement assets, the median retirement account balance (excluding pension obligations) for all ages 25-64 in 2010 was $40,000; and the median balance for those near retirement (age 55-64) was $100,000. These numbers suggest a substantial shortfall in retirement savings amounts relative to what most U.S. households will need to finance the average retirement period of 18 years. Indeed, the National Retirement Risk Index shows that, in 2013, 52 percent of households were at risk for not saving enough to maintain their living standards after retirement (Center for Retirement Research at Boston College).[1]

What are the causes of this retirement savings shortfall and what policies might counteract the under-saving phenomenon? In this paper we provide some answers to these questions by using a novel methodology - laboratory experiments with paid human subjects. Our aim is to first understand how individuals make consumption and savings decisions over a lifecycle. We study environments where subjects are induced to hold concave preferences over consumption in each of the 25 periods of the lifetimes so that lifecycle consumption smoothing is desirable as in the permanent-income approach. Within this environment, we consider how subjects make consumption and savings decisions facing several different lifecycle profiles for their income. These lifecycle income processes are know with certainty, and some of them involve explicit drops in income to mimic a retirement phase of life. To allow subjects

[1] The pattern of under-saving is confirmed by the economic literature. For instance, Mitchell and Moore (1998); Scholz et al. (2006); Love et al. (2008); Hurd and Rohwedder (2008); Poterba et al. (2011); Rhee (2013), argue that a substantial number of US households do not save enough for retirement, which indicates that these people have consumed too much during their working periods.

to learn, we have them participate in two 25-period lifetimes (sequences) under the same lifecycle income process.

Our assumption that the lifecycle income process is deterministic and known in advance is clearly an idealized, best-case-scenario, but it provides us with an important benchmark for more rigorous analysis; if subjects are unable to intertemporally smooth their consumption and save for retirement in this very simple environment, then such difficulties are likely to be further compounded in settings with uncertain and highly variable income processes. A further rationale for studying the model with a deterministic income process is that is possible to analytically solve for the optimal consumption path, given the induced concave utility function.[2]

Our aim in designing these experiments and analyzing the results is to first understand the extent to which theories of optimal intertemporal decision-making are relevant to our subject's decision-making. To preview our results, we find that subjects exhibit large and economically significant departures from the optimal path. In particular, they display excess sensitivity to current income and they over-consume in the early periods of life (relative to the optimal path), leading to lower wealth accumulation. Consequently, they under-consume in later periods of life. Our second aim is to propose and empirically validate an alternative behavioral model of consumption that can better explain subjects' behavior in this standard lifecycle framework. The development of such an alternative, behavioral model of lifecycle consumption behavior is a necessary first step for evaluating the role of various policy changes on consumption behavior.

Regarding possible policy interventions, we are particularly interested in how variations in the replacement rate of working year income during the retirement phase of life can aid or hinder our subjects' ability to accumulate enough wealth upon retirement thereby enabling

[2]As Carroll (2001) notes "when there is uncertainty about the future level of labor income, it appears to be impossible under plausible assumptions about the utility function to derive an explicit solution for consumption as a direct (analytical) function of the model's parameters." To better evaluate our subjects' performance we wish to study environments where the solution to the planning problem can be computed.

them to better smooth consumption over their lifetimes. Variations in the retirement income replacement rate comprise one of the main treatment variables of our experiment, and these variations can help us to better understand whether and how changes in government social security policies can affect the retirement planning choices of households. Such experiments are difficult to conduct in the field and indeed, our ability to explore the effects of different income processes and retirement replacement policies is the main advantage of our experimental approach.

This paper complements three strands of existing research. The first strand uses laboratory experiments to study consumption and saving decisions (Johnson et al., 1987; Fehr and Zych, 1998, 2008; Ballinger et al., 2003; Carbone and Hey, 2004; Carbone, 2006; Brown et al., 2009; Ballinger et al., 2011; Feltovich and Ejebu, 2013; Carbone and Duffy, 2014; Meissner, 2014; Meissner and Rostam-Afschar, 2014; Koehler et al., 2015). Many of these papers make use of more complicated lifecycle income processes, with no explicit retirement phase of lower income toward the end of life. Koehler et al. (2015) is the only study that includes a retirement phase, but they do not use an induced utility function. In such cases, it is not possible to easily determine an optimal consumption path in order to evaluate subject behavior. We contribute to this literature by studying settings where there is a drop-off in income in the retirement phase of life and where there always exists an optimal path. The second strand of the literature uses survey or field experiment methods to evaluate the efficacy of various interventions to aid in retirement planning (Brown et al., 2011, 2013; Liebman et al., 2015). Our research complements these studies by focusing on lifecycle consumption and saving decisions. The final strand of the literature documents that many US households do not save enough for retirement (Mitchell and Moore, 1998; Scholz et al., 2006; Love et al., 2008; Hurd and Rohwedder, 2008; Hastings and Mitchell, 2011; Poterba et al., 2011; Beshears et al., 2012; Rhee, 2013). The results of this paper provide some behavioral explanations for the lack of sufficient retirment savings.

The reminder of the paper proceeds as follows. Section 2 describes the theoretical framework that motivates the design of our experiment; Section 3 explains the experimental environment and model parameters; Section 4 provides our main research questions and Section 5 addresses these questions by reporting our main experimental findings; Section 6 proposes a behavioral model of lifecycle consumption that can explain the puzzling consumption/saving patterns found in the data; Section 7 estimates and evaluates this behavior model; Finally, section 8 provides a summary and conclusions.

2 Theoretical Framework

Our theoretical framework is the standard, intertemporal model of lifecycle consumption and savings choices originating in the work of Modigliani and Brumberg (1954) and Friedman (1957). We adopt this framework as it remains the workhorse approach to the modeling of household consumption and savings behavior in the macroeconomic and finance literatures, and we wish to present our results using a framework that is familiar to this audience, as we hope to move the discussion of lifecycle planning in a direction that takes greater account of departures from the rational choice ideal. We further restrict attention to the case of complete markets and no uncertainty as we wish to make the environment as simple as possible for our human subjects. As noted in the introduction, the world is far more complex—income is uncertain and markets are incomplete—but we wish to start with the simplest framework possible; if subjects are not able to optimally save for retirement in this simple setting, then it is unlikely that they will do better in a more complicated setting.

The theoretical framework can be described as follows. Each household i makes consumption and savings decisions in each of periods $p = 1,2,..P$, where P is perfectly known. Household i's endowment process over the lifecycle is also perfectly known, and denoted by

$\{e_{ip}\}_{p=1}^{P}$. Household i's objective is to:

$$\max_{\{c_{ip},a_{i(p+1)}\}_{p=1}^{P}} \sum_{p=1}^{P} u(c_{ip})$$

subject to

$$c_{ip} + \frac{a_{i(p+1)}}{1+r} = e_{ip} + a_{ip}, \quad \forall p$$
$$a_{i(p+1)} \geq 0 \quad \forall p, \text{ and } a_{i1} = 0.$$

Here, c_{ip} denotes household i's period p consumption, $a_{i(p+1)}$ denotes household i's initial assets for period $p+1$, and $r > 0$ is an exogenous fixed and known rate of interest; again, with the aim of simplicity, we are thus considering a partial equilibrium environment. We also impose a no-borrowing constraint, which should not be binding given a positive r and the specified utility function; again the rationale is simplicity, though we recognize that borrowing constraints can be empirically important in lifecycle consumption and savings decisions.[3] Notice further that we are ignoring any time discounting (i.e., we are setting the discount factor, $\beta = 1$) as our experiment will be conducted over several hours in a laboratory setting. The utility function $u(\cdot)$ is assumed to be increasing and concave, and represents the payoff function by which subject's period by period consumption choices earn them monetary payments. Compared with an alternative setting without induced utility, the introduction of $u(\cdot)$ yields a unique, optimal consumption path against which we can compare the behavior of our subjects.[4] We adopt a concave utility function specification as this implies that intertemporal smoothing of consumption is desirable (as in the lifecycle

[3]Allowing borrowing, we would have to specify borrowing constraints, which would further complicate the model. The optimal path for the model that we do implement does not require any borrowing.

[4]It would, of course, be interesting to study how individuals make consumption and savings decision over their lifetimes given their own, "homegrown" preferences, but it might be difficult to determine the nature of those preferences and thus the optimal consumption path, hence our decision to induce preferences.

theory).

Given the concavity of the utility function and given a lifetime endowment sequence, $\{e_{ip}\}_{p=1}^{P}$, it is straightforward to calculate, by working backwards, the solution to the maximization problem state above, which we refer to as the unconditional optimal path and denote by $\{c_{ip}^{**}, a_{i(p+1)}^{**}\}_{p=1}^{P}$. Recognizing that subjects may make decision errors over their lifetimes, we will also consider their behavior relative to the *conditionally* optimal consumption path, which we denote by $\{c_{ip}^{*}\}_{p=1}^{P}$. Formally, c_{ip}^{*} involves re-optimization at each new period of the lifecycle, based on current asset holdings, and is the solution to:

$$\max_{c_{ip}} \sum_{j=p}^{P} u(c_{ij})$$

subject to

$$c_{ij} + \frac{a_{i(j+1)}}{1+r} = e_{ij} + a_{ij}, \quad \forall j \geq p$$

$$a_{i(j+1)} \geq 0, \quad \forall j \geq p \text{ and } a_{ip} \text{ is given}$$

3 Experimental Design

In our experiment, we set $P = 25$ and $u(c) = 0.2\ln(0.01c + 1)$. Assuming that each period in the model represents 2.3 years, setting $P = 25$ periods corresponds to an economy where people begin life at age 23 and exit at age 79. More precisely, the first 17 periods correspond to ages 23-60 and represent the period of the lifecycle in which people work and receive (after-tax) earnings; the last 8 periods correspond to ages 61-79 and represent the period when people are retired and receive benefit income or consume out of their accumulated asset position. We induce a log utility function over consumption because the implied coefficient of relative risk aversion of 1 finds support in the empirical literature (Chetty, 2006). The interest rate, r, was set at 10 percent per model period and remained constant across all of our treatments; this choice implies an average annual real return of 4.5 percent on long term investments (Munnell et al., 2013).

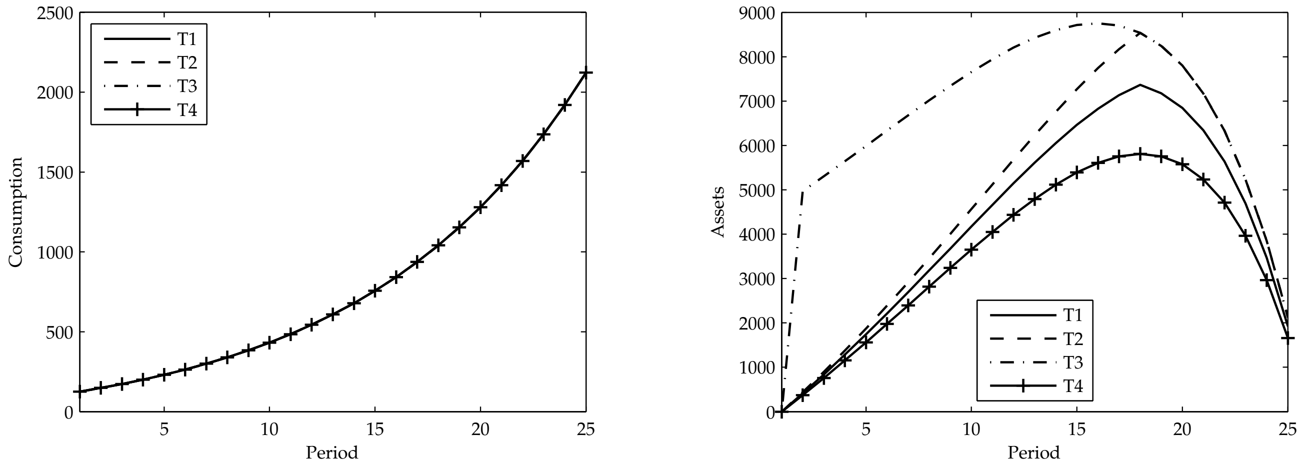
We consider four different lifetime sequences for endowments, which comprise our four main experimental treatments. All four endowment processes have the *same* present value, that is, for any two treatments $i \neq j$, it was always the case that:

$$\sum_{p=1}^{P} \frac{e_{ip}}{(1+r)^p} = \sum_{p=1}^{P} \frac{e_{jp}}{(1+r)^p}.$$

Our four treatments differ according to the distribution of endowments over the lifecycle, or, equivalently, the social security tax and benefit scheme. For instance, the endowment flow in treatment one (T1) is at a constant 500 "tokens" for the first 17 (work) periods, but in the last 8 (retirement) periods, this endowment amount drops to 200 tokens, which replaces 40 percent of the average endowment received during working periods. We chose a 40 percent replacement rate because this represents the replacement rate of social security benefits for a worker who earns the median U.S. income (Feldstein, 2005). Treatment two (T2) is designed to represent an economy without a social security system in which subjects receive a higher endowment than in T1 of 526 tokens during the first 17 working periods (as they pay no tax) but they receive a zero endowment in each of the final 8 periods of retirement. Hence, subjects in T2 must more actively save during their working years in order to have any consumption in the retirement phase of their lives. Treatment three (T3) is an extreme case where subjects receive a single lump-sum endowment of 4,644 tokens in the very first period of their lives and 0 in each of the remaining 24 periods, while treatment four (T4) represents the opposite extreme case where subjects receive a constant endowment of 465 tokens in each of the 25 periods of their lifetimes, which is lower than the endowment received during the working periods of T1 and T2. Treatment T4 can be viewed as a social security system that uses a greater payroll tax to fund a more generous retirement plan, which replaces 100 percent of pre-retirement after-tax earnings. Figure B.1 in Appendix B provides a visual illustration for these four endowment processes.

Each period, subjects are asked to decide how many tokens they wish to convert into money using the rate implied by the utility function. The remaining amount of tokens will be automatically saved for the future and earns the fixed interest rate of 10% per period. Following the completion of the final, 25th period, any tokens that were not converted into money were lost (had zero redemption value) and this fact was made known to subjects. This payment structure implies that maximization of monetary payoff in the experiment is equivalent to maximization of lifetime utility in the theoretical model. A sample screenshot for the decision process as well as the instructions distributed to subjects at the beginning of the experiment are provided in Appendix A.

In each session, subjects were first assigned to one endowment treatment condition for two, 25-period sequences (lifetimes), and then they are assigned to a second endowment treatment for an additional two, 25-period sequences. We repeated each endowment condition twice to allow for some learning by subjects. We chose to implement four different treatment orders: T1-T2, T2-T1, T3-T4, and T4-T3. Thus subjects who participated for example in the treatment order T1-T2 played two, 25-period sequences under the endowment profile of treatment 1 and then played 2 additional 25-period sequences under the endowment profile 2. In all cases, subjects were instructed in the endowment profile of the first treatment, and following completion of the two lifecycle sequences under that profile, they were instructed about the endowment profile of the second treatment. Subjects' actual monetary payoff was the sum of their experimental lifetime utility from two, randomly selected sequences (lifetimes), one separately from each of the two treatments of a session, plus a show-up payment. Subjects were paid in cash at the end of a session with the average payment being around $25 per subject.



(a) Consumption

(b) Assets

Figure 1: Optimal decisions implied by rational choice theory

Given the model parameters, Figure 1 plots the optimal lifecycle consumption and asset profiles for each treatment. Note that the no borrowing constraint is never binding if subjects behave rationally. As shown in Figure 1(a), the optimal consumption path is upward sloping and is the same across all four treatments. However, since the distribution of endowments differs by treatment, the optimal asset path varies across the four treatments. In particular, to offset for the sharp drop-off in endowments in later periods of life, subjects need to save more in treatments T3 and T2, as compared with treatments T4 and T1.

4 Questions

Our experiment is designed to answer three main questions:

1. Do subjects depart from the unconditional optimal path? If so, is the departure due to random errors made in the early periods of life, specifically, do decisions, on average, depart from the *conditionally* optimal level which takes into account both the distribution of past errors and the dispersion of current errors?

2. Does consumption respond to current endowments (income), and does the responsiveness vary with respect to the treatment specific distribution of those endowments across periods?

3. Does reaching the period of retirement (period 18) play any special role in changing the deviation of consumption from the conditionally optimal level? If so, does the effect differ across treatments?

In the next section we report on our experimental findings with the aim of addressing these questions.

5 Findings

The experimental subjects were all undergraduates at the University of California, Irvine who had no prior experience participating in any of our experimental treatments. The raw data is composed of 28, 32, 30, and 29 subjects for each of treatment orders T1-T2, T2-T1, T3-T4, and T4-T3, respectively. In the analysis that follows, we have dropped 9 subjects whose payments in any sequence were 2.5 standard deviations *below* the sequence mean. Such extremely low payment levels suggest that these subjects did not properly understand the decision problem they faced despite our best efforts to instruct them. For instance, these 9 subjects on average saved 3,133 tokens in the final 25the period, which had zero value to them as explained clearly in the experimental instructions and tested explicitly in a quiz prior to the start of decision-making. Our main results presented in this section are robust to the inclusion of these 9 subjects, but including these subjects leads to a large bias in the parameter estimates of our proposed behavioral model. As we did not design the model to capture the decisions of those who do not understand the consumption/saving task, to be consistent, we exclude these 9 subjects throughout our analysis. Table 1 reports characteristics of the remaining sample. A more detailed tabulation by sequence and by treatment are relegated to Table B.1 in Appendix B.

Table 1: Characteristics of Experimental Sessions

Treatment	Endowments	No. Obs.	Avg. Earnings
T1	500 for $t = 1, 2, \cdots, 17$ 200 for $t = 18, 19, \cdots, 25$.	116	\$8.53
T2	526 for $t = 1, 2, \cdots, 17$, 0 for $t = 18, 19, \cdots, 25$.	116	\$8.64
T3	$4,644$ for $t = 1$, 0 for $t = 2, 3, \cdots, 25$.	104	\$8.51
T4	465 for $t = 1, 2, \cdots, 25$.	104	\$8.89

Notes: The unit of observation is one-subject-one-25-period sequence. The earnings from adopting the optimal consumption path in a sequence is \$9.78. Recall that subjects were paid for two randomly chosen sequences plus a show-up payment.

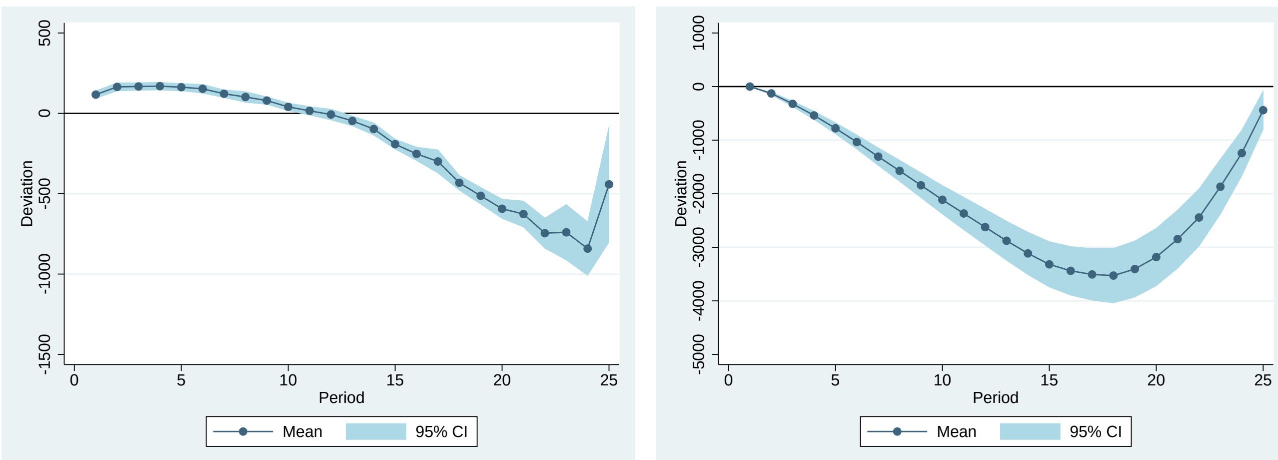
We have analyzed our experimental data with the aim of addressing each of our three main questions. We summarize our analysis as a number of different findings.

Finding 1 *Subjects depart from both the optimal path and the conditionally optimal path. In particular, they over-consume when young and they under-consume when old.*

Figure 2 presents the average deviation from the optimal path and its 95% confidence interval.[5] This figure clearly indicates that decisions observed in the experiment depart from optimal decisions implied by rational choice theory. Subjects consume more than the optimal level in early periods, and hence, relative to that optimal level, subjects accumulate fewer assets and can afford less consumption in the later periods of their lives. To further illustrate the magnitude of deviations from the optimal paths, Figure 3 plots the *percentage* deviations of consumption and assets relative to the optimal path. As shown in Figure 3(a), in the first three periods, consumption in our experiment is around 100 percent greater than that predicted by rational choice theory. Over time, the percentage difference becomes smaller and

[5]The average is calculated for each period based on observations from all treatments and all sequences. Figure B.2 in Appendix B provides additional information about deviations for each sequence and treatment. The patterns presented here hold for every sequence and treatment.

negative and reaches its lowest level beginning around period 18 (the retirement period). As shown in Figure 3(b), due to over-consumption in the early periods, the observed assets are more than 40 percent lower than that predicted by rational choice theory from periods 7 through 22. Due to under-consumption in the later periods, the asset deviation becomes smaller in the very last three periods, but it is still below zero through the end of a 25-period sequence.

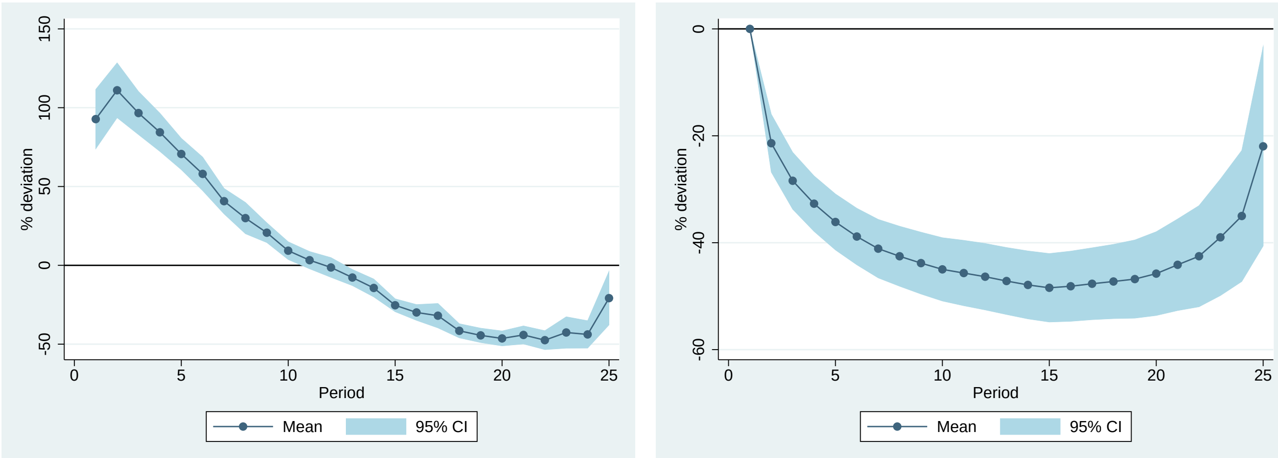


(a) Consumption

(b) Assets

Figure 2: Average deviation from the optimal path

One concern of studying deviations from the optimal path is that errors made in one period not only affect that period's deviation but also have a permanent effect on all future deviations, even if subjects behave optimally from that period onwards. To address this concern, Figure 4(a) plots the average consumption deviation from the *conditionally* optimal path, which eliminates the effect of past decision errors on current deviations. Notice that since the deviation in consumption exactly mirrors the deviation in assets when evaluated both relatively to the conditionally optimal level, there is no need to present a separate figure for the asset profile. It transpires that the pattern for consumption deviations found in Figure 2(a) is preserved in Figure 4(a): relative to the conditionally optimal path, subjects

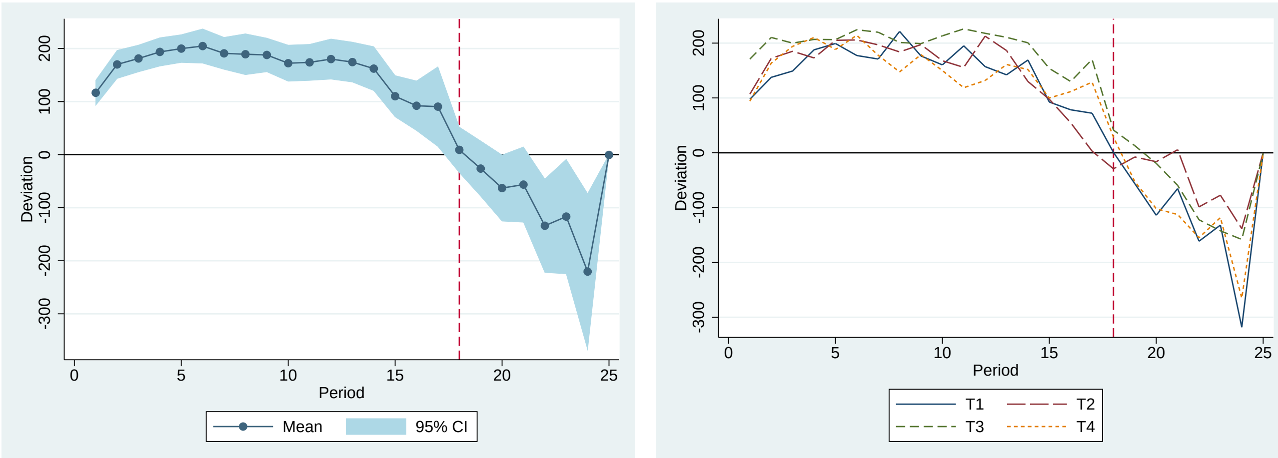


(a) Consumption (b) Assets

Figure 3: Average percent deviation from optimal path

continue to over-consume in early periods and under-consume in later periods. The only difference is that compared with Figure 2(a), in Figure 4(a), the deviation from the optimal path remains positive for a longer period of time, and only after period 18 do subjects begin to consume less than the conditionally optimal level. To understand whether the drop in this deviation over the life cycle is driven by treatments T1 and T2, which are the only two treatments with a reduction in endowments starting in period 18, Figure 4(b) plots the consumption deviation from the conditionally optimal level for each of the four treatments individually. We find that for all four treatments, including treatments T3 and T4 that have no change in endowments there is a reduction in the deviation of consumption from the conditionally optimal path around period 18, indicating that the shortening life span is the more likely cause for this reduction, although the effect could certainly be amplified by the declining endowments starting in period 18 of Treatments T1-T2.

To summarize the deviations of actual decisions from the rational choice predictions over a lifecycle we calculate the Root-Mean-Square-Deviation (RMSD) for each subject in each sequence. Denote the deviation for subject i in sequence s of treatment t for period p by



(a) All (b) By Treatment

Figure 4: Average consumption deviation from the conditionally optimal path
Notes: The vertical dashed line marks period 18.

z_{istp}. Then, the RMSD for subject i in sequence s is given by:

$$RMSD_{is} = \sqrt{\frac{1}{P}\sum_{p=1}^{P} z_{istp}^2}.$$

In practice, we calculate the deviation using three different measures: the deviation of consumption from the unconditional optimum, $(c_{istp} - c^{**}_{istp})$, the deviation of assets from the unconditional optimum $(a_{istp} - a^{**}_{istp})$, and the deviation of consumption from the conditional optimum $(c_{istp} - c^{*}_{istp})$. The comparison of the average of RMSDs across treatments and across sequences helps us to understand whether the endowment process and past experimental experience with a given endowment profile matters for the size of these deviations.

As reported in Table 2, in all treatments and sequences, subjects' decisions are significantly different from the rational choice model predictions: on average, actual consumption differs from the unconditionally optimal level by about 700 tokens and from the conditionally optimal level by about 400 tokens; actual assets differ from the unconditionally optimal level by about 3,000 tokens. It turns out that the different endowment processes across treatments have very little effect on the extent of these deviations. Among the 18 pair-wise comparisons (6 pairs for each variable) in Panel A, only two pair-wise comparisons result in deviations that are statistically different from one another: the RMSD of actual consumption from conditional optimum in T1 is significantly greater than that in: T3 at the 10 percent level and T4 at the 5 percent level.

Among the 18 pair-wise comparisons in Panel B, four pair-wise comparisons result in deviations that are statistically different: the deviation of consumption from the unconditional optimum in S1 is greater than that in S4 at the 10 percent level and the deviation of assets from the unconditional optimum in S1 is greater than that in: S2 at the 5 percent level, and S3 and S4 at the 1 percent level. These significant differences between earlier and later sequences indicates that subjects do learn from past experience, and move in the direction of the rational choice model predictions over time, although the magnitude of the improvement is relatively small.

Finding 2 *The amount and timing of endowments affects consumption.*

Several empirical studies have found that consumption is sensitive to current income by examining consumption responses to exogenous variability in tax rebates (Shapiro and Slemrod, 2003; Agarwal et al., 2007; Parker et al., 2013). To understand whether such responsiveness of consumption to current income can be replicated in the laboratory, we exploit the exogenous variation in endowments across periods and across treatments and estimate the effect of endowments on consumption (conditioning as well on conditionally optimal choices) using the following linear regression specification:

$$c_{istp} = Constant + \alpha_1 e_{istp} + \alpha_2 c^*_{istp} + \epsilon_{istp}. \quad (1)$$

Here, e_{istp} denotes the endowment for subject i in sequence s of treatment t for period p. The conditionally optimal consumption amount, c^*_{istp}, is added as a regressor to control

Table 2: Average of RMSD by treatment and sequences

Panel A: By treatment				
	T1	T2	T3	T4
$\sqrt{\frac{1}{P}\sum_{p=1}^{P}(c_{istp}-c_{istp}^{**})^2}$	730.88***	659.16***	687.07***	650.63***
	(33.84)	(33.84)	(35.74)	(35.74)
$\sqrt{\frac{1}{P}\sum_{p=1}^{P}(a_{istp}-a_{istp}^{**})^2}$	3175.28***	3014.29***	3275.77***	3018.06***
	(117.39)	(117.39)	(123.98)	(123.98)
$\sqrt{\frac{1}{P}\sum_{p=1}^{P}(c_{istp}-c_{istp}^{*})^2}$	404.98***	347.88***	345.13***	332.35***
	(24.58)	(24.58)	(25.96)	(25.96)
Panel B: By sequences				
	S1	S2	S3	S4
$\sqrt{\frac{1}{P}\sum_{p=1}^{P}(c_{istp}-c_{istp}^{**})^2}$	729.08***	675.12***	686.34***	640.06***
	(34.75)	(34.75)	(34.75)	(34.75)
$\sqrt{\frac{1}{P}\sum_{p=1}^{P}(a_{istp}-a_{istp}^{**})^2}$	3489.35***	3091.17***	2978.33***	2918.88***
	(119.11)	(119.11)	(119.11)	(119.11)
$\sqrt{\frac{1}{P}\sum_{p=1}^{P}(c_{istp}-c_{istp}^{*})^2}$	381.24***	346.26***	374.99***	331.96***
	(25.31)	(25.31)	(25.31)	(25.31)

Notes : Panel A reports the average RMSD for each treatment. Panel B reports the average RMSD for each sequence within a given treatment. Standard errors are reported in parentheses. ***>0.01, **>0.05, *>0.1.

for the correlation between e_{istp} and c^*_{istp}. The final term, ϵ_{istp}, is a random error that is clustered at the subject level. The coefficient of interest, α_1, measures the effect of current endowments on consumption. Because T3 has very little variation in endowments and T4 has no variation, we restrict our analysis to the data from treatments T1 and T2.

Table 3: Effects of Endowment on Consumption

	All	S1	S2	S3	S4	T1	T2
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
α_1	0.18***	0.22**	0.23***	0.13*	0.16**	0.38***	0.14***
	(0.05)	(0.09)	(0.08)	(0.08)	(0.08)	(0.11)	(0.05)
α_2	0.81***	0.82***	0.78***	0.83***	0.81***	0.81***	0.81***
	(0.01)	(0.03)	(0.01)	(0.02)	(0.02)	(0.02)	(0.02)
Constant	112.82***	114.97***	116.67***	101.01***	110.57***	17.29	137.93***
	(21.30)	(31.37)	(36.30)	(33.76)	(33.98)	(45.47)	(18.55)
R^2	0.703	0.632	0.7	0.74	0.741	0.693	0.719
Obs	5800	1450	1450	1450	1450	2900	2900

Notes: The sample is restricted to data from treatments T1 and T2. Columns (1), (2), (3), (4), (5), (6), and (7) report the parameter estimates based on observations from all sequences and all treatments, sequence 1, sequence 2, sequence 3, sequence 4, T1, and T2, respectively. Standard errors are clustered at the subject level and are reported in parentheses. ***>0.01, **>0.05, *>0.1.

As reported in column (1) of Table 3, the current period endowment income matters for consumption: holding the conditionally optimal consumption constant, a one token increase in current endowments raises current consumption by 0.2 tokens. It is also interesting to find that the sum of α_1 and α_2 are close to 1, indicating that actual consumption decisions can be characterized by a constant plus a weighted average of endowments and conditionally optimal consumption amounts. One interpretation for the constant term is that subjects make systemic errors in calculating either the conditionally optimal consumption level or the weighted average. This finding that consumption is sensitive to current endowments, even conditioning on the conditionally optimal level of consumption, provides the motivation for our behavioral model developed in the next section.

To understand whether subjects learn across lifecycles, Equation (1) is estimated separately for different sequences, as reported in Columns (2)-(5) of Table 3. The limited change across sequences suggests that the effect of endowments on consumption does not weaken with repetition. Further, to assess the difference across treatments, we separately estimate Equation (1) for each treatment. As shown in Columns (6) and (7), we find that, compared with treatment T1, consumption in treatment T2 is less sensitive to current endowments, and the difference in α_1 between these two treatments is significant at the 5% level. As the endowment for the last 8 periods is 0 in T1 and 200 in T2, it is possible that subjects in T1 are more alarmed by the future zero endowment flow, exert more effort to solve their retirement consumption problem, and hence respond less to the reduction in endowments. This difference in responsiveness is also incorporated in our behavioral model of consumption behavior.

Finding 3 *The deviation of consumption from the conditionally optimal level drops significantly upon reaching period 18 (the calibrated retirement period).*

There is an empirical literature documenting the fact that households reduce their expenses upon retirement.[6] It is interesting to see whether our laboratory experiment replicates this finding. Note first, however, that in our experiment, $\beta(1 + r)$ is set to be greater than 1 ($\beta = 1, r = 0.1$), leading to an upwards-sloping (optimal) consumption profile. One way to control for this induced upward trend is to calculate the deviation in consumption from conditionally optimal levels (hereafter referred to as the "consumption deviation") and examine whether this consumption deviation is affected by the (calibrated) timing of retirement. Formally, we estimate the effect of reaching period 18 on consumption deviations

[6]Banks et al. (1998) and Bernheim et al. (2001) find that people reduce their consumption when they retire, behavior that is considered to be inconsistent with rational choice theory; Aguiar and Hurst (2005, 2013), and Hurd and Rohwedder (2003) argue that such reduction in expenses is caused by the cessation of work-related expenses and the substitution of home production for market-purchased goods and services. But using survey data, one cannot test whether such reductions in expenses are anticipated before retirement or not. It is possible that households do not perfectly foresee the future: following the reduction in current income due to retirement, households have an immediate need to cut expenses, and increasing home production is one way to satisfy this need, although such a response is not expected beforehand.

using the following regression equation:

$$\Delta c_{istp} = Constant + \eta Post18_p + \varepsilon_{istp}. \quad (2)$$

Here, $\Delta c_{istp} = c_{istp} - c^*_{istp}$ is the consumption deviation by subject i in sequence s of treatment t for period p, $Post18_p$ is an indicator function that takes on the value of 1 for periods 18 to 25, ε_{istp} denotes a random error term clustered at the subject level and η is the coefficient of interest, measuring the effect of reaching period 18 on consumption deviations.

Table 4: Effects of reaching period 18 on the deviation of consumption from conditionally optimal level

	All	T1	T2	T3	T4
	(1)	(2)	(3)	(4)	(5)
Panel A: All periods					
η	-240.17***	-257.82***	-200.23***	-253.72***	-251.50***
	(23.91)	(47.04)	(34.81)	(36.29)	(38.43)
Constant	164.13***	152.03***	154.97***	197.71***	154.26***
	(12.69)	(23.67)	(19.63)	(16.29)	(18.36)
R^2	0.066	0.056	0.056	0.081	0.078
Obs	11000	2900	2900	2600	2600
Panel B: Periods 15-20					
η	-124.35***	-137.55***	-69.53*	-139.71***	-155.39***
	(18.45)	(36.92)	(39.28)	(34.10)	(34.15)
Constant	97.60***	81.04*	51.81	151.36***	113.39***
	(23.89)	(46.25)	(33.09)	(36.60)	(41.03)
R^2	0.021	0.021	0.007	0.021	0.039
Obs	2640	696	696	624	624
Panel C: Periods 17-18					
η	-81.47**	-71.39	-32.3	-128.86	-100.16
	(31.58)	(46.20)	(36.10)	(83.13)	(87.04)
Constant	90.49**	72.16	3.06	170.22*	128.72
	(38.34)	(58.03)	(38.65)	(89.10)	(91.38)
R^2	0.005	0.001	-0.002	0.005	0.005
Obs	880	232	232	208	208

Notes: Column (1), (2), (3), (4), and (5), reports the parameter estimates based on observations from all treatments, T1, T2, T3, T4, respectively. Panels A, B, and C report the parameter estimates based on observations from all periods, periods 15-20, and periods 17-18, respectively. Standard errors are clustered at the subject level and are reported in parentheses. ***>0.01, **>0.05, *>0.1.

As reported in Column (1) of Panel A in Table 4, reaching period 18 significantly reduces consumption deviations. One possibility for this finding is that the average measured reduction could be driven by over-consumption made at the beginning and under-consumption made the end of each life cycle. Thus Panels B and C restrict the sample to include only decisions that are made around the time of the retirement period and re-estimate Equation (2). The comparison across panels indicates that the reduction in consumption deviations becomes smaller as the sample becomes more restricted, but the reduction is still statistically significant and relatively large even when the sample only includes observations from periods 17 and 18. To understand whether the observed reduction is explained solely by endowment variability in treatments T1 and T2, which have a drop in endowment income at period 18, we estimate Equation (2) separately for different treatments and report the results in Columns (2)-(5). The comparison across columns makes it clear that the reduction in consumption deviations is similar for all treatments, indicating that a reduction of consumption around the retirement age is likely a response to the shortened remaining life-span rather than a more direct response to a change in endowments.

6 Behavioral Model

Motivated by the consumption patterns reported on in the previous section, in this section we develop a behavioral model that can explain subjects' departures from the predictions of rational choice theory. The idea behind our behavioral model originates with the dual process model of psychology. According to this theory, human decisions are affected by two different systems: system 1 is fast, instinctive and emotional, while system 2 is slower, more deliberative, and more logical (see, e.g. Kahneman (2011)). In the context of consumption/saving decisions, we view the instinctive—system 1—choice as being to consume all current period endowment income e_{tp}, while the more deliberative—system 2—choice is to carefully evaluate the decision problem and consume the conditionally optimal consumption amount, c^*_{istp}.[7] Note that in our design, current endowment income is a function of both the treatment number and the period number, while conditionally optimal consumption is a function of both model parameters and individual subjects' own past decisions.

We note that these two systems have counterparts in the macroeconomic consumption literature: on the one hand, Keynes (1936) proposed that consumption was a function of current income, and for those with zero assets, current income equals endowments; on the other hand, the permanent income approach of Friedman (1957) posits that consumption is a more deliberate, forward–looking function of permanent lifecycle income (wealth) and equal to the conditionally optimal level. We combine these two alternative theories, and propose that subjects are simultaneously affected by both "systems". In particular, their actual consumption decision, c_{istp}, is a weighted average of e_{tp} and c^*_{istp} if there is no calculation error.[8] Furthermore, inspired by our finding that the influence of endowments is smaller in T2 as compared with T1, we propose that the weight allocated to the system 2 choice, c^*_{istp}, is negatively related to the risk of following the system 1 choice of immediately consuming all endowment income e_{tp} in each period. Since this risk is closely linked to the endowment income that subjects expect to receive in the future, we make use of the *average future endowment*, denoted by $e^f_{tp} = \sum_{j=p+1}^{T} \frac{e_{tp}}{(T-p)}$, as a proxy for this risk. Formally, our behavioral model of consumption is represented by the following equation:

$$c_{istp} = min\{\gamma(e^f_{tp})c^*_{istp} + (1 - \gamma(e^f_{tp}))e_{tp} + \eta_{st} + \epsilon_{ispt}, x_{istp}\}, \tag{3}$$

[7] Alternatively, the system 1 choice can be thought as consuming all current income consisting of both endowment and interest income in each period. The results presented in the next section are robust to this alternative specification of the model. More information about this alternative specification is available upon request.

[8] This approach is similar in spirit to Simon (1990); Arthur (1994); Clark (1997); Howitt and Özak (2014), which all assume that individuals exhibit some type of bounded rationality.

subject to:

$$0 \leq \gamma(e^f_{tp}) \leq 1, \quad \forall e^f_{tp}. \tag{4}$$

Note that $\gamma(\cdot)$ is a function that describes how the average future endowment affects the weight allocated to the system 2 choice—which represents the conditionally optimal consumption amount. Both η_{st} and ϵ_{ispt} are calculation error terms. The difference is that η_{st} is a systemic error term common to all subjects in one sequence and treatment, while ϵ_{ispt} represents a random error term specific to individual subject i. Note that the case where subjects' decisions are fully determined by one system or the other is nested in the Equation (3): if $\gamma(e^f_{st}) = 0, \forall e^f_{st}$, subjects are "hand-to-mouth" consumers and their decisions are fully determined by system 1 while if $\gamma(e^f_{st}) = 1, \forall e^f_{st}$, subjects are "rational" consumers and their decisions are fully determined by system 2. Finally, $x_{istp} = e_{tp} + a_{ispt}$ denotes subject i's "cash on hand" in sequence s, period p of treatment t. Due to the no-borrowing constraint, consumption cannot be greater than this cash on hand amount, hence its inclusion in the minimum function determining c_{istp}.

By contrast with the rational choice approach, our proposed behavioral model is consistent with the three main findings established in the previous section. First, it should be evident that in our behavioral model, consumption will depart from the rational choice prediction since subjects' endowments differ from the conditionally optimal consumption path and individuals make calculation errors. That is,

$$\Delta c_{istp} = c_{istp} - c^*_{istp} = min\{(1 - \gamma(e^f_{tp}))(e_{istp} - c^*_{istp}) + \eta_{st} + \epsilon_{ispt}, x_{istp} - c^*_{istp}\} \tag{5}$$

Notice several things: first, the random error ϵ_{ispt} has a mean of zero and does not affect the average of consumption deviations for each period; second, the systematic error term η_{st} is constant for each sequence and does not contribute to life cycle changes in consumption deviations. Third, since $\beta(1+r) > 1$, the difference $x_{istp} - c^*_{istp}$ is always positive. It follows that the change in the average consumption deviation over the life cycle is equal to $(1-\gamma(e^f_{tp}))(e_{istp} - c^*_{istp})$, provided that this amount does not exceed $x_{istp} - c^*_{istp}$. Given a constant $\gamma(e^f_{tp})$, $(1-\gamma(e^f_{tp}))(e_{istp} - c^*_{istp})$ is initially positive (since in the initial periods, $e > c^*$) and declines over the periods of the lifecycle, as c^* is increasing over the lifecycle and e is non-increasing across all four treatments. Thus, there may exist a *threshold period* before which subjects over-consume and after which subjects under-consume, which is exactly the pattern shown earlier in Figure 4. Of course, taking into account the variability in $\gamma(e^f_{tp})$, the actual effect could be different.

Next, from Equation (3), it follows that consumption should also be responsive to current endowment income. Further, if $\gamma(e^f_{tp})$ decreases with respect to e^f_{tp}, our behavioral model can also explain why the responsiveness of consumption towards current income is smaller in treatment T2 relative to T1.

Finally, our model can also explain why there is a negative effect on consumption deviations in all treatments at retirement period 18, including those treatments with no change in endowment income in period 18. The reason is that reaching period 18 significantly reduces $(e_{istp} - c^*_{istp})$. Notice that $(1-\gamma(e^f_{tp}))$ does not play a significant role in determining the change around period 18, since in all treatments, from period 17, e^f_{tp} is a constant number. To characterize the effect of reaching period 18 on $(e_{istp} - c^*_{istp})$, we estimated the following equation:

$$e_{istp} - c^*_{istp} = Constant + \psi Post18_p + \varepsilon_{istp} \tag{6}$$

where $Post18_p$ is the same indicator function used previously, that takes the value of 1 for periods 18 to 25. Note that the experiment sets $e_{istp} = e_{tp}$ for all subjects.

Table 5 reports the regression results for the same sample size periods considered earlier in Table 4. The results clearly show that reaching period 18 lowers $(e_{istp} - c^*_{istp})$ in every treatment.[9] This explains why the reduction in Δc_{istp} is observed not only for treatments with reduced endowments at period 18 (T1 and T2) but also for treatments with no endowment change at period 18 (treatments T3 and T4). Moreover, as the sample size becomes more restricted in terms of covered periods (moving from Panels A to B to C), the estimates of ψ become smaller and change in the same direction as do the estimates of η in Equation (2), suggesting that the proposed behavioral model can also explain the change in Δc_{istp} for periods other than 18.

7 Estimation and Evaluation of the Behavioral Model

In this section, we first estimate the parameters of the behavioral model from the experimental data, and then we evaluate the model by comparing model-generated life cycle profiles for consumption and assets with the actual data profiles of these two variables and with profiles produced by alternative models.

7.1 Estimation

The function $\gamma(e^f_{tp})$ is parameterized as a linear function of e^f_{tp}. Under this assumption, the decision rule can be rewritten as:

$$c_{istp} = min\{(\gamma_1 + \gamma_2 e^f_{tp})c^*_{istp} + (1 - (\gamma_1 + \gamma_2 e^f_{tp}))e_{istp} + \eta_{st} + \epsilon_{ispt}, x_{istp}\}, \quad (7)$$

where γ_1 and γ_2 are the parameters governing the mapping from e^f_{tp} to $\gamma(e^f_{tp})$. The null hypothesis is that subjects' decisions conform, on average, to rational choice theory predictions: $\gamma_1 = 1$, $\gamma_2 = 0$, $\eta_{st} = 0, \forall s, t$.

[9] Note that the standard errors reported in this table are smaller than those reported in Table 4, because c^*_{istp} has a smaller variance than does c_{istp}.

Table 5: Effects of reaching period 18 on the difference between endowments and conditionally optimal consumption

	All Ts	T1	T2	T3	T4
	(1)	(2)	(3)	(4)	(5)
Panel A: All periods					
ψ	-974.84***	-1067.23***	-1211.94***	-836.87***	-745.30***
	(68.33)	(123.82)	(91.63)	(89.63)	(100.00)
Constant	147.40***	191.27***	226.94***	-1.43	158.59***
	(11.04)	(15.99)	(13.96)	(13.83)	(15.88)
R^2	0.221	0.273	0.423	0.105	0.191
Obs	11000	2900	2900	2600	2600
Panel B: Periods 15-20					
ψ	-389.83***	-487.92***	-720.14***	-128.84***	-172.97***
	(27.38)	(31.25)	(23.70)	(23.14)	(24.72)
Constant	-120.02***	-25.34	20.55	-440.98***	-61.45
	(26.19)	(41.94)	(36.01)	(32.89)	(39.32)
R^2	0.154	0.2	0.426	0.027	0.045
Obs	2640	696	696	624	624
Panel C: Periods 17-18					
ψ	-270.05***	-357.71***	-591.20***	-34.35**	-49.77***
	(21.77)	(11.82)	(8.75)	(12.94)	(12.55)
Constant	-166.90***	-76.34	-30.17	-477.58***	-109.72**
	(29.61)	(49.50)	(42.39)	(37.14)	(44.76)
R^2	0.089	0.131	0.361	-0.002	0
Obs	880	232	232	208	208

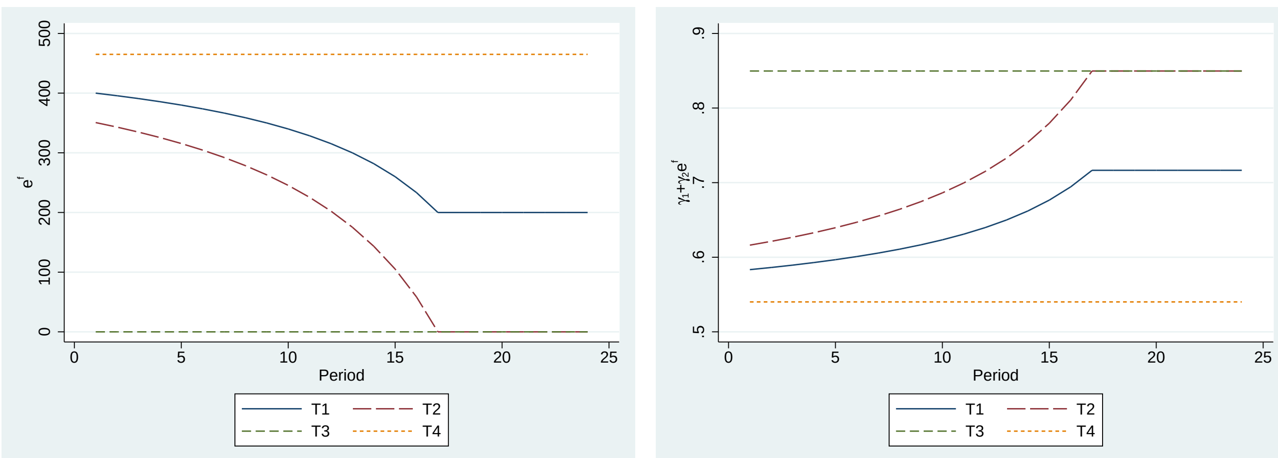
Notes: Column (1), (2), (3), (4), and (5), reports parameter estimates based on observations from all treatments, T1, T2, T3, T4, respectively. Panels A, B, and C report parameter estimates based on observations from all periods, periods 15-20, and periods 17-18, respectively. Standard errors are clustered at the subject level and are reported in parentheses. ***>0.01, **>0.05, *>0.1.

Table 6: Parameters estimates for the behavioral model

Weights	γ_1	γ_2		
	0.85***	-0.0007***		
	(0.03)	(0.0001)		
S1 errors	η_{11}	η_{12}	η_{13}	η_{14}
	82.17**	120.98***	177.02***	116.69***
	(38.21)	(16.25)	(29.95)	(7.49)
S2 errors	η_{21}	η_{22}	η_{23}	η_{24}
	103.64***	69.33**	97.94***	119.73***
	(27.86)	(34.15)	(36.81)	(7.10)
S3 errors	η_{31}	η_{32}	η_{33}	η_{34}
	69.21***	53.64*	195.29***	54.70**
	(24.13)	(27.41)	(24.43)	(24.25)
S4 errors	η_{41}	η_{42}	η_{43}	η_{44}
	76.37***	68.91**	158.61***	81.21***
	(27.22)	(31.54)	(27.37)	(22.81)

Notes: The sample excludes the final period decisions of each sequence since subjects are told explicitly in the instructions to consume all cash on hand in that period, which is the conditionally optimal choice, in the last period of each sequence. The number of observations is 10,560. R^2 is 0.729. Standard errors are clustered at the subject level and are reported in parentheses. ***>0.01, **>0.05, *>0.1.

The model's parameters are estimated using a nonlinear least-squares method, and are reported in Table 6. The null hypothesis is clearly rejected, suggesting that subjects do not behave according to the rational choice predictions. Specifically, subjects' consumption decisions are substantially affected by current endowments ($1-(\gamma_1+\gamma_2 e^f_{tp})>0$); and they systematically overstate the value of the conditionally optimal consumption ($\eta_{st}>0, \forall s,t$). Furthermore, we find that average future endowments negatively affect the weight assigned to the system 2 conditionally optimal consumption choice ($\gamma_2<0$).[10]



(a) Average future endowment

(b) Weight on System 2

Figure 5: System 2's weight by treatment and period

To illustrate the changing influence of system 2 on consumption decisions, Figure 5 plots the average future endowment, e^f_{tp}, by treatment and by period in the left panel and the implied weight of the system 2 choice in the right panel. Specifically, the right panel of Figure 5 plots $\gamma_1+\gamma_2 e^f_{tp}$ using the estimates for γ_1 and γ_2 reported in the first row of Table 6. Reflecting the difference across the average future endowments, the weights allocated to the system 2 choice range from 0.54 to 0.85, satisfying Constraint (4). Since the average future endowment does not vary in treatments T3 and T4, these two treatments

[10]The parameter γ_2 is identified solely from the variability of decisions across periods in treatments T1 and T2 and the difference between T1 and T2, since the average future endowment is constant in treatments T3 and T4.

have constant weights: 0.85 for T3 and 0.54 for T4. For the other two treatments, over the course of a lifetime, the system 2 weight increases from 0.58 to 0.72 in T1 and from 0.62 to 0.85 in T2 to reflect the fact that the average future endowment, e^f_{tp}, declines over time from 400 to 200 in T1 and from 351 to 0 in T2. If we neglect calculation errors, these weights suggest that dispensing with a social security system as in treatments T2 and T4, or lowering the replacement rate (as in the difference between treatments T4 and T1) lessens the departure of consumption from the conditionally optimal path, since individuals respond to the decrease in endowment income toward the end of their lives by putting greater weight on the deliberative system 2 choice, and behave more like rational agents. This channel indicates that subjects in treatments T2 and T3 should have greater lifetime utility as compared with subjects in treatments T1 and T4. On the other hand, the comparison of systematic errors across treatments in sequence one (the second row of Table 6) suggests that the systematic errors for treatments T2 and T3 are greater than those for treatments T1 and T4. Thus, reducing retirement benefits raises the difficulty of the life cycle problem and as a result, subjects make larger systemic errors. Although the difference between T2 and treatments T1 and T4 in sequence one is not statistically significant and the difference between T3 and treatments T1 and T4 is no longer significant with repetition (sequence two), the variation in systemic errors across treatments could weaken the positive effect of reducing retirement benefits on intertemporal allocations. In the experiment, these two opposing channels almost cancel each other out, and hence there is little difference in average final payments across the four treatments (See Table 1).

7.2 Evaluation

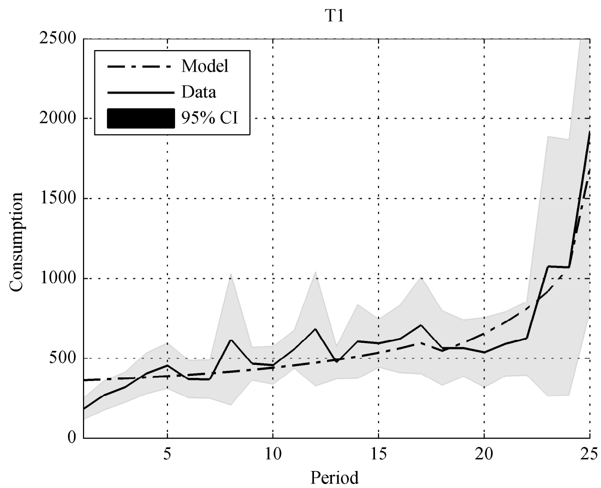
Given the parameter estimates obtained in the previous subsection, we simulate the average decision rules for each period, treatment and sequence cell using the following equations:

$$c_{stp} = min\{(\gamma_1 + \gamma_2 e^f_{tp})c^*_{stp} + (1 - (\gamma_1 + \gamma_2 e^f_{tp}))e_{stp} + \eta_{st}, x_{stp}\},$$
$$a_{st(p+1)} = (1 + r)(x_{stp} - min\{(\gamma_1 + \gamma_2 e^f_{tp})c^*_{stp} + (1 - (\gamma_1 + \gamma_2 e^f_{tp}))e_{stp} + \eta_{st}, x_{stp}\}).$$

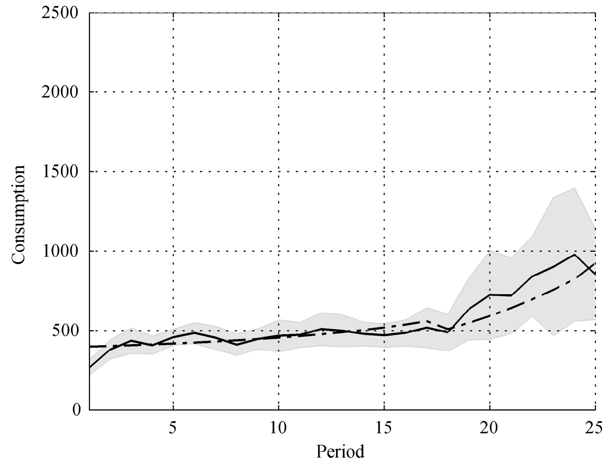
Note that the subscript i is dropped to represent the average for each sequence, treatment and period cell, and that the random error averages out across subjects in the aggregate.

Figures 6 and 7, respectively, compare the life cycle profile of average consumption and assets generated by our model with those in the first sequence of the experiment. The results for other sequences are similar and are relegated to Appendix B. As shown in Figure 6, our model performs well in capturing the changes in consumption over the life cycle for all four treatments. In particular, due to the influence of the system 1 choice, the predicted consumption growth over the life cycle in our model is lower than that under the rational choice model and is also closer to the growth rate observed in the data. Most importantly, our model is able to replicate the fact that subjects over-consume in the early periods of life and under-consume in the later periods of life.

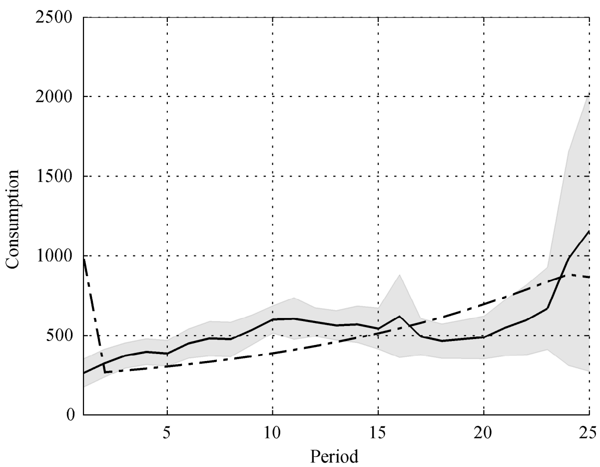
Not only does our model fit the pattern of consumption choices over the lifecycle, it also provides a good approximation to the accumulation/decumulation of assets over the life cycle as well. As shown in Figure 7, the model correctly predicts two counter-intuitive features of the data. First, subjects do not accumulate sufficient savings for retirement. For instance, in sequence 1, the ratio of assets at the retirement period of 18 predicted by our model relative to the amount of assets needed to maximize lifetime utility is 0.49, 0.45, 0.51, and 0.18 for treatments T1, T2, T3, and T4, respectively, and the corresponding ratios in the experimental data are 0.47, 0.51, 0.43, and 0.25, respectively. Second, with 40



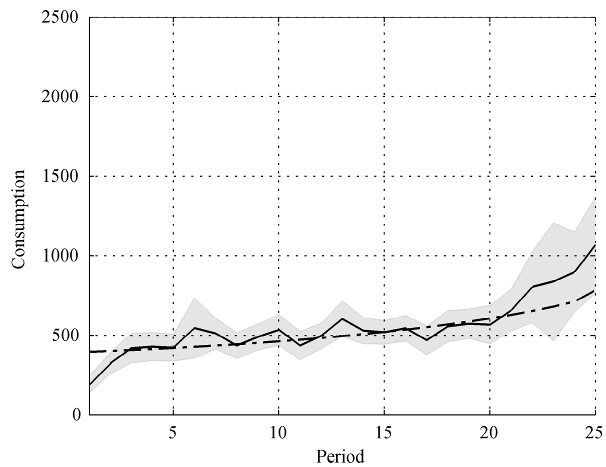
(a) T1



(b) T2



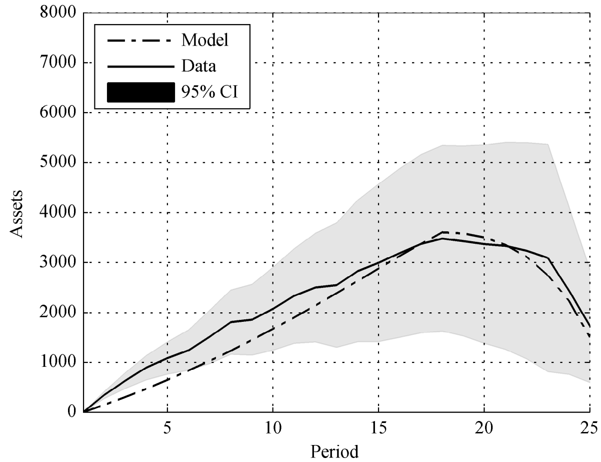
(c) T3



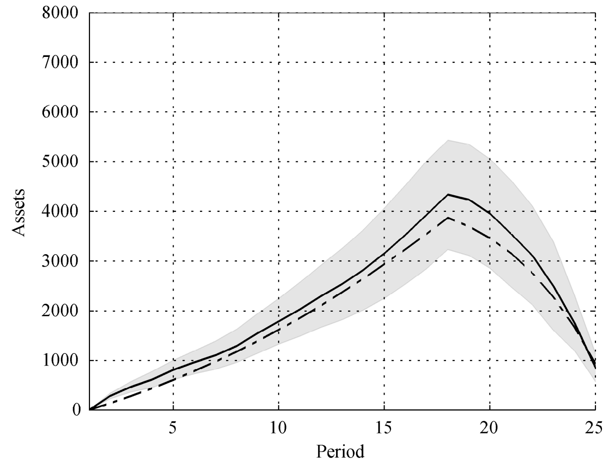
(d) T4

Figure 6: Average consumption by period in sequence 1

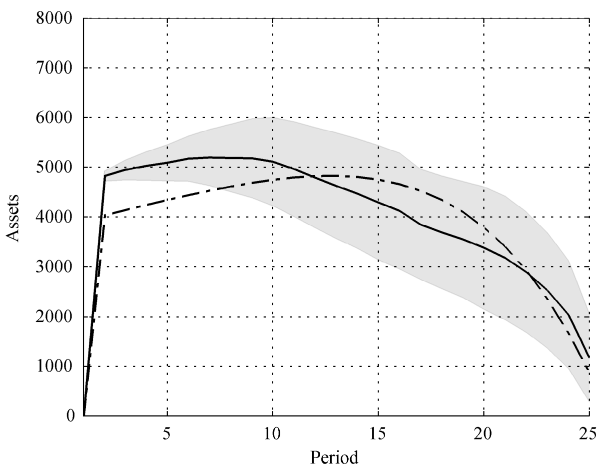
percent of pre-retirement earnings replaced by social security benefits as in treatment T1, post retirement, subjects decumulate assets at a rate that is slower than the optimal level and hold assets in an amount that is higher than what is needed until the last period of life. Specifically, the rational choice model predicts that by period 25, subjects should reduce their asset holdings by 73.9 percent relative to their holdings in period 18. By contrast, in the first sequence of treatment T1, this reduction in assets is only 50.5 percent. The



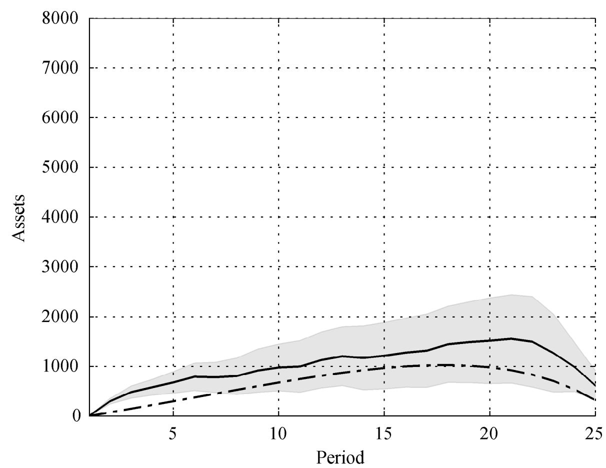
(a) T1



(b) T2



(c) T3



(d) T4

Figure 7: Average assets by period in sequence 1

predicted reduction using our model is closer to the data and is 58.6 percent. However, due to the presence of systematic calculation errors, the post-retirement decumulation of assets in both the data and our model need not always be slower than what is predicted by the rational choice model. For instance, in sequence 1 of treatment T2 the reduction in asset holdings by period 25 relative to period 18 is 80.3 percent in the data, 76.1 percent in our model, and 75.1 percent in the rational choice model.

To assess the performance of our behavioral model relative to some alternative models, we compare the RMSD of the experimental data (the data mean in Figures 6, 7, and B.3-B.8) from the predictions of four alternative models: our own behavioral model, the rational choice model, a heuristic model that assumes agents consume all of their endowment in each period and hence have zero assets (Winter et al., 2012), and finally, a two–type model which considers the coexistence of both fully rational agents and hand-to-mouth consumers (Campbell and Mankiw, 1989). When computing the RMSD, we exclude the last period of life, since subjects are explicitly instructed to consume the conditionally optimal amount in that final period. Specifically, the RMSD for model m and sequence s is calculated as follows:

$$RMSD_{sm} = \sqrt{\frac{1}{P-1}\sum_{p=t}^{P-1}(\overline{x}_{stp} - x_{stp}^{m})^2}$$

where $\overline{x}_{stp}$ denotes the average of consumption or assets for all subjects in sequence s of treatment t for period p, and x_{stp}^{m} denotes the predicted value using model m, where m can take four values B, R, H, T, respectively, representing our behavioral model, the rational choice model, the hand-to-mouth heuristic model, and the two-type model.

The solutions to the first two alternative models can be calculated independently of the data: $c_{stp}^{R} = c_{stp}^{**}, a_{stp}^{R} = a_{stp}^{**}$ for the rational choice model, and $c_{stp}^{H} = e_{tp}, a_{stp}^{H} = 0$ for the hand-to-mouth model. As before, subscript i is dropped to represent the average in each sequence, treatment and period. For the two-type model, we must first identify the share of rational agents using the data. Specifically, this share is estimated using the following equation:

$$c_{istp} = \zeta_{st} c_{tp}^{**} + (1 - \zeta_{st}) e_{tp} + \epsilon_{ispt}, \tag{8}$$

where ζ_{st} is the coefficient of interest, measuring the share of rational agents in each treatment and sequence and ϵ_{ispt} is a random error that is not part of the two-type model but is added for the estimation.

Our behavioral model differs from the two-type model in three important ways. First, the two-type model assumes that agents either behave rationally, choosing the optimal consumption path, or behave irrationally by consuming their endowment in each period. By contrast our model allows each agent to be simultaneously influenced irrational instinct and rational forward-looking planning (system 1 versus system 2). Second, the two-type model assumes that the rational-type agent makes the optimal consumption decision from the very beginning of each sequence, and hence the average consumption decision is a combination of c_{tp}^{**} and e_{tp}. By contrast, in our model, agents recognize past deviations from the optimal path and update the system 2 choice each period. As a result, the average consumption decision is a combination of c_{istp}^{*} and e_{tp}. Finally, the no borrowing constraint is required for our model but not for the two-type model, because the constraint never binds for rational agents and is equivalent to the endowment amount for hand-to-mouth consumers.

Campbell and Mankiw (1989) find that to account for the volatility in aggregate consumption in the U.S. quarterly time series field data, the population should be approximately equally split between rational and hand-to-mouth consumers. Table 7 reports the share of rational agents for the different treatments and sequences in our experimental data. Interestingly, we also find that the estimated share of rational agents in treatments with more realistic endowment flows (T1 and T2) is very close to 0.50, and the share in treatments with less realistic endowment flows (T3 and T4) is further away from 0.50. In particular, with one lump-sum payment in the very first period (T3), there are fewer subjects behaving like hand-to-mouth consumers; while with a constant endowment flow (T4), there are many more subjects behaving like hand-to-mouth consumers. This change in the share of rational agents across treatments is similar to findings about the change in the relative importance of the system two choice in our behavioral model (see Figure 5). Together, these findings suggest that, in response to a declining risk of consuming all of one's endowment in each period, subjects' consumption decisions will be less influenced by forward looking system 2 thinking and increasingly influenced by the simple (system 1) heuristic of consuming endowments.

Table 7: Share estimates of the two type model

S1	ζ_{11}	ζ_{12}	ζ_{13}	ζ_{14}
	0.43***	0.50***	0.75***	0.25***
	(0.13)	(0.08)	(0.03)	(0.07)
S2	ζ_{21}	ζ_{22}	ζ_{23}	ζ_{24}
	0.35***	0.54***	0.80***	0.30***
	(0.06)	(0.07)	(0.02)	(0.09)
S3	ζ_{31}	ζ_{32}	ζ_{33}	ζ_{34}
	0.62***	0.69***	0.75***	0.56***
	(0.09)	(0.08)	(0.03)	(0.11)
S4	ζ_{41}	ζ_{42}	ζ_{43}	ζ_{44}
	0.61***	0.58***	0.77***	0.49***
	(0.09)	(0.07)	(0.03)	(0.11)

Notes: The sample excludes final period decisions since subjects were told in the instruction to consume all available resources in the last period of each sequence, which is the conditionally optimal choice. Number of observations is 10560. R^2 is 0.635. Standard errors are clustered at the subject level and are reported in parentheses. ***>0.01, **>0.05, *>0.1.

Given the estimated share of rational agents for each sequence and treatment ζ_{st}, the predictions under the two-type model were then calculated as follows:

$$c^T_{stp} = \zeta_{st} c^{**}_{tp} + (1 - \zeta_{st}) e_{tp},$$

$$a^T_{st(p+1)} = (1 + r)(x_{stp} - (\zeta_{st} c^{**}_{stp} + (1 - \zeta_{st}) e_{stp})).$$

The RMSD are separately computed for the four alternative models and are reported in Table 8 in columns (1)-(4), respectively, reporting the results for our behavioral model, the rational choice model, the hand-to-mouth heuristic model, and the two-type model. If we look at the average across all sequences and treatments (the first row in each panel), for both consumption and assets, the RMSD generated by our behavioral model is much smaller than that produced by the rational choice model or the hand-to-mouth heuristic model, and

Table 8: RMSD of data period average from predictions of alternative models

	Behavioral (1)	Rational (2)	Hand-to-mouth (3)	Two type (4)
Panel A: Consumption				
All	122.44	382.69	538.96	140.57
S1	117.01	444.98	490.58	158.72
S2	115.52	413.65	492.43	120.36
S3	132.94	330.97	604.64	158.99
S4	124.29	341.16	568.19	124.23
T1	113.56	370.50	373.75	83.51
T2	82.92	356.77	486.37	81.62
T3	183.58	442.23	1048.06	328.20
T4	109.70	361.26	247.65	68.98
Panel B: Assets				
All	478.28	2369.02	3099.63	591.04
S1	368.13	2893.78	2596.83	648.51
S2	383.59	2527.28	2903.30	406.83
S3	579.23	1974.68	3531.31	732.11
S4	582.19	2080.34	3367.08	576.72
T1	496.50	2193.22	2721.31	371.18
T2	304.60	2275.35	3249.97	284.91
T3	439.74	2801.04	4537.00	1365.90
T4	672.29	2206.46	1890.24	342.19

Notes: The sample excludes the last period of life, since subjects are explicitly instructed to consume the conditionally optimal amount (all assets and endowment income) in the final period. For each panel, the first row reports the average value across all sequences and treatments; the second through the fifth rows report the average across the four sequences of a single treatment; the sixth through ninth rows report the average across the four treatments in a single sequence.

is similar in magnitude to that produced by the two-type model. The comparison across sequences (the second through fifth rows in each panel) indicates that the gap in RMSD persists with repetition. The comparison across treatments (the last four rows) shows that our model continues to provide a better fit to the data relative to the rational choice model and the hand-to-mouth heuristic model in all treatments, but the two-type model slightly outperforms our behavioral model in treatments T1, T2, and T4.

In summary, our model is on a par with the two-type model in matching average profile of consumption and assets—both of them provide a better explanation of the over-and-under consumption pattern during the life cycle as compared with either the rational choice model or the heuristic model that assumes agents consumes their endowment in each period. However, it is important to note that the two-type model fails in one important micro-dimension: among a total number of 476 combinations of sequences and subjects (including the 9 outliers dropped for the above analysis), no subject in our experiment behaved like a perfectly rational agent. Only 3 subjects behaved like a perfect hand-to-mouth consumer in 7 different sequences (1.5 percent of the sample). Thus, for explaining the aggregate-level data, the two-type model performs very similarly to our behavioral model, but our model accounts better for the micro-level variation in consumption/saving decisions in the sense that there is little evidence for the existence of two pure types of the two-type model. We note that the latter observation is really only possible to obtain in a controlled laboratory setting such as the one we have implemented, where we have induced a utility function and various endowment paths and can thus determine what constitutes optimal behavior.

8 Conclusions

We have reported on a laboratory experiment designed to understand how individuals make consumption and savings decisions over the lifecycle given a concave utility function objective and facing deterministic endowment profiles over that lifecycle. While the certain, deterministic nature of the endowment profile may not be very realistic, it provides a simple framework that enables us to compute the optimal solution, and this forward-looking view of lifecycle consumption *is* the workhorse model used in the macroeconomics and finance literatures. If subjects are unable to make optimal decisions in this simplified framework, it seems doubtful that they would perform better in richer, stochastic frameworks that better reflect real lifecycle decision-making.

We were particularly interested in how subjects responded to variations in the lifecycle endowment profile. In particular, in two of our four treatments, endowment income drops during the retirement phase and our focus here was on whether subjects who were fully informed of this drop in retirement income would respond to it as the rational choice theory predicts, by accumulating assets in such a way as to smooth consumption over their entire lifetimes. Our experiment has yielded several important findings. First, we found that in all four treatments, subjects over-consume relative to the optimal path in the early periods of life and as a consequence they do not accumulate the assets they need to achieve optimal consumption in the later periods of their lives, so that they under-consume in those periods. Other experimenters have also documented this finding, but the difference here is that we have considered a variety of lifecycle endowment profiles, including a constant endowment profile (treatment T4) and we continue to obtain the same pattern of over- and under-consumption over the lifecycle. Second we found that the deviation of consumption from the conditionally optimal level drops significantly upon reaching period 18 (the calibrated retirement period). This drop occurs for all four treatments, not just those where the endowment income declines in the retirement period suggesting that subjects are changing their behavior as the end of their lifetimes is approaching. Third, we also find that the amount and timing of endowments affects consumption choices. Surprisingly, providing a more smooth consumption path as in our treatments T1 and T4 need not result in consumption profiles that are closer to the optimal path. Finally, we develop a behavioral model of consumption behavior that borrows from the dual process theory of psychology where subjects are modeled as making consumption decisions both instinctually, based on current endowment income alone and fully rationally, base on the conditionally optimal level. We find that our dual-system behavioral model provides a very good fit to the experimental data in terms of RMSD, outperforming both the rational choice model and the heuristic hand-to-mouth consumption models, and performing similarly to the two-type model of Campbell and Mankiw (1989). However, by contrast with the latter model, we argue that our model fits the micro-level facts of the experimental data better in the sense that there is no evidence for the existence of either of the two pure types (rational or hand to mouth) that is assumed in the two-type model. We suspect that this observation would also carry over to consumption decisions made by households in the field.

The construction of a behavioral model validated using experimental data is a necessary first step in understanding how individuals are likely to respond to changes in social security and other retirement savings vehicles. We think that an obvious next step is to determine how well our model matches features of the time series data on household consumption and asset accumulation over the lifecycle, and whether various modifications to the model, e.g. allowing for borrowing constraints, mortality risk, stochastic income and unemployment, among other factors, would improve the fit. We leave these extensions to future research.

References

Agarwal, Sumit, Chunlin Liu, and Nicholas S Souleles, "The Reaction of Consumer Spending and Debt to Tax RebatesEvidence from Consumer Credit Data," *Journal of Political Economy*, 2007, *115* (6).

Aguiar, Mark and Erik Hurst, "Consumption versus expenditure," *Journal of Political Economy*, 2005, *113* (5).

— **and** — , "Deconstructing life cycle expenditure," *Journal of Political Economy*, 2013, *121* (3), 437–492.

Arthur, W Brian, "Inductive reasoning and bounded rationality," *The American Economic Review*, 1994, pp. 406–411.

Ballinger, T Parker, Eric Hudson, Leonie Karkoviata, and Nathaniel T Wilcox, "Saving behavior and cognitive abilities," *Experimental Economics*, 2011, *14* (3), 349–374.

__ , Michael G Palumbo, and Nathaniel T Wilcox, "Precautionary Saving and Social Learning across Generations: an Experiment," *The Economic Journal*, 2003, *113* (490), 920–947.

Banks, James, Richard Blundell, and Sarah Tanner, "Is there a retirement-savings puzzle?," *The American Economic Review*, 1998, pp. 769–788.

Bernheim, B Douglas, Jonathan Skinner, and Steven Weinberg, "What accounts for the variation in retirement wealth among US households?," *The American Economic Review*, 2001, pp. 832–857.

Beshears, John, James J Choi, David Laibson, and Brigitte C Madrian, "The impact of a Roth option on outcomes in employer-sponsored savings plans," NBER Working Paper 2012.

Brown, Alexander L, Zhikang Eric Chua, and Colin Camerer, "Learning and visceral temptation in dynamic savings experiments," *Quarterly Journal of Economics*, 2009, *124* (1), 197–231.

Brown, Jeffrey R, Arie Kapteyn, and Olivia S Mitchell, "Framing effects and expected social security claiming behavior," NBER Working Paper 2011.

__ , __ , Erzo FP Luttmer, and Olivia S Mitchell, "Cognitive constraints on valuing annuities," NBER Working Paper 2013.

Campbell, John Y and N Gregory Mankiw, "Consumption, income and interest rates: Reinterpreting the time series evidence," in "NBER Macroeconomics Annual 1989, Volume 4," MIT Press, 1989, pp. 185–246.

Carbone, Enrica, "Understanding Intertemporal Choices," *Applied Economics*, 2006, *38* (8), 889–898.

__ and John D Hey, "The effect of unemployment on consumption: an experimental analysis," *The Economic Journal*, 2004, *114* (497), 660–683.

__ and John Duffy, "Lifecycle consumption plans, social learning and external habits: Experimental evidence," *Journal of Economic Behavior & Organization*, 2014, *106*, 413–427.

Carroll, Christopher D, "A theory of the consumption function, with and without liquidity constraints," *Journal of Economic perspectives*, 2001, pp. 23–45.

Chetty, Raj, "A new method of estimating risk aversion," *The American Economic Review*, 2006, pp. 1821–1834.

Clark, Andy, *Being there: Putting brain, body, and world together again*, MIT press, 1997.

Fehr, Ernst and Peter K Zych, "Do Addicts Behave Rationally?," *The Scandinavian Journal of Economics*, 1998, *100* (3), 643–661.

__ and __ , "Intertemporal Choice under Habit Formation," *Handbook of Experimental Economics Results*, 2008, *1*, 923–928.

Feldstein, Martin, "Structural reform of social security," *Journal of Economic Perspectives*, 2005, *19* (2), 33–55.

Feltovich, Nick and Ourega-Zoé Ejebu, "Do Positional Goods Inhibit Saving? Evidence from a Life-Cycle Experiment," *Working Paper*, 2013.

Friedman, Milton, *A theory of the consumption*, Princeton University Press Princeton, NJ, 1957.

Hastings, Justine S and Olivia S Mitchell, "How financial literacy and impatience shape retirement wealth and investment behaviors," NBER Working Paper 2011.

Howitt, Peter and Ömer Özak, "Adaptive consumption behavior," *Journal of Economic Dynamics and Control*, 2014, *39*, 37–61.

Hurd, Michael and Susann Rohwedder, "The retirement-consumption puzzle: Anticipated and actual declines in spending at retirement," NBER Working Paper 2003.

Hurd, Michael D and Susann Rohwedder, "The adequacy of economic resources in retirement," MRRC Working Papper 2008-184 2008.

Johnson, Stephen, Laurence J Kotlikoff, and William Samuelson, "Can People Compute? An Experimental Test of the Life Cycle Consumption Model," *NBER Working Paper No. 2183*, 1987.

Koehler, Derek J, Jesse Langstaff, and Wu-Qi Liu, "A simulated financial savings task for studying consumption and retirement decision making," *Journal of Economic Psychology*, 2015, *46*, 89–97.

Liebman, Jeffrey B, Erzo FP Luttmer et al., "Would people behave differently if they better understood social security? Evidence from a field experiment.," *American Economic Journal: Economic Policy*, 2015, *7* (1), 275–99.

Love, David A, Paul A Smith, and Lucy C McNair, "A new look at the wealth adequacy of older US households," *Review of Income and Wealth*, 2008, *54* (4), 616–642.

Meissner, Thomas, "Intertemporal consumption and debt aversion: an experimental study," *Experimental Economics*, 2014, pp. 1–18.

_ **and Davud Rostam-Afschar**, "Do tax cuts increase consumption? An experimental test of Ricardian Equivalence," Working Paper 2014.

Mitchell, Olivia S and James F Moore, "Can Americans afford to retire? New evidence on retirement saving adequacy," *Journal of Risk and Insurance*, 1998, pp. 371–400.

Modigliani, Franco and Richard Brumberg, "Utility analysis and the consumption function: An interpretation of cross-section data," *Post-Keynesian Economics*, 1954, *1.*

Munnell, Alicia H, Jean-Pierre Aubry, Josh Hurwitz et al., "How sensitive is public pension funding to investment returns," CRR Working Paper 2013.

Parker, Jonathan A, Nicholas S Souleles, David S Johnson, and Robert McClelland, "Consumer Spending and the Economic Stimulus Payments of 2008," *American Economic Review*, 2013, *103* (6), 2530–53.

Poterba, James M, Steven F Venti, and David A Wise, "Were they prepared for retirement? Financial status at advanced ages in the HRS and AHEAD cohorts," in "Investigations in the Economics of Aging," University of Chicago Press, 2011, pp. 21–69.

Rhee, Nari, "The retirement savings crisis: Is it worse than we think?," Working paper 2013.

Scholz, John Karl, Ananth Seshadri, and Surachai Khitatrakun, "Are Americans saving "optimally' for retirement?," *Journal of Political Economy*, 2006, *114* (4).

Shapiro, Matthew D and Joel Slemrod, "Did the 2001 tax rebate stimulate spending? Evidence from taxpayer surveys," in "Tax Policy and the Economy, Volume 17," MIT Press, 2003, pp. 83–110.

Simon, Herbert A, "Invariants of human behavior," *Annual Review of Psychology*, 1990, *41* (1), 1–20.

Winter, Joachim K., Kathrin Schlafmann, and Ralf Rodepeter, "Rules of thumb in life-cycle saving decisions," *The Economic Journal*, 2012, *122* (560), 479–501.

A Sample Screenshots and Instruction

In this section, we include the instruction for the treatment order T1-T2, and a sample screenshot for the experiment. Instructions for other treatment orders are similar to the reported one except that the distribution of endowments are different.

Instructions

Overview

Welcome to this experiment in the economics of decision-making. You are guaranteed $7 for showing up and completing this experiment. These instructions explain how you can earn additional amounts of money from the decisions that you make in today's session. There is no talking for the duration of this session. Please silence all mobile devices. If you have a question, please raise your hand and your question will be answered in private.

Today's session consists of two parts. These instructions are for the first part. After completing the first part of the experiment, you will receive instructions for the second part. At the end of the second part you will be paid your earnings from both parts together with your $7 show-up payment in cash and in private.

Part One Instructions

The first part of today's experiment involves two "sequences". Each sequence consists of 25 "periods" of decision-making. At the start of each period you are endowed with a certain number of "tokens." The exact number of tokens given to you in each of the 25 periods of a sequence is shown in Table 1 and is graphed in Figure 1. Please take a moment to look at this sequence of tokens that you will be given. Notice that in some periods, you are given a large number of tokens while in other periods you are given a small number of tokens. The number of tokens you are given each period will also be indicated on your computer screen. In addition to the tokens you are given each period you may have additional tokens that you have saved from prior periods which earn interest in terms of additional tokens as explained below. After viewing the *total* number of tokens you have available --the amount you are given for the period and your tokens from savings and interest-- you must decide how many of these tokens you wish to convert into money for the period. You can convert any number of tokens from 0 up to the maximum total tokens you have available in each period, and you can choose to convert fractions of tokens up to four decimal places. If the 25th period has not yet been reached, then any remaining tokens that you do not convert into money will be saved for your use in later periods, and these savings will earn interest in the form of additional tokens available to you in these later periods as explained in more detail below. In the 25th period, any tokens that you do not convert into money will become worthless.

Your earnings for each period depend on the number of tokens that you convert into money in that period and are shown in Table 2 and graphed in Figure 2. Notice several things. First, only some token amounts that you may wish to convert into money are shown, e.g., 0, 100,…,500,…2000,…10,000. The precise formula used to determine your earnings (in dollars) from converting tokens into money is given at the bottom of Table 2. Second, notice that the more tokens you convert, the greater are your money earnings for that period. Finally, notice also that the money you earn from converting tokens is proportionally *diminishing*; the difference in your money earnings from converting 500 rather than 400 tokens is larger than the difference in your money earnings from converting 1500 rather than 1400 tokens.

At the start of all 25 periods in a sequence you receive some number of tokens as reported in Table 1 and Figure 1. In addition, in periods 2,…25, you may have *additional* tokens available to you depending on whether you have saved any tokens in prior periods; in that case, you will also receive interest on those savings paid to you in additional tokens. Specifically, you will earn an interest rate of 10 percent per period, paid to you in additional tokens, at the start of the next period. Thus, if in this period you saved $S>0$ tokens, then at the start of the next period you would have $S+ (S \times .10)$ (equivalently $(1.10)\times S$) tokens available to you in addition to the tokens you receive at the start of each new period as given in Table 1. Table 3 shows how various token amounts saved (S) in one period result in additional token amounts of $(1+.10)\times S$ in the following period.

Thus at the start of every period you may have some tokens available to you. Your decision screen will report this total available token number to you, breaking it down according to:

1) Token endowment this period: as given in Table 1.
2) Tokens saved from the last period: S
3) Interest earned on tokens saved from last period savings: $S \times .10$

The total tokens you have available to convert into money or to save in the current period will be the sum of these three numbers.

Your Decision

Type the number of tokens you wish to convert into money (up to four decimal places) in the input box on your decision screen. You may refer to Table 2 and Figure 2 to understand how your token conversion decision determines your earnings, but you can also use the calculator on the top left part of this decision screen to determine how your token conversion decision will translate into money this period. Once you have entered your choice click the Submit button to confirm your choice. You can change your mind anytime prior to clicking the Submit button.

Once the first 25-period sequence is completed, you will begin playing a second 25-period sequence. The second sequence will be just like the first sequence in that you will again receive the same endowment of tokens in each of the 25 periods as indicated in Table 1 and Figure 1 and you will again make token conversion decisions each period as before. Table 2, Figure 2 and Table 3 will continue to apply for determining your money earnings and how saving decisions determine additional tokens.

Information

Following the first period of a sequence, and after every period thereafter, you will be reminded of the total tokens you initially had available at the start of the period, your token conversion decision, your saved tokens, your money earnings for the period as well as your cumulative total money payoff for the current 25-period sequence. Please record this information on your Record Sheets under the appropriate headings. For your convenience, a complete history of this information will be provided at the bottom of your decision screen (following the first period of each sequence).

Earnings

After the second 25-period sequence has been completed, we will randomly select *one* of the two 25-period sequences you played. Both sequences have an equal chance of being chosen. Your cumulative money earnings from the one chosen sequence will comprise your earnings for this first part of today's experiment.

Questions? Now is the time for questions. If you have a question, please raise your hand and the experimenter will answer your question in private.

Quiz

Before continuing on to the experiment, we ask that you complete the following quiz for the part one instructions. In answering these questions, you may consult the instructions, tables and figures. Your performance on this quiz does not affect your payoff in any way. Write or circle your answers to the quiz questions as indicated. Do not put your name on this quiz. If any questions are answered incorrectly, we will go over the relevant part of the instructions again.

1. In part one you will participate in ______ sequences. Each sequence consists of _____ periods.

2. Suppose it is period 1. What is the maximum number of tokens that you can convert into money this period? _______. What is the minimum number of tokens you can convert into money this period? ______.

3. Suppose it is period 10. What is your endowment of tokens in this period? ______ If, in period 9 your savings was 1,000 tokens, how many *total* tokens, including savings, interest earnings and your endowment of tokens for period 10 will you be able to convert into money in period 10? ______.

4. Suppose it is period 20. What is your endowment of tokens in this period? ______ If, in period 19 your savings was 7,000 tokens, how many *total* tokens, including savings, interest earnings and your endowment of tokens for period 20 will you be able to convert into money in period 20? ______.

5. Suppose it is period 25. If you choose to save some of your tokens in period 25, will they have any future value to you? Circle one Yes No.

6. True or false: Your earnings will depend on your cumulative money earnings from one of the two 25-period sequences you play, but you will not know which sequence will be chosen until the end of the session. Circle one: True False

Table 1: Endowment of Tokens	
Period	Tokens You are Given
1	500
2	500
3	500
4	500
5	500
6	500
7	500
8	500
9	500
10	500
11	500
12	500
13	500
14	500
15	500
16	500
17	500
18	200
19	200
20	200
21	200
22	200
23	200
24	200
25	200

Table 2: Token Conversions and Money Earned	
Tokens Converted	Money Earnings for the Period
0	0.00
100	0.14
200	0.22
300	0.28
400	0.32
500	0.36
600	0.39
700	0.42
800	0.44
900	0.46
1000	0.48
1100	0.50
1200	0.51
1300	0.53
1400	0.54
1500	0.55
1600	0.57
1700	0.58
1800	0.59
1900	0.60
2000	0.61
3000	0.69
4000	0.74
5000	0.79
6000	0.82
7000	0.85
8000	0.88
9000	0.90
10000	0.92

Money=$ 0.2*ln(0.01*Tokens Converted+1)

Table 3: Savings and Interest		
Tokens Saved	Interest Earned in Tokens	Savings+Interest in Tokens
0	0	0
100	10	110
200	20	220
300	30	330
400	40	440
500	50	550
600	60	660
700	70	770
800	80	880
900	90	990
1000	100	1100
1100	110	1210
1200	120	1320
1300	130	1430
1400	140	1540
1500	150	1650
1600	160	1760
1700	170	1870
1800	180	1980
1900	190	2090
2000	200	2200
3000	300	3300
4000	400	4400
5000	500	5500
6000	600	6600
7000	700	7700
8000	800	8800
9000	900	9900
10000	1000	11000

Interest (in Tokens)=0.1*Tokens Saved

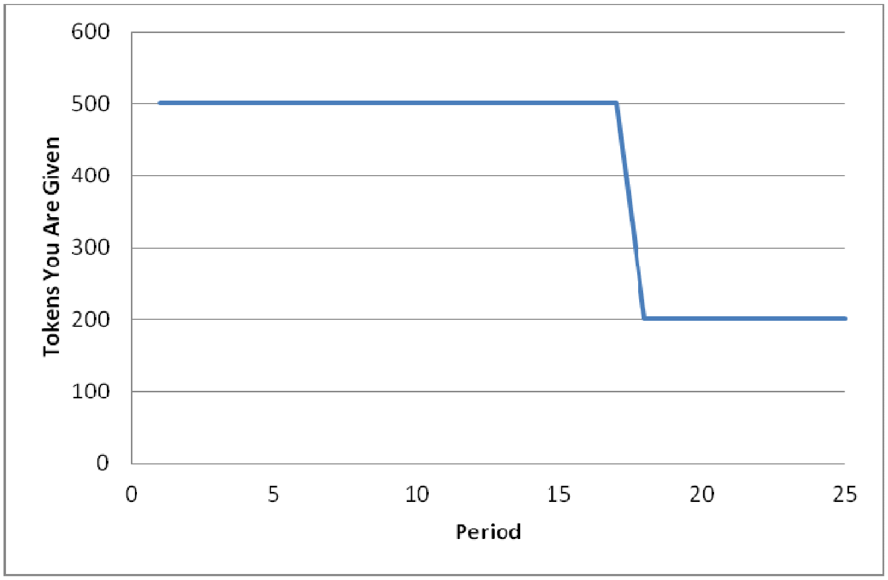


Figure 1: Token You are Given by Period

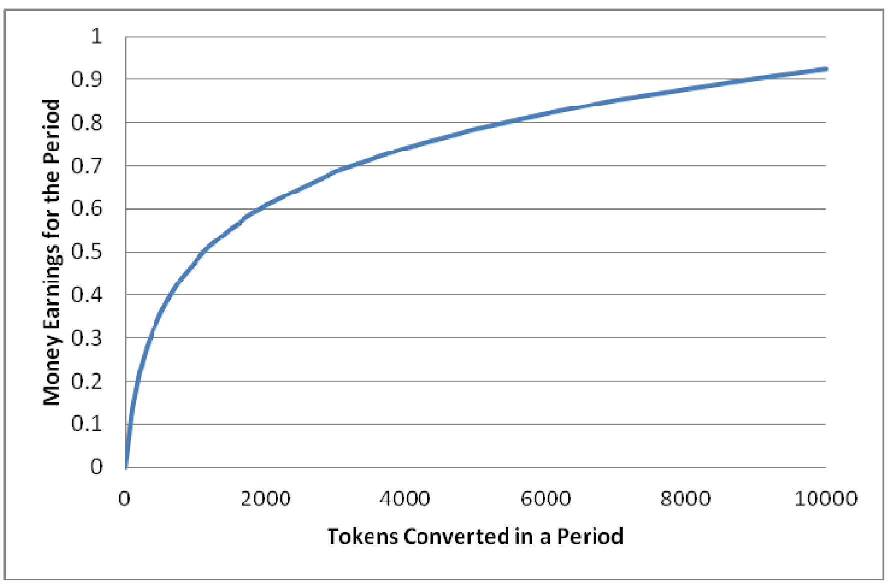


Figure 2: Token Conversions and Money Earned

Record Sheet Part 1 Player ID _________ Age _______ Sex(Circle) F M

Sequence	Period	Initial Total Tokens at the Start of this Period	Number of Tokens You Converted this Period	Number of Tokens You Saved this Period	Money Earned for this Period	Cumulative Money Earnings as of this Period
1	1					
1	2					
1	3					
1	4					
1	5					
1	6					
1	7					
1	8					
1	9					
1	10					
1	11					
1	12					
1	13					
1	14					
1	15					
1	16					
1	17					
1	18					
1	19					
1	20					
1	21					
1	22					
1	23					
1	24					
1	25					

Record Sheet Part 1 Player ID _________ Age _______ Sex(Circle) F M

Sequence	Period	Initial Total Tokens at the Start of this Period	Number of Tokens You Converted this Period	Number of Tokens You Saved this Period	Money Earned for this Period	Cumulative Money Earnings as of this Period
2	1					
2	2					
2	3					
2	4					
2	5					
2	6					
2	7					
2	8					
2	9					
2	10					
2	11					
2	12					
2	13					
2	14					
2	15					
2	16					
2	17					
2	18					
2	19					
2	20					
2	21					
2	22					
2	23					
2	24					
2	25					

Instructions, Continued

Part Two Instructions

The second part of today's experiment is similar to the first part and involves two more 25-period sequences of decision-making. At the start of each period you are again endowed with a certain number of tokens and must again decide how many of your total available tokens you wish to convert into money each period. The only difference from the first part is that in this second part of the experiment, the number of tokens given to you in each of the 25 periods of a sequence is *different* from before and is now shown in Table 4 and graphed in Figure 3. Please take a moment to look at this new sequence of token amounts. Notice that in some periods you are given a large number of tokens while in other periods you are given 0 tokens. The number of tokens you are given in each of the 25 periods will again be indicated on your computer screen. As in the first part, in addition to the tokens you are given each period you may have additional tokens that you have saved from prior periods which earn interest at the same rate of 10 percent as in the first part. After viewing the *total* number of tokens you have available -- the amount you are given for the period and your tokens from any prior period savings and interest-- you must decide how many of these tokens you wish to convert into money for the period. You can convert any number of tokens from 0 up to the maximum total tokens you have available for that period, and you can choose to convert fractions of tokens up to four decimal places. If the 25th period has not yet been reached, then the remaining tokens that you do not convert into money will be saved for your use in later periods, and these savings will earn 10 percent interest per period in the form of additional tokens available to you next period just as in the first part. In the 25th period, any tokens that you do not convert into money will become worthless.

The amounts of money you can earn from converting tokens each period is the *same* as in the first part and thus continues to be given by Table 2 for certain possible token conversion amounts and is graphed in Figure 2. (These are reprinted below). As before, a calculator is available on the top left side of your decision screen to help you determine how your token conversion decisions translate into money earnings each period. As noted above, the interest rate on savings remains the same at 10 percent per period, so that Table 3 (also reprinted below) continues to reveal how various token amounts saved this period earn interest for you in terms of additional tokens next period.

As in the first part you will complete two, 25-period sequences of decision-making. The second sequence will be just like the first sequence in that you will continue to receive the same endowment of tokens in each of the 25 periods as now indicated in the new Table 4 and you will make token conversion decisions each period just as before.

To reiterate, the *only* change from the first part is that the endowments of tokens that you are given in each of the 25 periods of each sequence in this second part of the experiment are *different* and are now given in the new Table 4.

Information

Following the first period of a sequence, and after every period thereafter, you will again be reminded of the total tokens you initially had available at the start of the period, your token conversion decision, your saved tokens, your money payoff for the period as well as your cumulative total money earnings for the current 25-period sequence. Please record this information on your Record Sheets under the appropriate headings. For your convenience, a complete history of this information will be provided at the bottom of your decision screen (following the first period of each sequence).

Earnings

After the second 25-period sequence has been completed, we will randomly select *one* of the two 25-period sequences you played. Both sequences have an equal chance of being chosen. Your cumulative money earnings from the one chosen sequence will comprise your earnings for this second part of today's experiment.

Following the completion of this second part, the experiment will be over. You will be paid your earnings from the first and second parts together with your $7 show-up payment in cash and in private.

Questions?

Now is the time for questions. If you have a question, please raise your hand and the experimenter will answer your question in private.

.

Table 4: Endowments of Tokens	
Period	Tokens You are Given
1	526
2	526
3	526
4	526
5	526
6	526
7	526
8	526
9	526
10	526
11	526
12	526
13	526
14	526
15	526
16	526
17	526
18	0
19	0
20	0
21	0
22	0
23	0
24	0
25	0

Table 2: Token Conversions and Money Earned	
Tokens Converted	Money Earnings for the Period
0	0.00
100	0.14
200	0.22
300	0.28
400	0.32
500	0.36
600	0.39
700	0.42
800	0.44
900	0.46
1000	0.48
1100	0.50
1200	0.51
1300	0.53
1400	0.54
1500	0.55
1600	0.57
1700	0.58
1800	0.59
1900	0.60
2000	0.61
3000	0.69
4000	0.74
5000	0.79
6000	0.82
7000	0.85
8000	0.88
9000	0.90
10000	0.92

Table 3: Savings and Interest		
Tokens Saved	Interest Earned in Tokens	Savings+Interest in Tokens
0	0	0
100	10	110
200	20	220
300	30	330
400	40	440
500	50	550
600	60	660
700	70	770
800	80	880
900	90	990
1000	100	1100
1100	110	1210
1200	120	1320
1300	130	1430
1400	140	1540
1500	150	1650
1600	160	1760
1700	170	1870
1800	180	1980
1900	190	2090
2000	200	2200
3000	300	3300
4000	400	4400
5000	500	5500
6000	600	6600
7000	700	7700
8000	800	8800
9000	900	9900
10000	1000	11000

Money=$ 0.2*ln(0.01*Tokens Converted+1)

Interest (in Tokens)=0.1*Tokens Saved

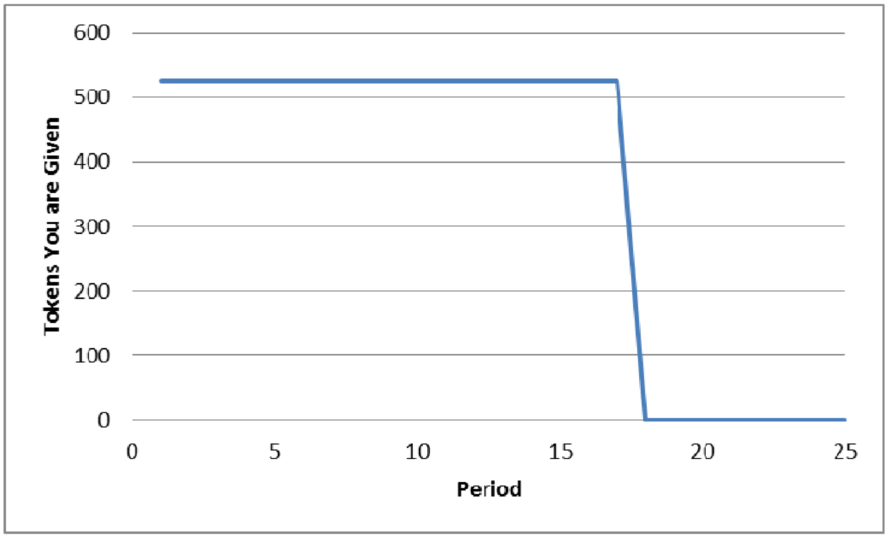


Figure 3: Token You are Given by Period

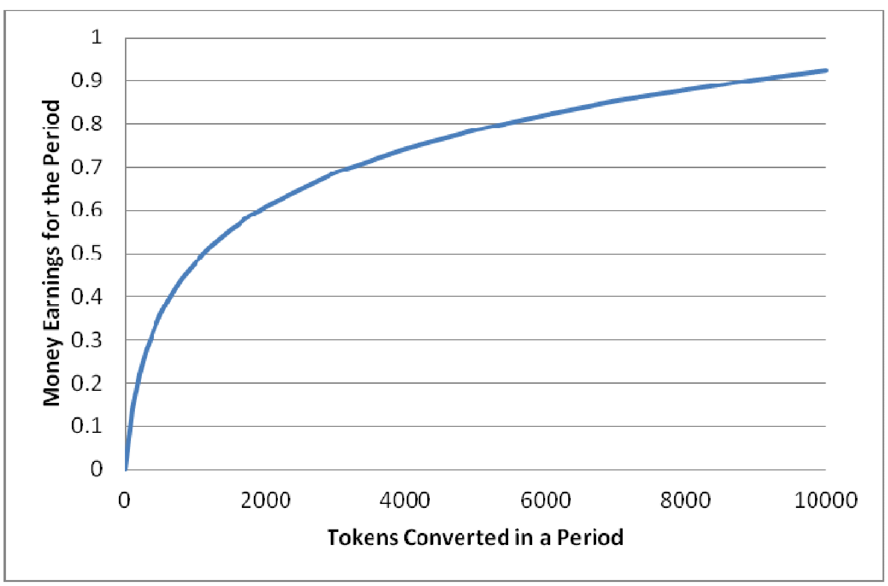


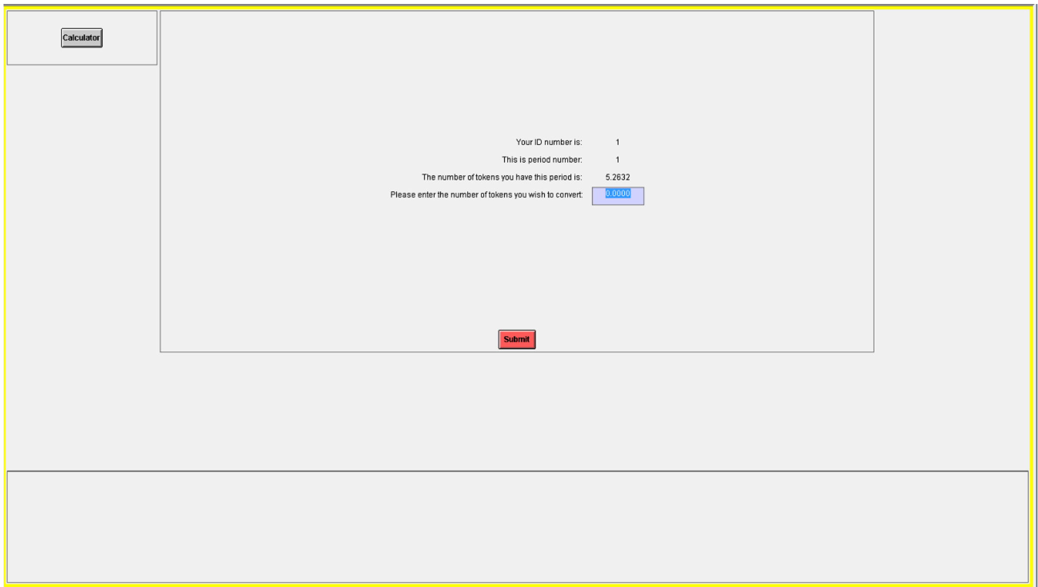
Figure 2: Token Conversions and Money Earned

Record Sheet Part 2 Player ID _________ Age _______ Sex(Circle) F M

Sequence	Period	Initial Total Tokens at the Start of this Period	Number of Tokens You Converted this Period	Number of Tokens You Saved this Period	Money Earned for this Period	Cumulative Money Earnings as of this Period
1	1					
1	2					
1	3					
1	4					
1	5					
1	6					
1	7					
1	8					
1	9					
1	10					
1	11					
1	12					
1	13					
1	14					
1	15					
1	16					
1	17					
1	18					
1	19					
1	20					
1	21					
1	22					
1	23					
1	24					
1	25					

Record Sheet Part 2   Player ID _________   Age _______   Sex(Circle)   F   M

Sequence	Period	Initial Total Tokens at the Start of this Period	Number of Tokens You Converted this Period	Number of Tokens You Saved this Period	Money Earned for this Period	Cumulative Money Earnings as of this Period
2	1					
2	2					
2	3					
2	4					
2	5					
2	6					
2	7					
2	8					
2	9					
2	10					
2	11					
2	12					
2	13					
2	14					
2	15					
2	16					
2	17					
2	18					
2	19					
2	20					
2	21					
2	22					
2	23					
2	24					
2	25					



(a) Decision

(b) Results

Figure A.1: Screenshots in the experiment

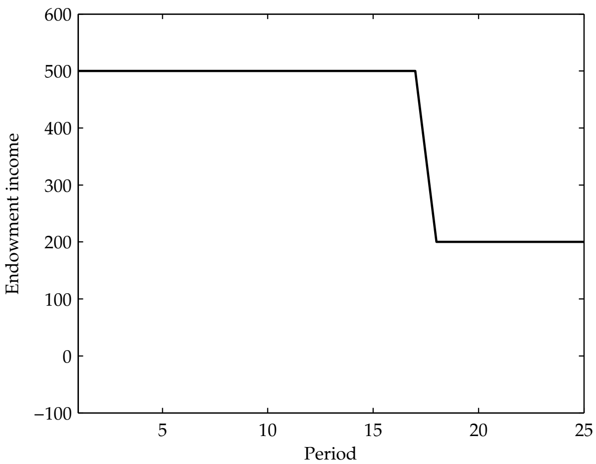
B Tables and Figures of Interest

In this section, we include a few tables and figures that clarify and elaborate upon various aspects of our experiment and analysis. Figure B.1 illustrates the endowment processes for four different treatments; Figure B.2 plots the deviation of consumption and assets from the optimal path by treatment and by sequence. Figures B.3-B.8 report the fitness of the behavioral model with the data for sequences two to four.

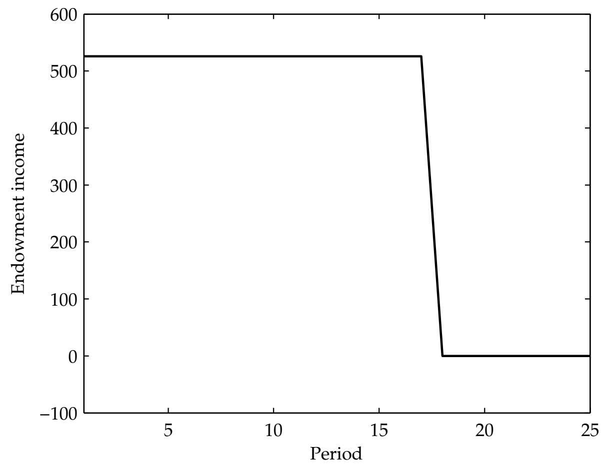
Table B.1: Numbers of observations and average earnings by treatment and by sequence

Panel A: Number of observations				
	T1	T2	T3	T4
S1	27	31	26	26
S2	27	31	26	26
S3	31	27	26	26
S4	31	27	26	26
Panel B: Average Earnings				
	T1	T2	T3	T4
S1	$7.90	$8.44	$8.17	$8.71
S2	$8.48	$8.59	$8.93	$8.86
S3	$8.83	$8.87	$8.19	$8.96
S4	$8.82	$8.71	$8.76	$9.01

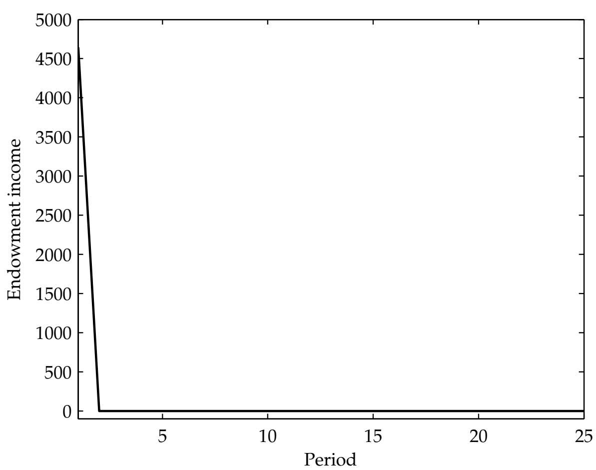
Notes: In each panel, the cell for row i and column j reports the number for sequence i and treatment j.



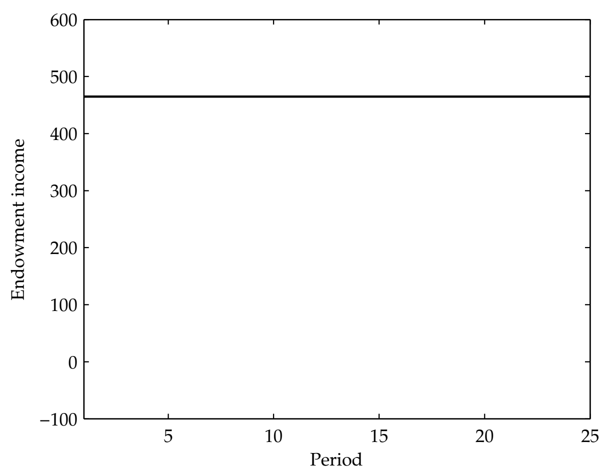
(a) T1



(b) T2

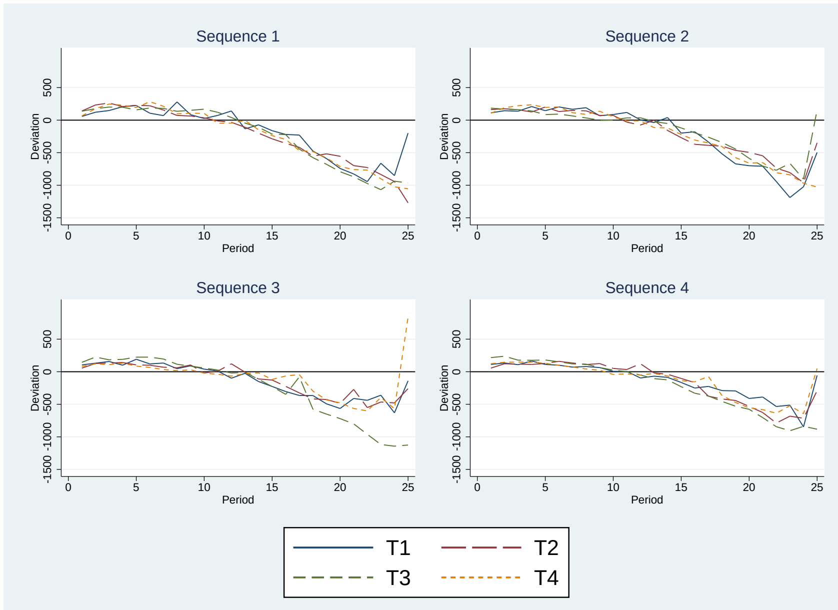


(c) T3

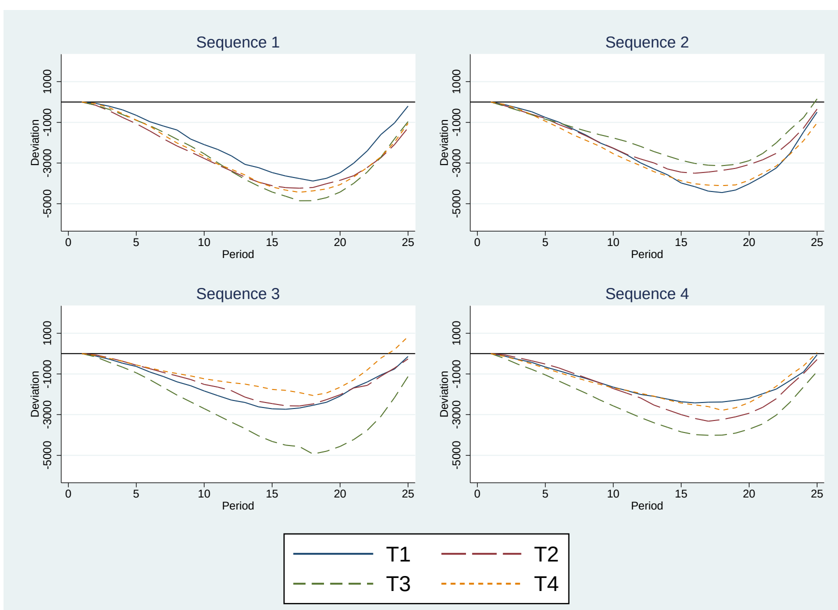


(d) T4

Figure B.1: Endowment income by period

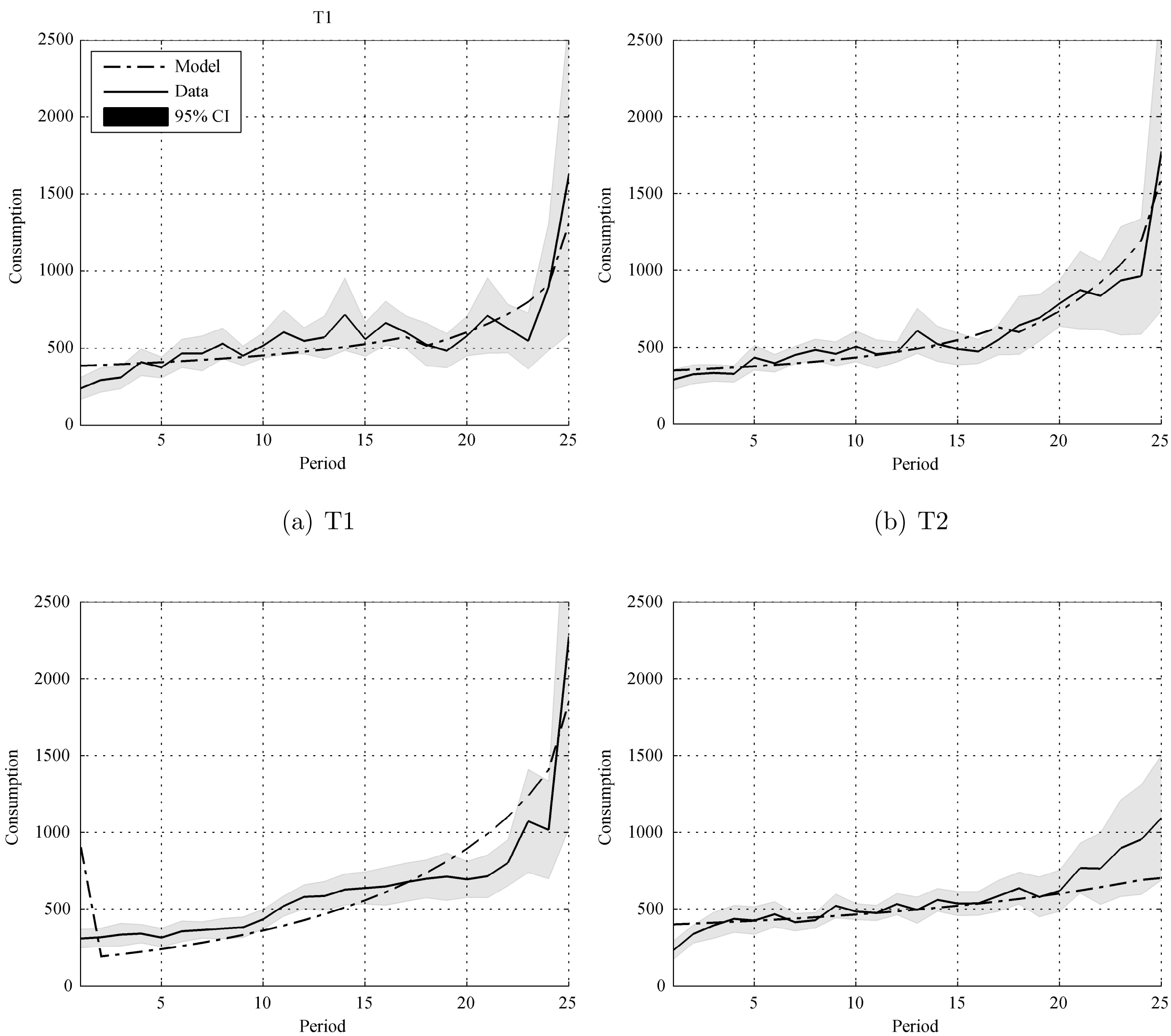


(a) Consumption



(b) Assets

Figure B.2: Average deviation from the optimal path



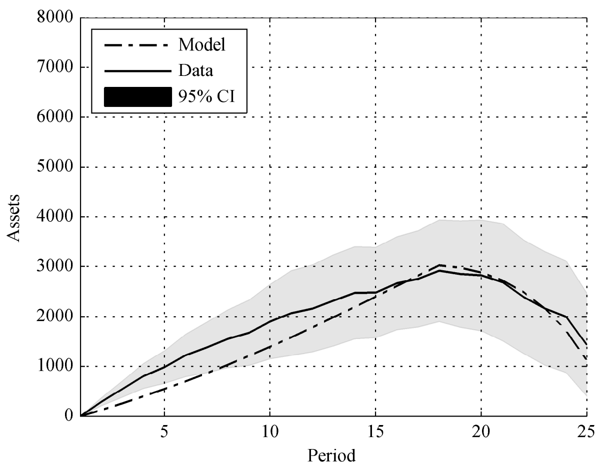
(a) T1

(b) T2

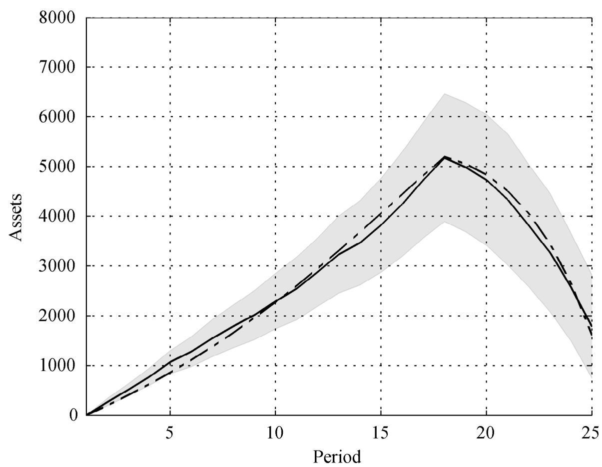
(c) T3

(d) T4

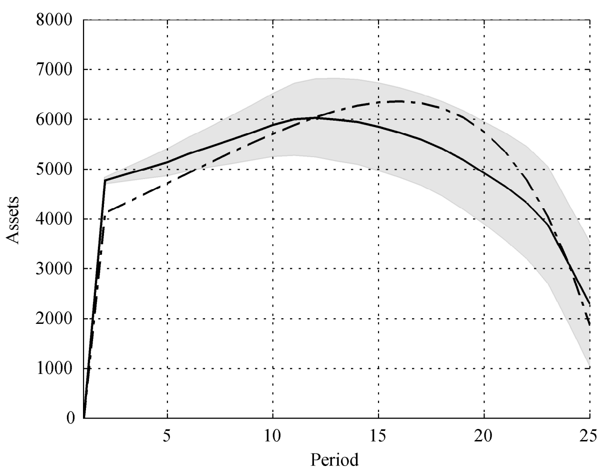
Figure B.3: Average consumption by period in sequence 2



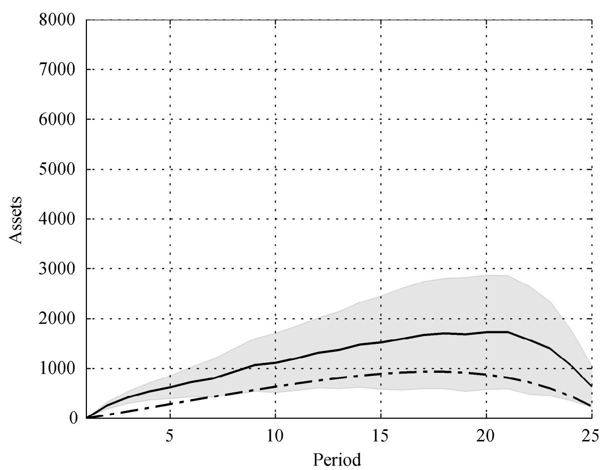
(a) T1



(b) T2

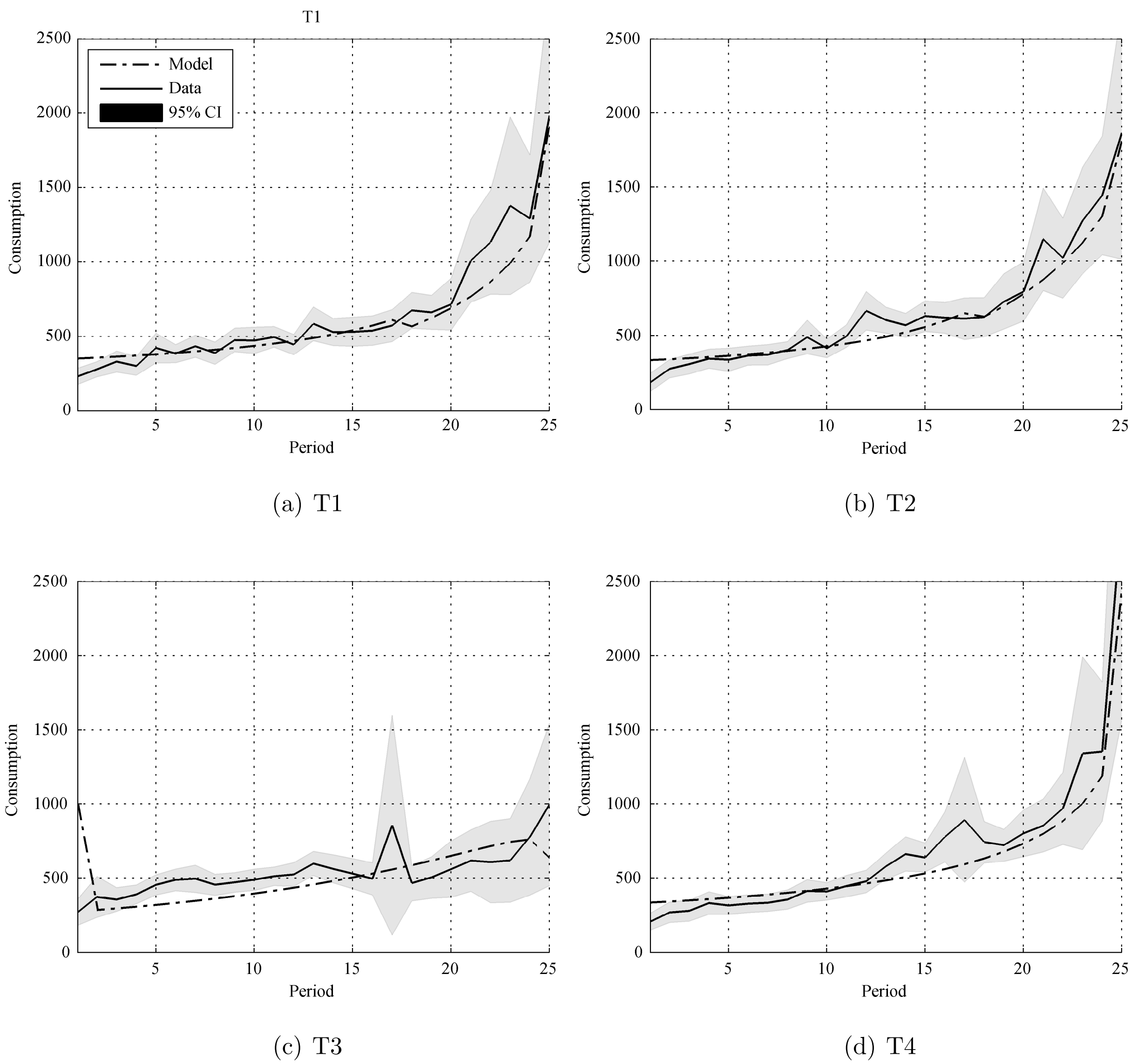


(c) T3



(d) T4

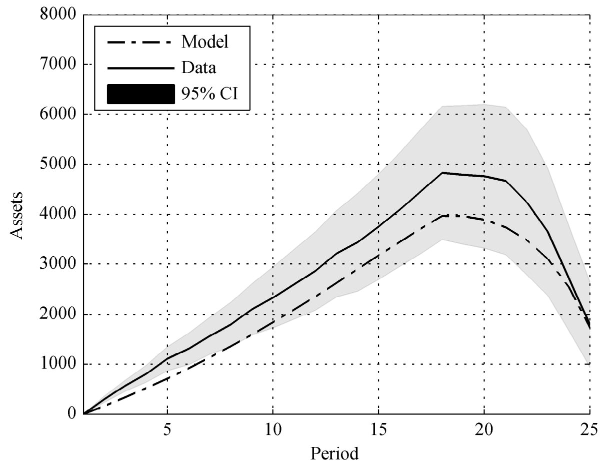
Figure B.4: Average assets by period in sequence 2



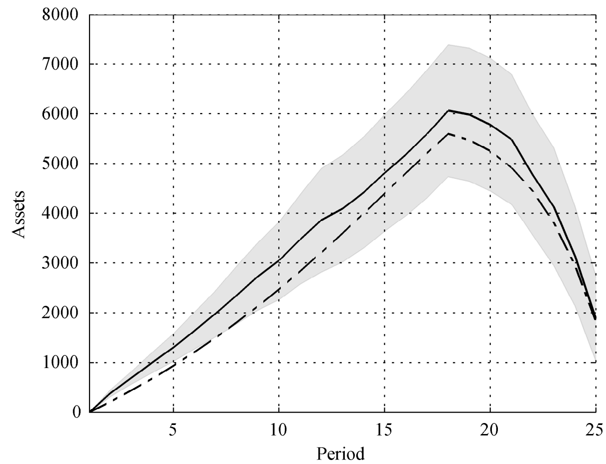
(a) T1 (b) T2

(c) T3 (d) T4

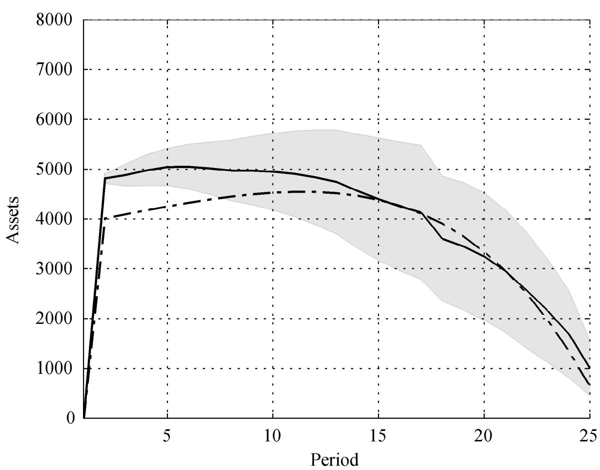
Figure B.5: Average consumption by period in sequence 3



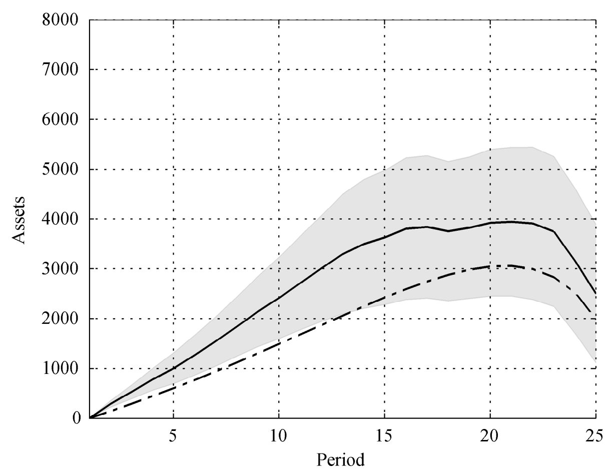
(a) T1



(b) T2

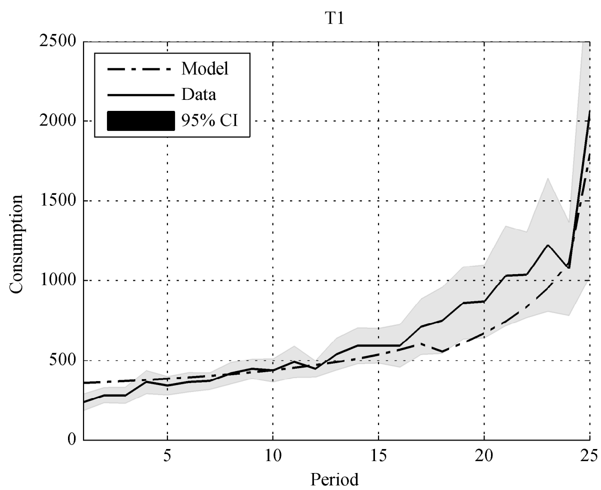


(c) T3

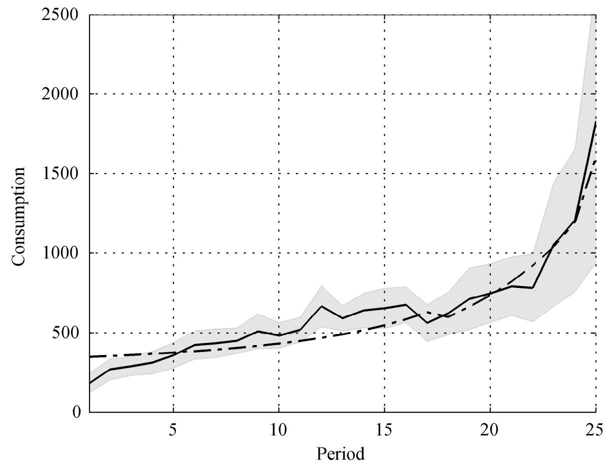


(d) T4

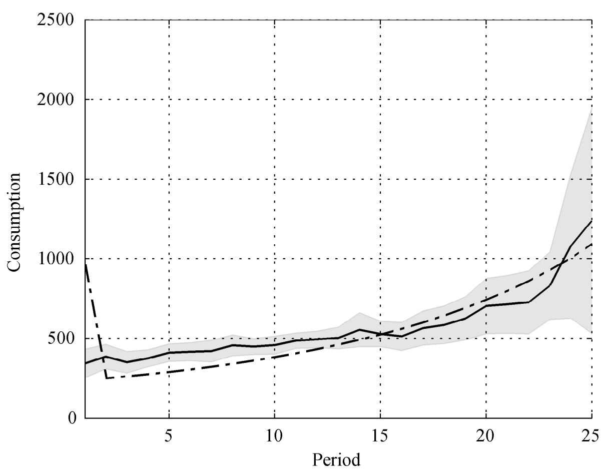
Figure B.6: Average assets by period in sequence 3



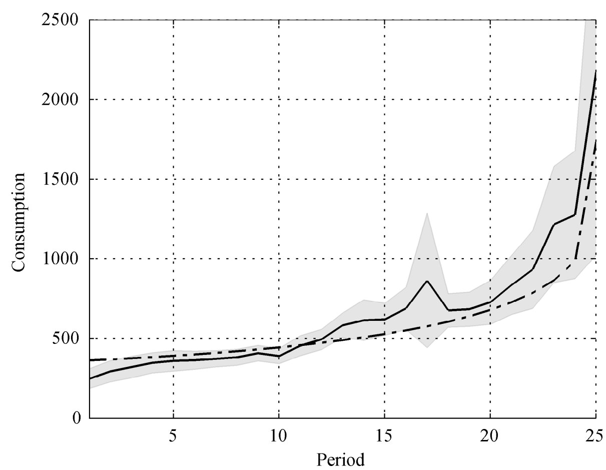
(a) T1



(b) T2

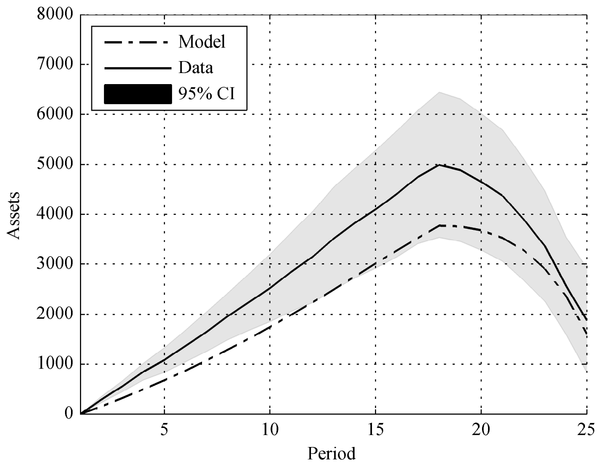


(c) T3

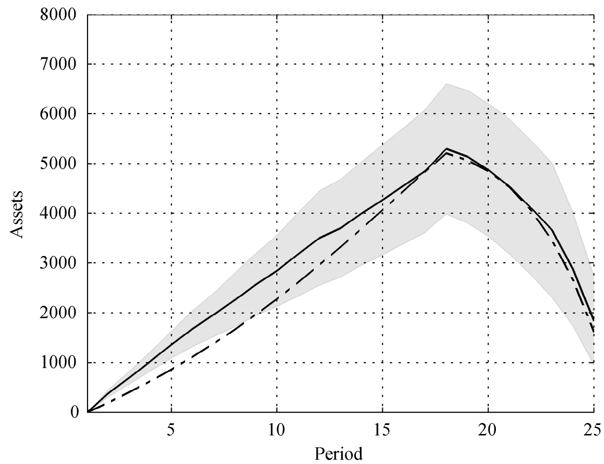


(d) T4

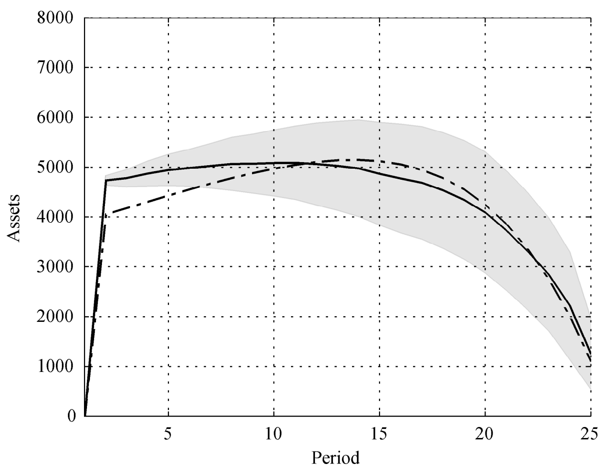
Figure B.7: Average consumption by period in sequence 4



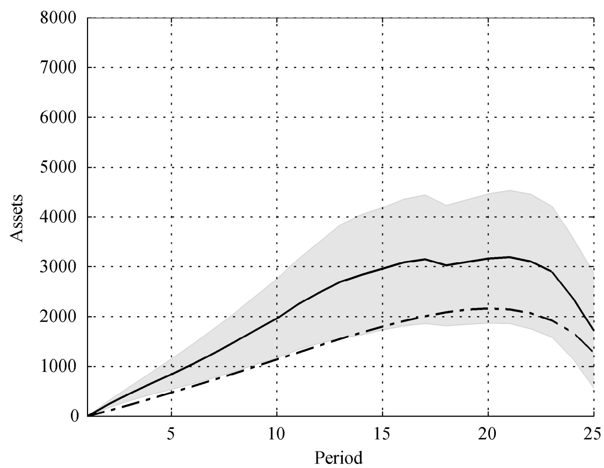
(a) T1



(b) T2



(c) T3



(d) T4

Figure B.8: Average assets by period in sequence 4