Joint vs. Individual Performance in a Dynamic Choice Problem *

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October 2021

Abstract

This paper compares the relative ability of individuals and pairs to solve a finite, stochastic lifecycle problem in order to test the pervasive practice of using individuals as representative decision-makers in dynamic choice experiments. Pairs are significantly better aligned with the rational, representative-agent benchmark than individuals; subjects forming a joint decision earn about 40% more, on average, than subjects making individual decisions. Chat data reveals that pairs mostly discuss spending, rather than saving or borrowing, and adhere to consumption heuristics that are largely invariant to past errors.

JEL classifications: c90, C91, C92, D11, D12, D15, D16, E21

Keywords: Individual Behavior, Group Behavior, Intertemporal Household Choice; Life Cycle Models and Saving, Collaborative Consumption, Consumption; Saving; Wealth

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*We thank Catherine Eckel, Don Koh, John Duffy, Luba Petersen, Sherry Li, and Pete McGee for helpful comments. We thank seminar participants at the 7th Annual TExAS conference and the University of Arkansas for valuable feedback. Finally, we also thank Tenley Getschman and Caleb Hill for outstanding research assistance.

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1 Introduction

Modern macroeconomic theory typically models decision-makers as rational individuals capable of solving complex, dynamic choice problems without influence from, and independent of, other economic agents. Indeed, this representative agent assumption critically influences how monetary and fiscal policy operate in these models. Macroeconomists, who entered the lab in earnest following Lucas (1986), have taken this representative agent assumption seriously when designing experiments to test the micro-foundations of macroeconomic theory (Duffy, 2006).

However, using individuals as representative decision-makers in the lab may not fully capture the behavior modeled in macroeconomic theory. Among the macroeconomic models that do assume a representative household or firm, most do not explicitly rule out the notion of joint decision making within that household or firm. In fact, theory sometimes explicitly models this. For example, many theories include the assumption of multiple decision roles in the household, like the worker-shopper pair introduced by Lucas and Stokey (1987). Suggestive evidence using Panel Study of Income Dynamics (PSID) data shows that there are many households making these sorts of joint decisions and joint-decision households respond quite differently to negative income shocks than individual-decision households.[1] To understand this heterogeneity, it is critical to understand both joint and individual decision-making.

This paper revisits dynamic optimization in the laboratory to explore differences in how individuals and pairs, who form joint decisions, solve dynamic optimization problems. We do this by having either individuals or pairs solve a dynamic optimization problem in a simple, finite-period environment that features a stochastic income process and allows for both borrowing and saving. Pairs in our experiment engage in unrestricted communication via a chat window to form joint decisions.

We find that allowing pairs to communicate to form joint decisions significantly improves decisions, compared to individuals, relative to the rational, representative benchmark. This is true when we measure performance along both the unconditionally- and conditionally-optimal consumption paths. On average, pairs earn about 40% more than individuals after accounting for fixed show-up fees paid to all subjects.

Chat data collected from our pairs treatment provides valuable insight into how subjects in those treatments think through dynamic choice problems. Textual analysis reveals that subjects almost exclusively frame discussions in terms of spending even though saving and borrowing are important components of earnings maximization. Further, subjects develop simple, invariant heuristics that can lead to persistent and compounding errors. This textual analysis corroborates our classification of individuals and pairs into different consumption heuristics.

We find that both pairs and individuals adhere primarily to a constant marginal propensity to consume (MPC) heuristic, but find that pairs have higher MPCs on average. This leads to fewer instances of under-spending, mitigates the compounding nature of conditional errors, and also leads to less severe and less frequent consumption binges relative to individuals.

[1] We provide details about this suggestive evidence in Section 7.4 of the appendix.

Finally, we see that pairs often include a participant who nudges the initial joint decision toward the rational benchmark, most often by advocating for higher spending.

2 Literature Review

There is an extensive literature, thoroughly discussed in Duffy (2016) and summarized here, that studies the ability of individuals to solve dynamic stochastic optimization problems.

Hey and Dardanoni (1988) study dynamic optimization in a pure exchange economy in which individual subjects, acting as representative agents, earn a constant return on savings, face a no-borrowing constraint, and receive a per-period stochastic income. They find that consumption decisions deviate significantly from the theoretically optimal decisions. Carbone and Hey (2004) and Carbone (2006) simplify this design by eliminating discounting, using a finite-horizon, 25-period-model, and by simplifying the stochastic income process by using a two-state Markov process to determine whether a subject is employed and receives and income or is unemployed and does not. They find that subjects overreact to an increased probability of remaining employed, under-react to the probability of becoming employed, are myopic, and that current consumption is too dependent upon current income. Carbone and Infante (2014) study behavior in a dynamic optimization game under certainty, risk, and ambiguity. The authors find that subjects significantly under consume when faced with ambiguity relative to risk and certainty. Neugebauer, Carbone, and Hey (2020) study consumption smoothing in a Lucas Tree model where subjects trade consumption claims via a long-lived asset, with an alternative solution, where agents can trade short-lived consumption claims between periods. They find the exchange economy with short-lived assets is more efficient in encouraging consumption smoothing.

Others have studied various types of learning in dynamic optimization by allowing individual decision-makers to interact in various capacities. Ballinger, Palumbo, and Wilcox (2003) provide evidence in support of inter-generational learning in the context of dynamic choice via a 60-period life-cycle problem under income uncertainty. The authors grouped subjects into three-member "families" and randomly assigned each family member to either the first, second, or third generation. Members of the first generation had no opportunity to learn. However, members of subsequent generations could both observe and communicate with members of the previous generation for several periods before beginning to make their own decisions. This generational transmission of information improves decisions of subsequent generations. Our study differs from theirs in that subjects in our Pairs treatments do not pass along knowledge but instead work together to generate knowledge, and our Pairs subjects form joint decisions and share the payoff of this joint decision.

Brown et al. (2009) show that allowing for social learning improves the speed of own-learning compared to rates of own-learning from subjects in private-learning treatments. In contrast, Carbone and Duffy (2014) show that revealing the average level of past consumption causes subjects to deviate further from both the conditionally- and unconditionally optimal consumption path. Bao, Duffy, and Hommes (2013) show that pairing subjects together and having each subject either forecast or optimize leads to quicker convergence to the rational expectations equilibrium than does having a single subject perform both tasks.

Duffy and Orland (2020) test a buffer stock model in the lab and show that imposing liquidity constraints does not increase savings but higher income variation does.

Ubiquitous across these previous studies is the use of individual decision-makers. However, there are also studies comparing the behavior of groups in macroeconomic settings. For example, Blinder and Morgan (2005) show that groups outperform individuals setting monetary policy to maintain to stabilize an experimental economy around inflation and employment targets. This finding was corroborated by Lombardelli et al. (2005) who also show that groups outperform individuals as policymakers because groups can strip out the effect of bad play in a given period, and because group members are able to share information and learn from each other's interest rate decisions. Similarly, Rholes and Petersen (2020) show in a learning-to-forecast experiment that aggregating over group expectations produces more stable inflation dynamics than do individual expectations.

Most closely related to our work are Carbone and Infante (2015), and Carbone, Georgalos, and Infante (2019), which both study differences between pairs and individuals in a dynamic optimization setting. Carbone and Infante (2015) conclude that stable pairs perform no differently than individuals in solving the life cycle problem once experienced and that pairs with rematching perform worse than individuals. We find the opposite − stable pairs in our experiment consistently outperform individuals as planners, even after gaining experience. Carbone, Georgalos, and Infante (2019) compare group and individual performance in an optimization task while facing either risk or ambiguity and find that groups are better planners under ambiguity but individuals are better planners under risk. Because the support and distribution of the stochastic income process in our environment are known to our subjects, our setting best matches decisions under risk. Thus, our results again differ in that groups in our environment consistently outperform individuals.

A possible explanation for these differing results is that differing experimental designs lead to different levels of complexity. Both Carbone and Infante (2015), and Carbone, Georgalos, & Infante (2019) consider an environment that includes a positive interest rate, does not allow borrowing within a period, and features a bimodal income distribution. The confluence of these design choices yields an environment in which it is optimal for subjects to accumulate wealth and increase spending toward the end of the lifecycle.

Finally, we also contribute to the extensive literature that studies differences between groups and individuals. Examples are Cooper and Kagel (2005) who find that teams play more strategically than individuals and Kugler, Bornstein, Kocher, and Sutter (2007) who have show groups are less trusting than individuals but are equally trustworthy. Charness and Sutter (2012), note that group choices better align with standard game-theoretic predictions and Kagel and McGee (2016) who show that, with experience, teams cooperate more than individuals in prisoner's dilemma games.

3 Theory

Subjects in both our Individual and Pairs treatments maximize their discounted lifetime utility, subject to an intertemporal budget constraint:

$$max\ \mathbb{E}_0 \sum_{t=1}^{t=T} \beta^t U(c_t) \tag{1}$$

$$s.t.\ \sum_{t=1}^{t=T} c_t \leq \sum_{t=1}^{t=T} w_t + a_0 \tag{2}$$

where c_t is consumption, a_0 is initial wealth, and w_t is an i.i.d. per-period stochastic income with $w \sim U\{\underline{w}, \overline{w}\}$.[2] Subjects in our experiment save freely and borrow up to $\underline{w}$ in all but the final decision period. We denote saving and borrowing throughout as s_t.

We induce the quadratic utility function

$$U(c_t) = \phi c_t - \frac{1}{2} c_t^2. \tag{3}$$

This functional form is useful for several reasons. First, it allows subjects to consume zero in any period without incurring negative utility. Second, it is concave across the action space, which induces a consumption smoothing motive.[3] Finally, combining this functional form with equations above yields Hall's (1978) stochastic equation:

$$c_t = (1 - \kappa)\phi + \kappa \mathbb{E}_t c_{t+1} \tag{4}$$

where $\kappa \equiv \beta(1+r)$. Setting $\beta = 1,\ r = 0$ allows us to reduce Equation (4) to the consumption Euler equation:

$$c_t = \mathbb{E}_t c_{t+1}. \tag{5}$$

Solving by backward induction yields our unconditionally-optimal consumption path [4]

[2]Income is drawn from a discrete uniform distribution so that per-period income is always an integer value.

[3]Restrictions on ϕ are such that, across the feasible action space, the first derivative of $u(c_t)$ is strictly positive and the second derivative is strictly negative. This means that subjects in our experiment can never consume beyond the bliss point regardless of how much wealth they accumulate.

[4]Notice that if $r > 0$ then per-period consumption is lower and per-period savings are higher in most periods. This might lead to behavior similar to that found in Carbone and Infante (2015).

$$c_{T-j} = \begin{cases} y_{T-j} + s_{T-j-1}, & j = 0 \\ \frac{j}{j+1}\mu + \frac{j-1}{j+1}(y_{t-j} + s_{t-j-1}), & j \in (1, 2, ..., T-1) \end{cases}$$

This solution indicates that optimal consumption is a linear function of the mean of the income distribution, μ, and period wealth. Intuitively, subjects should focus less on the income distribution and more on wealth as the game nears completion. We plot the unconditionally-optimal consumption path alongside the income processes used in all experimental sessions in Figure 1. The unconditionally-optimal path is the same for all subjects because we hold the stochastic income processes constant across all subjects.

We also consider subjects' decisions relative to a conditionally-optimal level of consumption, $\hat{c_t^*}$, which accounts for past consumption errors by recalculating optimal consumption for each remaining period conditional on past mistakes.[5]

$$\hat{c_t^*} = c_t^* + \frac{(y_t - c_t^*) + s_{t-1}}{T - (t-1)}, \; \forall \; t \; \in \; \{2, ..., T-1\} \tag{6}$$

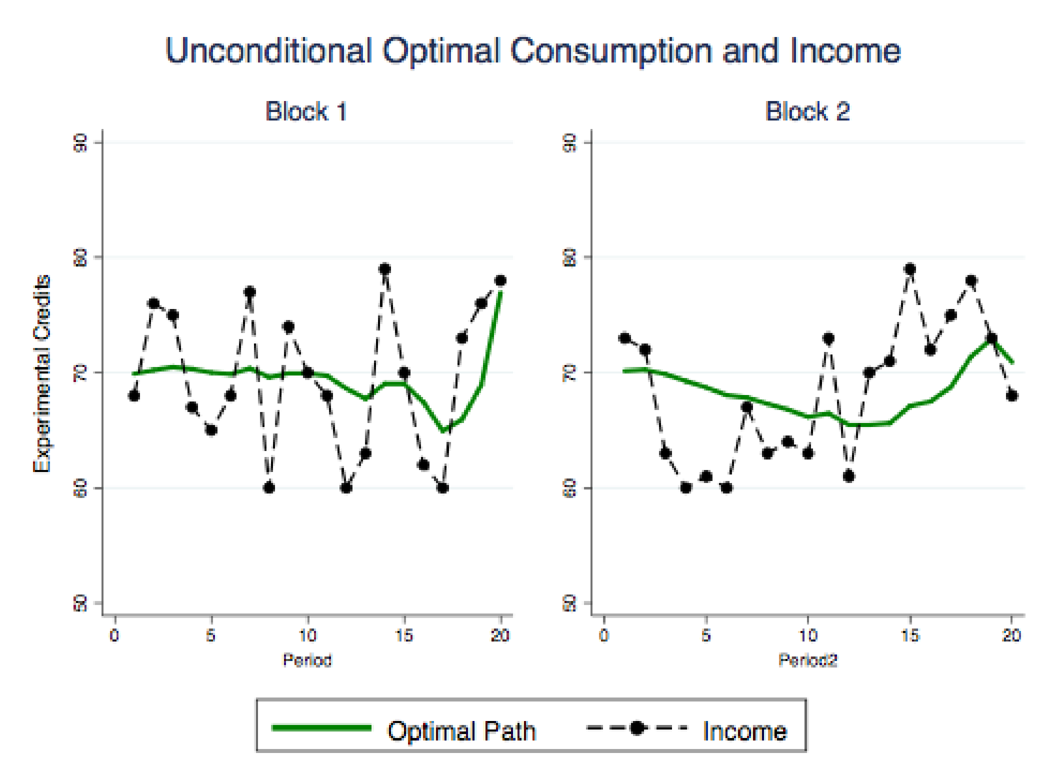

Figure 1: This figure shows the unconditionally-optimal consumption path for decision blocks 1 and 2 of all experimental sessions. The graph also includes the pre-drawn stochastic income processes used for blocks 1 and 2 in all experimental sessions.

[5]We do not plot the conditionally-optimal path here since it depends on individual deviations from the unconditionally-optimal consumption path.

4 Experimental Design

We use a simple 2×1, between-subjects design built around a standard learning-to-optimize (LTO) framework where we compare the ability of individuals and pairs to solve two different twenty-period decision blocks of the finite-period smoothing problem outlined in Section 3. We set $\phi = 1,600$, $\overline{w} = 80$, $\underline{w} = 60$, $\beta = 1$, $r = 0$ for all sessions. The consumption smoothing motive in our setting comes from the concavity of the induced quadratic utility function. Subjects spent, saved, and borrowed per-period income, allotted as experimental credits (ECs) according to two pre-drawn stochastic income processes. Importantly, subjects received consumption points in each period equivalent the consumption utility resulting from their consumption decision in that period. Using pre-drawn income processes allowed us to hold the income process constant across treatments for each decision block.

Sessions began with a 6-question, individual-level Cognitive Reflection Test (CRT) introduced by (Frederick, 2005) , also adopting questions from the Cognitive Reflection Test-Long (CRT-L) developed by (Primi et al., 2016). Subjects had 90 seconds to answer each CRT question and earned \$.25 for each correct answer. We followed this with an individual-level Eckel-Grossman test of risk preferences (Eckel and Grossman, 2002). Following these two tasks, subjects in individual sessions worked alone to solve both lifecycle problems. For the Pairs treatment, we randomly matched individuals into stable pairs and allowed them to engage in unrestricted chat to solve the lifecycle problems. Pairs had to reach a consensus to enter a consumption decision. Subjects were not time-constrained when solving the lifecycle problem in either treatment. All subjects were undergraduate students recruited at the University of Arkansas.[6] We ended each session with a demographic survey that also included a survey of attitudes toward debt and spending.

Instructions provided detailed information about the utility function, income process, lifecycle duration, and borrowing and saving so that they had sufficient information to fully solve the lifecycle problem. Further, we provided subjects with information about their per-period income, and their current bank account balance to help them keep track of their borrowing/savings. We also provided subjects with a consumption smoothing tool to reduce the cognitive complexity of the problem. To use the tool, subjects could propose a hypothetical level of consumption and learn the corresponding levels of utility (we called these consumption points in the game), savings or debt, and the marginal utility of consumption (we called this the 'marginal increase' in the game). Subjects could use this tool as many or as few times as desired. We provide an example of the decision screen for an individual in Figure 5 and for pairs in Figure 6 in Section 7.1 of the Appendix.

We converted individual consumption points to U.S. dollars at 50 points per \$1 and pair consumption points at of 25 points per \$1.[7] This conversion scheme holds individual-level incentives constant across treatments. Subjects also received a \$10 show-up fee. We conducted all sessions at the University of Arkansas's Behavioral Business Research Laboratory. All subjects were undergraduates and were inexperienced. We have 26 individual observations

[6] IRB protocol #: 1908210566

[7] We rounded payoffs to the neat highest point. For example, a score of 51.4 points would earn an individual \$1.04.

and 27 pair observations, thus we had 80 total subjects.[8] We implemented our experiment using zTree (Fischbacher, 2007). We conducted all experimental sessions in the Business Behavioral Research Lab at the University of Arkansas using undergraduate student subjects.

5 Results

We show treatment-level mean absolute unconditional and conditional consumption errors by period and treatment in panels (a) and (c) of Figure 2, respectively.[9] We also show the difference in treatment-level mean absolute unconditional and conditional consumption errors in panels (b) and (d) of the same figure. For panel (b) and (d), observations above the x-axis denote an instance where pairs outperformed individuals. Visually, it appears that pairs outperform individuals in solving the finite life-cycle problem along both optimal consumption paths.

We confirm this result using both Mann-Whitney U tests and 2-sample t-tests. The null hypothesis for our Mann-Whiteny U test is that absolute consumption errors for pairs and individuals are drawn from the same distribution. The null hypothesis for out 2-sample t-test is that the mean difference of absolute consumption errors of individuals and pairs is zero. Results of both statistical tests are summarized in Table 1, which reports p-values for each test for each error type. We conduct statistical tests for each decision block independently and also for decisions from both blocks pooled together. We find that pairs significantly outperform Individuals regardless of test, data sample, or consumption path considered.

	Summary of Statistical Tests					
	Unconditional Absolute Error			**Conditional Absolute Error**		
	Block 1	**Block 2**	**Pooled**	**Block 1**	**Block 2**	**Pooled**
Mean Error - I	34.62	35.93	35.27	54.70	61.43	58.02
Mean Error - P	22.94	28.03	25.49	32.96	37.55	35.25
Mann-Whitney U	0.00	0.07	0.00	0.00	0.00	0.00
2-Sample t-test	0.00	0.02	0.00	0.00	0.00	0.00

Table 1: This table reports p-values from both Mann-Whitney U and 2-sample t-tests, which test for differences in mean absolute errors, expressed as ECs, across treatments.

Also worth noting in panel (c) of Figure 2 is the gradual buildup of absolute conditional errors toward the end of each decision block. This is due to the adoption of simple and invariant consumption heuristics. Because the conditionally-optimal path assumes subjects will account for previous mistakes in remaining decisions, these invariant heuristics are increasingly penalized when moving along the conditionally optimal consumption path. We discuss this further in our textual analysis section.

[8] We note our sample size is a bit smaller than the general rule-of-thumb of N=40. However, we feel this is okay given that our results are both stark and highly-significant despite our sample sizes.

[9] We show average consumption and per-period consumption heterogeneity in Figure 7 located in Section 7.2 of the Appendix.

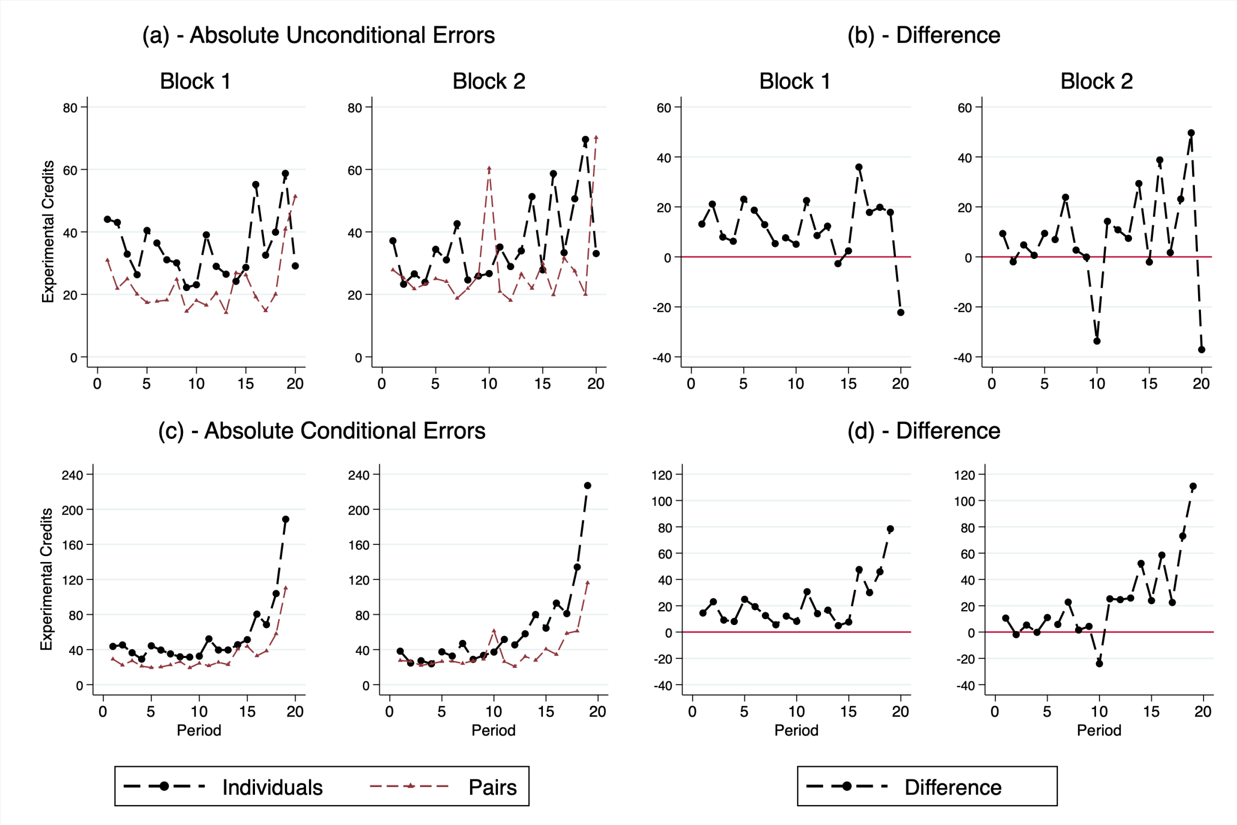

Figure 2: This figure depicts treatment-level average absolute consumption errors (panels (a) and (c)) and differences between the absolute consumption errors by treatment (panels (b) and (d)). For panels (b) and (d), values above zero indicate that pairs outperformed individuals in that period.

We next estimate a series of mixed-effects regression models of the form

$$Y_{i,t} = \beta_0 + \beta_{i,t} X_{i,t} + \mu_i + \epsilon_{i,t}. \tag{7}$$

where our outcomes of interest, $Y_{i,t}$ are either absolute unconditional consumption errors or absolute conditional consumption errors. Both outcomes are measured as absolute deviations from the respective optimal path in terms of ECs. We estimate Equation (7) while restricting our data by treatment and also for our full data sample.[10] We report results of these estimation exercises in Table 2.

Columns 2-5 of this table report results using unconditional absolute consumption errors while columns 5-9 report results using conditional absolute consumption errors. Columns labeled Individual use only data from our Individual treatment, Pairs use only data from our Pairs treatment, and Pooled uses data from both. We can compare coefficient estimates in the Individuals column to its counterpart in the Pairs column for a given error type to learn about how equivalent information differently influences consumption errors for pairs

[10]Though random effects models are common in this literature (examples are Carbone and Duffy (2014), Ballinger et al. (2011)), a Hausman test indicates the need to control for potential fixed effects, which perhaps result from static session effects (Fréchette, 2012).

and individuals. MaxCRT refers to the highest CRT score within a pair and MinCRT refers to the lowest CRT score within a pair. For individuals, MaxCRT simply refers to the individual's CRT score. Wealth refers to subjects' accumulated savings, Income represents current-period income (in ECs), and Block is a dummy variable takes a value of 1 if data comes from the second finite lifecycle in a session.

We start by comparing between Individuals and Pairs. First, we note that CRT score significantly impacts neither unconditional or conditional absolute errors in our Individuals treatment. However, CRT score is a highly significant predictor of performance for Pairs regardless of outcome. In particular, increasing the maximum CRT score within a pair leads to decisions that are, on average, about 5.5 to 7 ECs closer to the optimal path. Interestingly, increasing the maximum CRT score improves performance along both pathways by about twice as much as increasing the minimum CRT score by the same amount.

A common finding in the LTO literature is that consumption overreacts to income. Our results align with this finding. We see that larger per-period income draws lead to larger conditional and unconditional errors for Pairs and larger conditional errors for Individuals. Interestingly, we see that the conditional errors in the Individual treatment react twice as strongly as conditional errors in our Pairs treatment.

Additionally, we see that consumption errors are increasing in the accumulation of savings. Focusing on conditional errors, we see that consumption errors from Individuals are four times as large as consumption errors for Pairs.

Our primary coefficient of interest in our Pooled columns is that associated with our indicator variable for Pairs decisions. As expected based on results in Table 1, we see that joint decisions from our Pairs treatment are significantly closer to optimal along both the unconditionally- and conditionally-optimal paths.

Regression results indicate that subjects making joint decisions in our Pairs treatment were, on average, more than 15 ECs closer to conditionally-optimal, and 9 ECs closer to the unconditionally-optimal, level of consumption. Additionally, we see that absolute consumption decisions increase whenever accumulated wealth increases and with higher income. and Both effects are considerably larger along the conditional than along the unconditional path.

Since subjects in our experiment are concerned with earnings maximization, it perhaps makes the most sense to consider average earnings differences between subjects in our Pairs and Individuals treatments. Subjects in the Individual treatment earned \$20.20 on average, while subjects in the Pairs treatment earned an average of \$24.34. Because we are concerned with earnings differences that result from differences in decisions, we subtract from these averages the fixed show-up fee of 10. we see that pairs earned approximately $\frac{\$14.34-\$10.20}{\$10.20} = 40.59\%$ more, on average, than individuals. Without making this adjustment, earnings differences are still quite large: pairs earn approximately 20% more than individuals.

Finally, we also quantify differences between pairs and individuals by comparing the performance of pairs to synthetic pairs formed using subjects in our Individuals treatment. Our interest is in how much we must improve the performance of these synthetic pairs before their decisions are no longer statistically distinguishable from real pairs at a 10% level of significance. To do this, we randomly match individuals into synthetic pairs and assume

	Regression Results - Mixed Effects Estimations							
	Unconditional Absolute Error				Conditional Absolute Error			
	Individuals	**Pairs**	**Pooled**	**Pooled**	**Individuals**	**Pairs**	**Pooled**	**Pooled**
Pairs			-9.78^{***}	-18.00^{***}			-22.77^{***}	-23.07^{***}
			(2.32)	(3.17)			(3.50)	(4.01)
MaxCRT	-2.41	-5.56^{***}		-4.37^{***}	-3.42	-7.21^{***}		-4.61^{***}
	(5.88)	(1.01)		(0.97)	(7.87)	(1.20)		(1.24)
MinCRT		-2.70^{*}		-3.10^{**}		-3.55^{*}		-4.88^{***}
		(1.55)		(1.46)		(1.89)		(1.85)
Wealth	0.03^{**}	0.010		0.03^{***}	0.24^{***}	0.06^{***}		0.20^{***}
	(0.01)	(0.01)		(0.01)	(0.04)	(0.02)		(0.03)
Income	0.43	0.35^{**}		0.40^{**}	2.61^{***}	1.32^{***}		2.03^{***}
	(0.30)	(0.18)		(0.17)	(0.43)	(0.21)		(0.25)
Block	1.91	5.65^{***}		3.99^{*}	9.28^{*}	6.34^{**}		8.84^{***}
	(4.06)	(2.16)		(2.29)	(5.56)	(2.51)		(3.10)
Constant	4.14^{***}	3.62^{***}	3.97^{***}	3.95^{***}	4.45^{***}	3.71^{***}	4.35^{***}	4.22^{***}
	(0.16)	(0.14)	(0.12)	(0.12)	(0.12)	(0.13)	(0.10)	(0.10)
N	1040	1080	2120	2120	988	1026	2014	2014

Table 2: This table shows of mixed effects regressions. Column 1 lists variable names, where maxCRT (min) refers to the highest (lowest) CRT score in the pair. For individuals, maxCRT refer to the individual's CRT score. Columns 2 thru 5 report results using the absolute unconditional consumption error as the dependent variable and columns 6 thru 9 report results using the absolute conditional consumption error as the dependent variable. Columns labeled 'Individuals' or 'Pairs' use only the data from their corresponding treatment. Columns labeled 'Pooled' use all data. We report standard errors in parentheses. Note that the difference in N arises because there is no conditional error in the first period of either decision block.

each pair consumed in a given period the average of what the two individuals consumed in that period. We repeat this matching process for all possible pairings and average results over all observations.[11]

We find that we can reduce the conditional consumption error of synthetic pairs by approximately 37%, on average, before the performance of real and synthetic pairs becomes indistinguishable. In level terms, this reduces the average conditional consumption error of synthetic pairs from 57.94 to approximately 36.5 experimental credits.

We also use this method to determine whether pairs and individuals learn at different rates in our experiment. If, for example, we have evidence that individuals learn more quickly than pairs, then we might expect that sufficient experience would yield convergence so that forming a joint decision offers no long-run benefit. To do this, we repeat the exercise described above for both the first ten periods and last ten periods of play. We find that we can reduce the conditional consumption errors of our synthetic pairs by 36.5% over the first ten periods of play and by approximately 47% in the last ten periods of play. This provides suggestive evidence of differential rates of learning favoring pairs over individuals. Though suggestive, this indicates that the benefit of forming joint rather than individual decisions increases with

[11] With 26 individuals, we have $c(26, 2) = 325$) possible pairings.

experience.

5.1 Textual Analysis

Because pairs in our experiment engaged in unrestricted chat to make joint decisions, we are able to use textual analysis to gain deeper insight into how subjects in the Pairs treatment frame the dynamic optimization problem and develop heuristics.

Following Cooper and Kagel (2005), we establish a set of categories we use to classify the language used by subjects in our Pairs treatment, which we describe in Table 3. These categories are neither exhaustive nor mutually exclusive. Rather, the categories are complementary, which allows for some nuance in classification despite the binary coding system. We trained two research assistants who then worked independently to classify language into our pre-selected categories. As an example, if a pair discussed how to allocate resources in terms of spending but never in terms of savings, the research assistants would likely code 'Discuss Savings' as a zero and 'Discuss Spending' as a one.

Category	**Description**	**Mean**	**Agreement(%)**
Discuss Saving	Pair frames discussion in terms of saving	.070	97.69
Discuss Spending	Pair frames discussion in terms of spending	.873	97.87
Save More	Someone proposes saving more relative to previous suggestion/period	.025	99.91
Save Less	Someone suggests saving less relative to previous suggestion/period	.004	100.00
Spend More	Someone proposes spending more relative to previous suggestion/period	.054	99.35
Spend Less	Someone proposes spending less relative to previous suggestion/period	.046	97.41
Nominal Target	Pair discusses a nominal target (i.e. consumption points)	.091	93.70
Real Target	Pair discusses a real target (i.e. total dollar earnings)	.017	99.72
Marginal Target	Pair targets a 'marginal increase' target	.048	100.00
Savings Target	Pair tries to maintain a certain amount of savings	.006	99.35
Period Earnings Target	Pair discusses a per-period earnings target	.014	97.41
Total Earnings Target	Pair discusses a lifetime earnings target	.011	98.43
Proportional Spender	Pair discusses spending a proportion of income or total wealth	.053	99.24
Borrow	Pair discusses borrowing against future income	.045	99.63
Constant Spending	Pair discusses spending a constant amount	.038	97.13
Save & Binge	Pair discusses saving heavily to spend a large lump sum later	.044	99.91

Table 3: This table provides information regarding our textual analysis. The first two columns define the categories used by two research assistants (RAs) who worked independently to classify the language used by pairs when forming joint decisions. The third column provides a measure of how frequently pairs used language consistent with each category. The fourth column provides a measure of the level of classification agreement between our two RAs. We construct values in column three by summing over all periods, sessions, and pairs for both RAs, and dividing this sum by two times the total number of periods times the total number of pairs. We construct our agreement measure by dividing the number of times the RAs disagree about a given classification by the number of opportunities to code a discussion category, subtracting this from one, and then converting to percentage terms.

We also report in Table 3 a measure that captures, on average, how often chat aligns with a given category. We construct this measure by first summing over all periods, sessions, and pairs for both research assistants and then dividing this sum by two times the total number of periods times the total number of pairs. Thus, we report a number bounded between zero and one where a value of one means all pairs used language compatible with that category in all periods. Anything less than one means that there is at least one pair who does not use that language in at least one period. To measure classification agreement, we divide the number of times the RA's disagree by the number of opportunities to code a discussion category, subtract this from one, and then convert to percentage terms.

Notice in Table 3 the relatively high frequency of the "Discuss Spending" category, which indicates that pairs mostly frame discussions around spending rather than saving or borrowing. Though subjects must spend credits to earn money, the stochastic income process, coupled with the consumption smoothing motive, makes saving and borrowing important components of earnings maximization. We also see that subjects, explicitly or implicitly, discuss spending strategies that fix consumption either in levels or as a proportion of wealth or income. This aligns with Figure 4, which shows that about half of our pairs use a constant marginal propensity to consume heuristic.

These sorts of simple heuristics greatly reduce the cognitive load of the optimization task but might fail subjects whenever saving or borrowing is necessary for optimization. For example, pairs spending a fixed proportion of the per-period endowment would not borrow whenever necessary to spend at the unconditionally- or conditionally-optimal level. This aligns with Carbone and Hey (2001) and Hey and Knoll (2011) who find that subjects are more likely to develop simple decision criteria and adopt strategies aimed at reducing the cognitive complexity of the choice task.

This also relates to Meissner (2016), who demonstrates that individuals perform worse when solving dynamic optimization problems that require borrowing relative to tasks that require saving. Our evidence may suggest that people don't borrow optimally because they employ heuristics that ignore borrowing and not necessarily because they are innately averse to debt.[12]

We also note that the adoption of these simple time- and wealth-invariant consumption heuristics might explain the upward trend in conditionally-optimal consumption errors that we do not see in the unconditionally-optimal consumption errors. This is because a heuristic that leads to an absolute error in one period will, on average, lead to a similar absolute error in a later period. The invariant nature of the heuristic could prevent subjects from avoiding current-period errors and adjusting for past errors.

We also observe that subjects more often frame discussions in nominal rather than real terms. This is not surprising, given that our pairs tend toward simple heuristics that reduce the complexity of dynamic choice. Since nominal and real earnings are isomorphic, it might be the case that subjects prefer nominal framing because it avoids the added complexity of real framing. This aligns with Petersen and Winn (2014), who find that nominal inertia arising in a choice task results from cognitive complexity and that money illusion exerts only second-order effects in the same task.

Finally, we see that our pairs discuss saving and binging as a strategy with surprising frequency. It is easy to assume that such behavior, first documented by Noussair and Matheny (2000), is reactionary since it demonstrates a misunderstanding of the consumption smoothing motive. However, we see here that this behavior can be thoughtful, planned, and forward-looking.

Next, we consider textual classifications by period, depicted in Figure 3, in order to better understand how communication evolves. To do this, we focus on six thematic categories and

[12] Of course, an innate aversion to debt may itself shape heuristic selection. Our data do not allow us to rule this out.

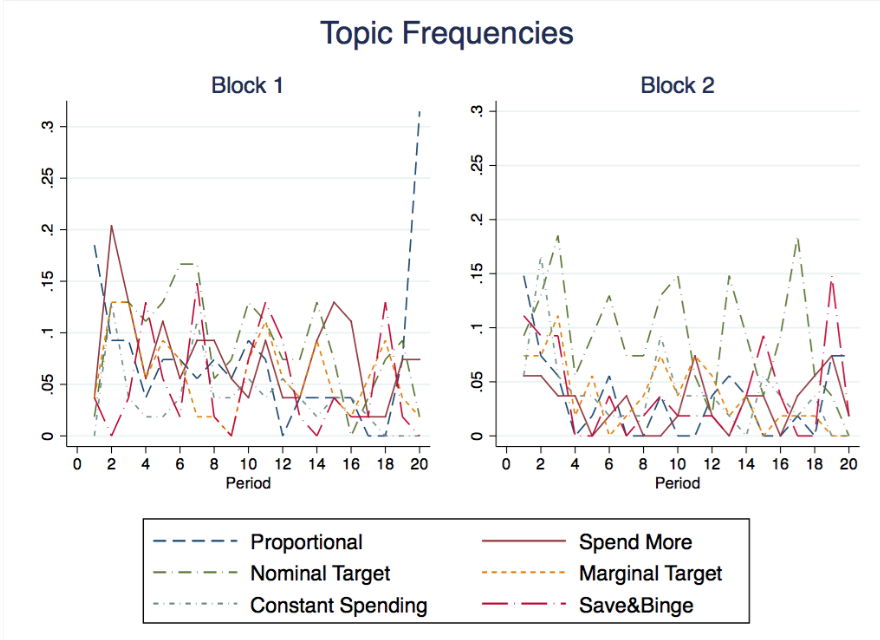

Figure 3: This graph plots, by period and block, the six language categorizations used most frequently by subjects in our Pairs treatment to reach a joint decision. The graph includes only those categories discussed by more than one pair within a single period at least once during the experiment. We construct this frequency measure by summing observations for a given category for all pairs within a period and by using observations from both RAs. We then divide this sum by two times the number of pairs.

eliminate categories not discussed by two or more pairs at least once in a single period. The proportional strategy indicates that a pair discussed spending or saving a proportion of their per-period endowment or accumulated wealth. The nominal and marginal strategies indicate a pair uses a nominal target or a marginal target to guide its consumption decision. The constant spending strategy emerges when pairs discuss spending a fixed level of EC's in each period. Finally, the save and binge strategy involves pairs saving EC's with the intention of 'binging' a large amount of EC's later in a single period. Similar to what we did in Table 3, we first sum the occurrences of a given category for all pairs and both research assistants and divide this number by two times the number of pairs. We then plot this number for each of our six categories by period.

The cyclical pattern of these frequencies suggests that not all pairs discuss a strategy in all periods. Instead, pairs discuss a strategy, follow it for some time, and then reaffirm or discuss the strategy again after a few additional periods. Second, we note that the frequency of discussion for all strategies, excluding the nominal target strategy, falls in block 2 relative to block 1, which could indicate that pairs settle into a heuristic as they gain experience. In particular, we see that pairs gradually think less about the marginal benefit of consumption when making decisions. Finally, we note that the discussion of proportional strategies spikes at the end of block 1, but not block 2. This is likely because pairs realized at the end of block 1 that they needed to spend all remaining savings. The absence of this same spike at the end of block 2 matches the marked decrease in binging behavior at the end of block 2 relative to block 1.

5.2 Consumption Heuristics

We now consider the heuristics used by individuals and pairs to make consumption decisions. To do this, we construct a set of 5 possible heuristics that may describe a subject's (or pair's) decisions (see Tasneem and Engle-Warnick (2018), and Fenig and Petersen (2020) for other examples of consumption heuristics.). We show these five heuristics in Figure 4.

Hand-to-Mouth assumes that a subject consumes all of her income in each period. This is equivalent to having a fixed marginal propensity to consume (MPC) of 1 in each period. A real-world equivalent is an individual or family that lives paycheck-to-paycheck. Unconditional Optimizer assumes that subjects optimize perfectly along the unconditionally-optimal path. This heuristic captures the behavior of a fully rational agent in the context of our finite lifecycle problem. Conditional Optimizer assumes that subjects optimize along the conditionally-optimal path. Constant MPC assumes that a subject i (or pair i) spends a fixed proportion α_i of income in each period. We consider a range of values for $\alpha_i = \frac{n}{30}$ for $n = \{1, 2, ..., 29\}$. Note that Hand-to-Mouth would be equivalent to Constant MPC whenever $n = 30$ since this yields $MPC = 1$.

We classify a subject (or pair) to one of the heuristics by comparing consumption in each period to what a subject would consume according to each possible heuristic and selecting the heuristic that minimizes the sum of absolute differences.

Initial results from this classification exercise, shown in the left panel of Figure 4, indicate that a smaller proportion of pairs than individuals are using a hand-to-mouth strategy and instead use a constant spending strategy. This aligns with our textual analysis, where we see many pairs setting nominal and marginal spending targets.

However, examining the distribution of α reveals systematic differences between pair and individual heuristics. We plot the distribution of MPC values that best describe decisions for pairs and individuals classified to the Constant MPC heuristic in the right panel of Figure 4. This shows that, on average, pairs adhere to a higher MPC than do individuals, which leads to less buildup of excess savings among pairs.

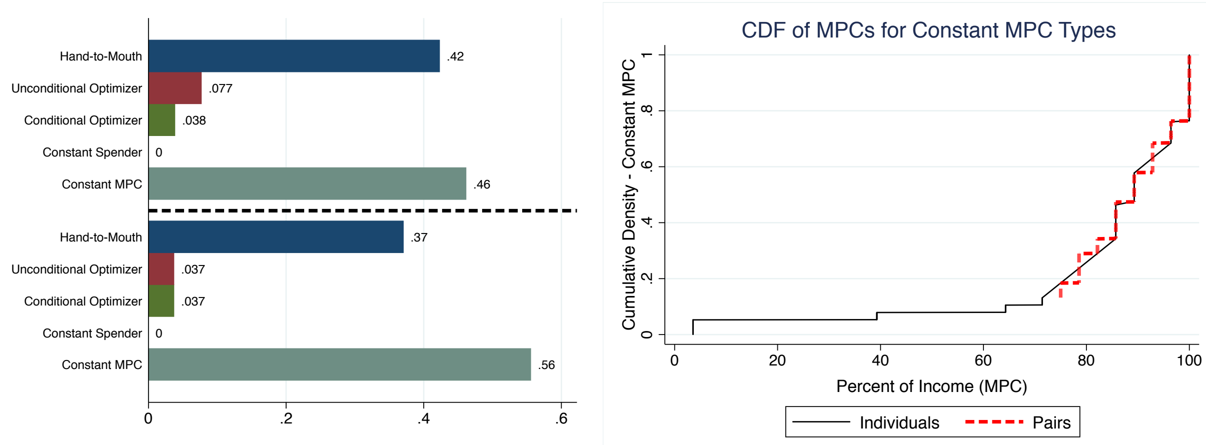

Figure 4: The left panel of this figure shows the proportion of individuals (top) and pairs (bottom) that, on average, adhere to a given consumption heuristic. We define these heuristics as: Hand-to-Mouth $c_{i,t} = y_t$, Unconditional Optimizer $c_{i,t} = c_t^*$, Conditional Optimizer $c_{i,t} = \hat{c_{i,t}^*}$, Constant MPC $c_{i,t} = \alpha_i y_t$, and Constant Spending $c_{i,t} = c_{i,t-1}$. The right panel shows the cumulative density function of MPC value for individuals and pairs using an constant MPC consumption heuristic.

6 Conclusion

This paper revisits the learning-to-optimize literature to ask whether or not the pervasive practice of using individuals as representative decision-makers is the best approach to testing the potential limits of rationality in the context of dynamic optimization. We do this by comparing the ability of pairs and individuals to solve a finite-period, dynamic optimization problem. We find that joint decision making leads pairs to significantly outperform individuals along both the unconditionally- and conditionally-optimal consumption paths. This performance gap, on average, leads to subjects in our Pairs treatment earning about 40% more than subjects in our Individuals treatment.

Textual analysis reveals that pairs almost exclusively frame discussions in terms of spending even though the stochastic per-period income process, coupled with the consumption smoothing motive, makes saving and borrowing important components of earnings maximization. Further, we see that pairs develop simple, invariant heuristics that can lead to persistent errors that compound over time, which explains why our subjects perform worse when measured along their conditionally-optimal consumption paths. Finally, we see that saving and binging is the outcome of thoughtful, forward-looking behavior and not the result of extreme myopia or lack of a strategy entirely.

Our heuristic classification reveals pairs and individuals predominately adhere to a constant MPC heuristic, but that pairs exhibit less heterogeneity in the measure of MPC used and have higher MPCs on average. These higher MPCs help mitigate the compounding nature of conditional errors because they lead to few and less-severe instances of underspending.

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7 Appendix

7.1 Screen Shots

Here we show the decision screens used by subjects in their respective treatments.

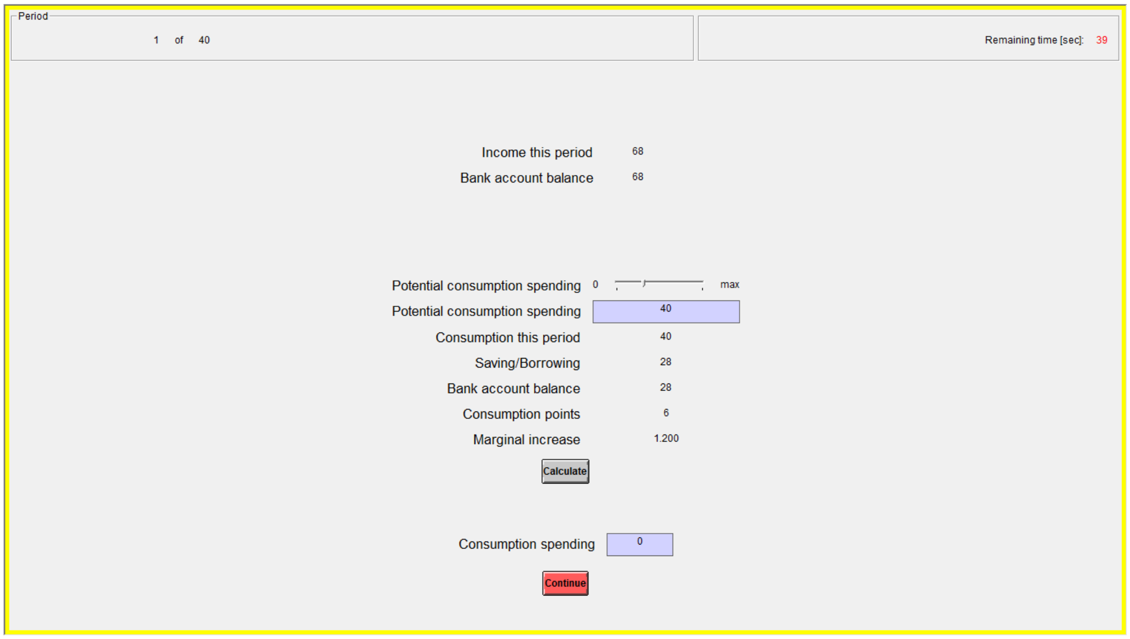


Figure 5: Decision screen for Individuals treatment.

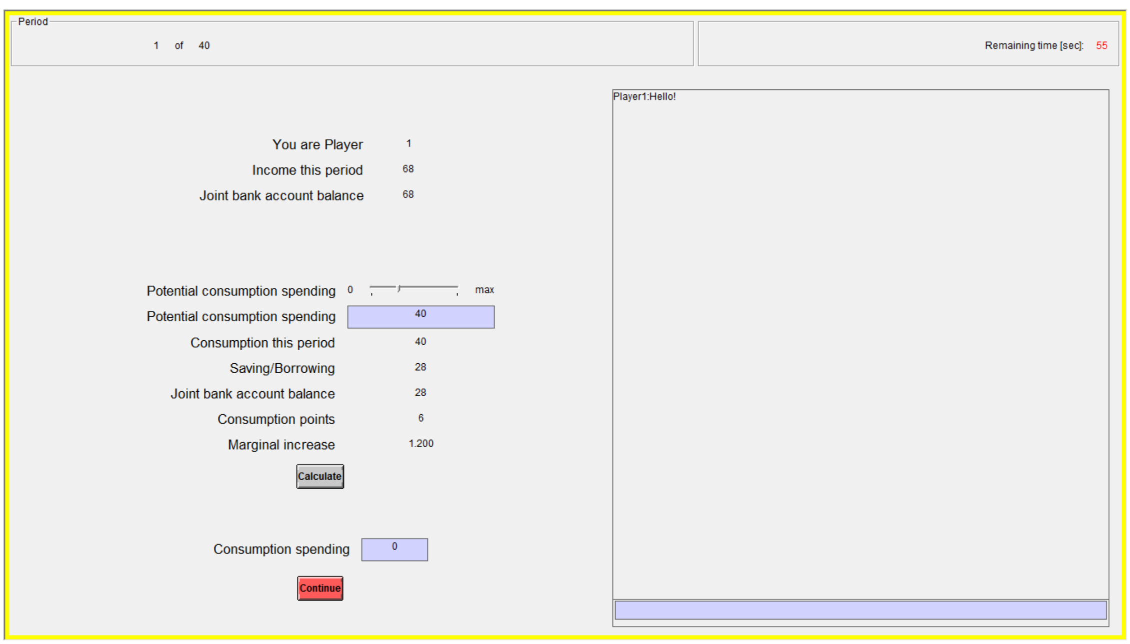


Figure 6: Decision screen for Pairs treatment.

We provide an example, corresponding to Figure 5, that explains how an individual might use the consumption tool and the available information to play this game.

Notice under 'Income this period' that our hypothetical subject has received an endowment of 68 experimental credits (ECs) in period 1. This is reflected in the "Bank account balance," which updates each period to account for per-period and previous saving/borrowing. The subject may then explore the outcome of all possible consumption decisions using the 'Potential consumption spending' slider or by entering hypothetical levels of consumption in the gray box labeled 'Potential consumption spending'.

For this example, our subject could spend between 0 and 128 ECs, since subjects could borrow up to 60ECs in all but the final period of a lifecycle. Moving the slider or entering a value in the box and clicking calculate will update all other variables. In Figure 5, our hypothetical subject has selected a potential consumption value of 40. Notice that all available information has been updated to reflect this. "Consumption this period" is updated to reflect the chosen value of 40.

The "Saving/Borrowing" field updates to 28 to reflect the 28 ECs that would remain in the subject's bank account after spending 40 of the available 68 ECs[13] This balance is also shown in the "Bank account balance" field within the consumption calculator.[14] Further, the "Consumption points" field updates to show the consumption points earned under a choice of spending 40 ECs on consumption, which is 6.

The subject is also shown the marginal utility from using one more EC on consumption in the "Marginal increase" field, which is 1.200. The subject then enters their chosen value for consumption in the 'Consumption spending' box and presses the red button labeled 'Continue' to proceed.

7.2 Average Consumption and Consumption Heterogeneity

This section of the appendix deals with the average consumption decisions, and average consumption heterogeneity, of both individuals and pairs, which we graph in Figure 7.

Worth noting in Figure 7 is that average consumption increases over time for both individuals and pairs in both decision blocks. Also, note in the top right panel of Figure 7, which shows average consumption decisions during the second decision block, that both pairs and individuals, on average, consume too little for approximately the first 10 periods relative to the unconditionally-optimal consumption path. This period of significant under consumption corresponds to a time where subjects must borrow to behave optimally. To see this, refer to the stochastic income process depicted in Figure 1, and note that per-period income was consistently below the unconditionally-optimal level of consumption. Finally, we note that participants in our Individual treatment seem to exhibit more heterogeneity in consumption than do pairs.

[13]This number would be negative if the subject decided to spend more than 68 ECs.

[14]These numbers match because this is period 1. They would not necessarily match in later periods.

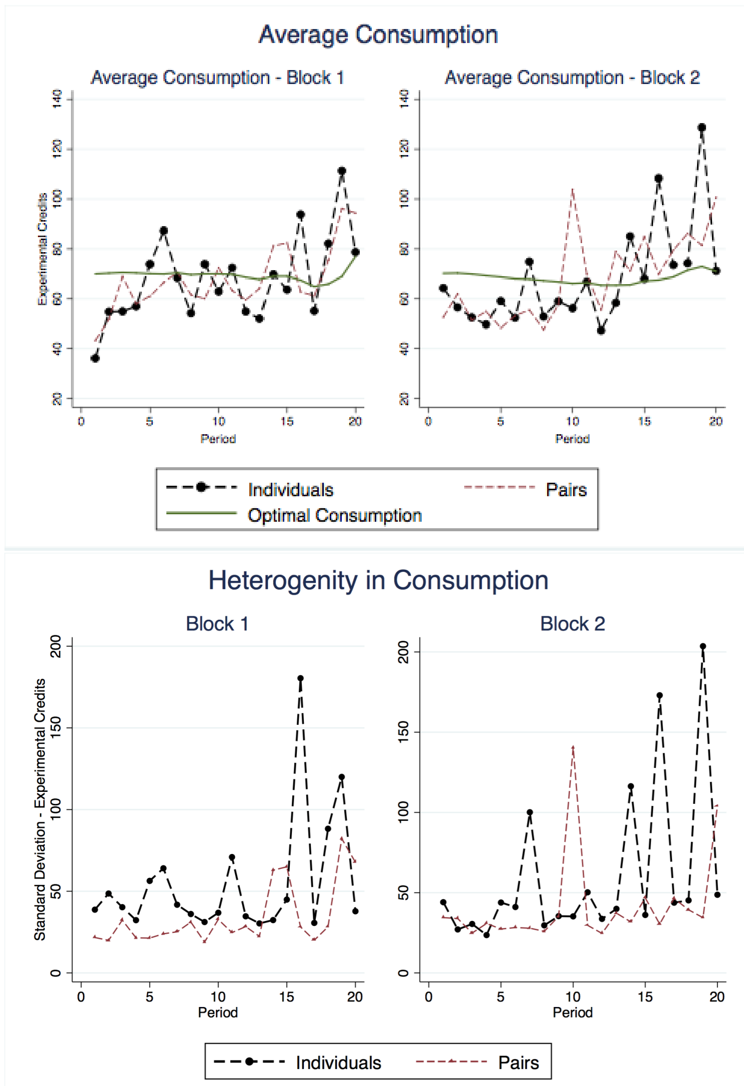


Figure 7: The top panel of this figure shows the average level of consumption expressed as experimental credits in each period by treatment. The bottom panel shows within-treatment heterogeneity in consumption by period.

7.3 Empirical Data

We analyze data from the Panel Study of Income Dynamics (PSID) at the family-level, or household level, to evaluate consumption smoothing. The PSID is a longitudinal household survey that has been conducted by the Institute for Social Research at the University of Michigan since 1968.[15]

Administrators of the PSID survey ask participants to report on their consumption expenditure totals across a large range of items over the course of the previous year. Examples of these items include food, utilities, transportation, education, childcare, and health care. Because respondents self-report data, people may over- or under-report their incomes and consumption expenditures for personal reasons, or due to memory lapse. Additionally, the PSID over-samples low-income families. However, we control for this in our analysis.

We restrict our sample to the years 1999 - 2017. We do this to account for two major changes in PSID data collection that came in 1999. First, surveyors began collecting data biannually instead of annually. Second, the PSID became a richer data source as surveyors began collecting additional information about household consumption and income.

For the purposes of this exercise, we made certain sample selection decisions when cleaning the PSID data. We restrict the sample to household heads aged 20 to 65. We used the OECD-modified adult equivalence scale to adjust for the increase that is proportionate per adult necessary to maintain some standard of living given a change in demographic circumstances, like the birth of a new child. We then adjusted all consumption and income measures by the personal consumption expenditure (PCE) index, to account for changes in prices, and by the OECD-modified equivalence scale. We drop all observations from the original Survey of Economic Opportunity (SEO) sample and the branches of this original sample to avoid the bias that would be introduced from the over sample of poor households, restricting our sample to just the Survey Research Center (SRC) sample. We drop observations where the household head reported working more than 5,200 hours or the household head reported working more than 520 hours at half of the minimum wage. We also drop observations where consumption expenditures are reported to be zero or negative. Thus, we restrict the sample to observations that only report positive consumption expenditures. Finally, we restrict the sample to the lowest income quartile.

7.4 Empirical Motivation

This section provides some suggestive empirical evidence that further motivates our laboratory experiment. Table 4 reports the results of regressing four types of consumption growth (food, non-durable, durable, and total) on a number of household characteristics, conditional on the household head receiving an income shock of spending some months unemployed.

We do this using feasible GLS and include both year and income group fixed effects. Additionally, we control for the reported sex of the head of household, the number of children living in the household, the number of adults living in the household, educational level of the

[15] Surveyors collect data on a range of topics including education, employment, income, wealth, and expenditures, which makes it well-suited for the study of consumption smoothing.

Table 4: Empirical Evidence

Variables	Food	Non-durable	Durable	Total
Single	-0.1781***	-0.0934**	-0.0697	-0.1112**
	(0.0719)	(0.0536)	(0.0613)	(0.0440)
Year FE	✓	✓	✓	✓
Y Group FE	✓	✓	✓	✓
Controls	✓	✓	✓	✓
Observations	848	857	830	857
R^2	0.0806	0.0179	0.0322	0.0538

head of household, and the reported race of the head of household. Columns two through four in Table 4 show the effect of a negative income shock on consumption across three categories: food consumption, consumption of non-durable goods, and durable goods. Column five reports the effect of a negative income shock on total consumption.

The coefficients reported in Table 4 show the percentage point response of consumption growth, by category, to an unemployment shock. Thus, relative to a married household, a single household experiences a 17.81 percentage point decrease in food consumption, a 9.34 percentage point decrease in non-durable consumption, and an 11.12 percentage point decrease in total consumption. If markets were complete, meaning consumers are able to insure against all possible states of the world, these coefficients should take a value of zero, which would indicate no change in consumption growth in response to an unemployment shock.

7.5 Ledger Treatment

A possible concern is that two things could contribute to differences between individual and pair outcomes. First, subjects in a pair are able to discuss strategies and exchange ideas. Second, subjects in a pair articulate the logic of their decisions while communicating. Thus, one could question if pairs do better because they are are making a joint decision or instead because they are articulating the logic of the consumption/savings decision.

We test this by implementing a third treatment, which we call the Ledger treatment. The Ledger treatment is identical to the individual treatment, except that subjects in the Ledger treatment have access to the same chat window as do subjects in group treatments. Subjects can use this window as a sort of journal to articulate the logic underlying their individual decisions, which could lead to more careful thought and therefore better decisions. In order to be consistent with the Pairs treatment, we neither require subjects in the Ledger treatment to use the ledger nor do we allow them access to ledger entries from previous periods.

Of the 10 subjects who participated in our Ledger treatment, one subject used the ledger one time. A two-sided Student's T-test shows that the mean absolute consumption error (both unconditional and conditional) for subjects in the Ledger and Individual treatments is not significantly different. However, the same test shows that decisions from subjects in the Pairs and Ledger treatments are highly significantly different.

7.6 Instructions for Individuals

Overview:

Welcome! You are here today to participate in an economic experiment involving the experimental simulation of an economy. If you read these instructions carefully and make appropriate decisions, you may earn a considerable amount of money that will be paid to you in cash immediately following the experiment.

We will pay each participant $10 for attending this experimental session. Throughout the experiment you can accrue additional earnings based on the decisions and predictions you make. You will earn points for each decision you make. Every 50 points you earn is worth an additional $1.

You are not allowed to communicate with other participants during this experiment. If you have any questions, the experimenter will be glad to answer them privately. If you have not done so already, please turn off your cell phone now. If you do not comply with these instructions, you will be excluded from the experiment and deprived of all payments aside from the minimum payment of $10 for attending.

Today's experiment consists of 2 sections.

Section 1 Instructions:

The first section has two parts. The first part of section one requires you to choose among a set of possible gambles. We will implement whichever gamble you choose and pay you based on the outcome of this gamble. The second part of section 1 requires you to answer a series of questions. We will pay you $.25 for each question you answer correctly. We will provide further instructions for section 1 on your screen whenever necessary.

The second section of today's experiment involves two 'sequences' of decision making. Each sequence consists of 20 periods. You will make a new decision in each of these periods. You will make these decisions using an experimental program displayed on the screen at your terminal. Your goal during the second section of today's experiment is to convert income into consumption points. Your income in this game is valueless until you convert it into consumption points. We will convert these consumption points into cash and pay you at the end of this experiment.

Section 2 Instructions:

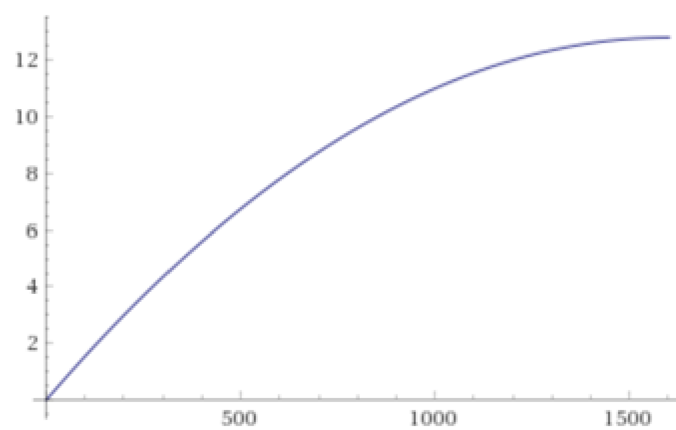
You are endowed with experimental credits (ECs) at the beginning of each period. We refer to these experimental credits as income. The amount of income you receive in each period is determined randomly and will always be an amount between 60 and 80, inclusively. You may receive as income any number of ECs between 60 and 80 with equal probability. Income in each period is independent of whatever income you received before.

After randomly determining your per-period income, the program will display this amount to you and deposit this money automatically into your bank account. The program will also display bank account balance (see Figure 1). This amount in your bank account represents your total wealth.

You must decide in each period how much of your total wealth to convert into consumption points for that period. You will earn points for consuming. Specifically, the number of points you earn in a single period is given by:

$$u(c_t) = [1600 * c_t - (1/2)c_t^2]\frac{1}{50}$$

Graphically:

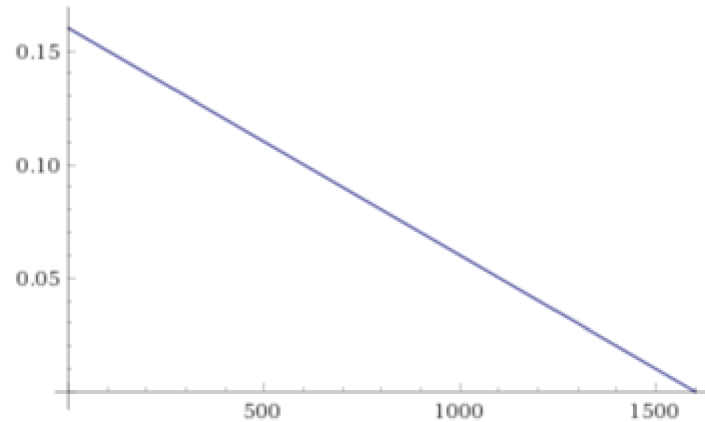


You can see from the graph above that each EC you spend on consumption (X-axis) earns a positive, but diminishing, number of consumption points (Y-axis). Each EC that you spend within a period will earn you less consumption points than the previous EC spent in the same period. This is known as diminishing marginal returns.

Specifically, the rate at which you can convert wealth into consumption points is given by:

$$u'(c_t) = 16 - \frac{c_t}{50}$$

Graphically:



This graph shows you how many additional points you receive within a period (Y-axis) for spending a certain amount of wealth (X-axis).

ECs have no value in this experiment. Only consumption points have value. We convert consumption points to U.S. dollars at the rate of 50 points for $1.

Saving and borrow:

Saving:

You may save money in this experiment. Saving occurs automatically. If you spend an amount of ECs that is less than the amount of ECs in your bank account at the beginning of a period, this is called saving. Since we automatically deposit your per-period into your bank account and all of your available income is stored in your bank account, saving requires no additional actions.

Any wealth that you do not use in a period for consuming will remain in your bank account and will be available for consuming in later periods. Note that your bank balance does not earn interest. Any money left in your account at the end of the 20th period of a sequence becomes worthless.

Borrowing:

You may borrow up to 60 credits in all periods except the last period. You cannot borrow in the last period because you are not allowed to end this game with a negative balance. Borrowing is also straightforward. If you wish to borrow money for consumption, simply add the amount of money you wish to borrow for consumption to your consumption decision. The program will always allow you to spend (except in the final period) an amount equal to whatever is in your bank account at the beginning of a period plus 60 ECs.

Saving and Borrowing example:

Suppose you have 100 ECs in your bank account at the beginning of period 2:

1. Suppose you spend 75 ECs on consumption. Then your bank account balance at the end of period 2 will be 25 ECs. Your bank account balance at the start of period 3 will be 25 ECs plus whatever endowment you receive for period 3.

2. Suppose you decide you want to spend 130 ECs. To do this, simply submit 130 ECs as your consumption decision (we discuss how to do this later in instructions). The program will allow you to spend the 130ECs and your bank account balance at the end of period 2 will be -30 ECs. Your bank account balance at the beginning of period 3 will be -30 ECs plus whatever endowment you receive for period 3.

Making a consumption decision:

We discuss two things in this section of the instructions. First, we discuss a tool available to you that will aid your consumption decision. We call this tool the consumption calculator. Second, we discuss how to submit a consumption decision.

Consumption Calculator:

We provide you with a consumption calculator to assist you when making a consumption decision. This is shown in Figure 1 below.

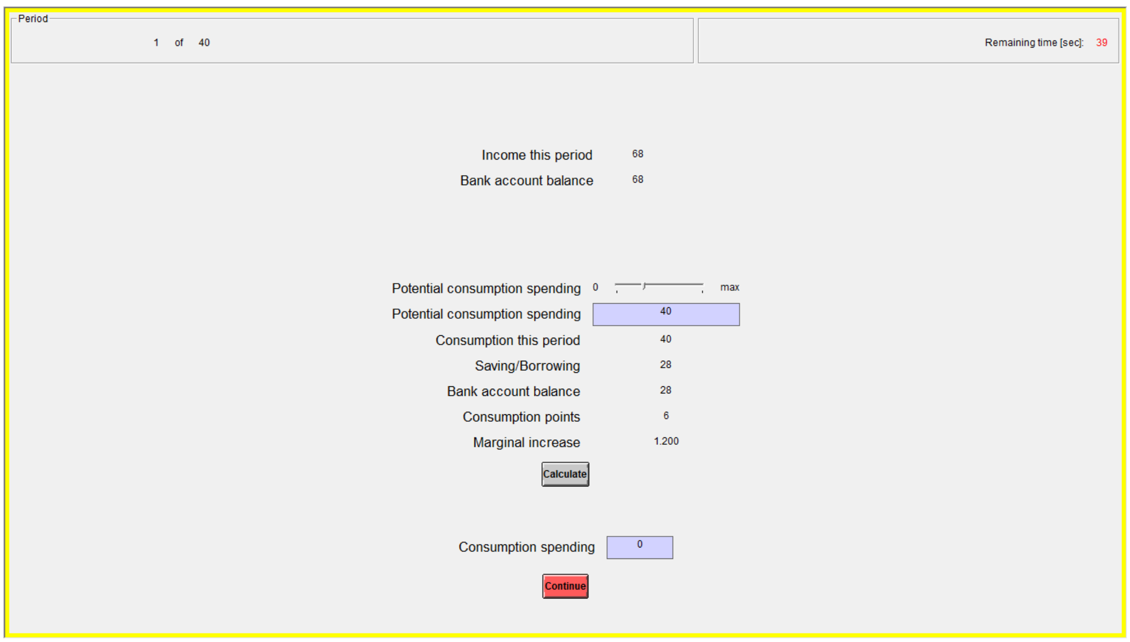


Figure 8: Decision screen for Individuals treatment.

The consumption calculator allows you to select a potential level of income you'd like to spend on consumption and shows you how much money you would save or borrow based on that decision, your resulting bank account balance, and the number of consumption points you would earn for spending that amount of income on consumption in that period.

You can choose a potential level of consumption income in two ways. First, you can move the slider (top line of the middle section of the screen in Figure 1) to some potential level of consumption spending. Doing this will cause all information to update automatically. Second, you can type a level of potential consumption spending into the box in the same section. Next, clicking the 'calculate' button in this section will cause all information to update based on whatever number you entered into the box.

Additionally, this calculator will show you the additional amount of consumption points you would earn if you decided to spend an additional EC in that period. This is called the marginal return to consumption. Recall, Each EC that you spend within a period will earn you less consumption points than the previous EC spent in the same period.

Information:

As shown in Figure 1 above, you will always have information about your current period endowment and bank account balance whenever making a consumption decision. Furthermore, you will always have the consumption calculator available to help you understand how a potential level of consumption spending would impact your earnings and change your available bank account balance for spending in future periods.

Additionally, we will complete each period (after you make a consumption decision) by providing a review screen that reminds you of how much income you spent on consumption in that period, your bank account balance at the end of that period, the amount of consumption points you earned in that period, and your total earnings. This is shown in Figure 2.

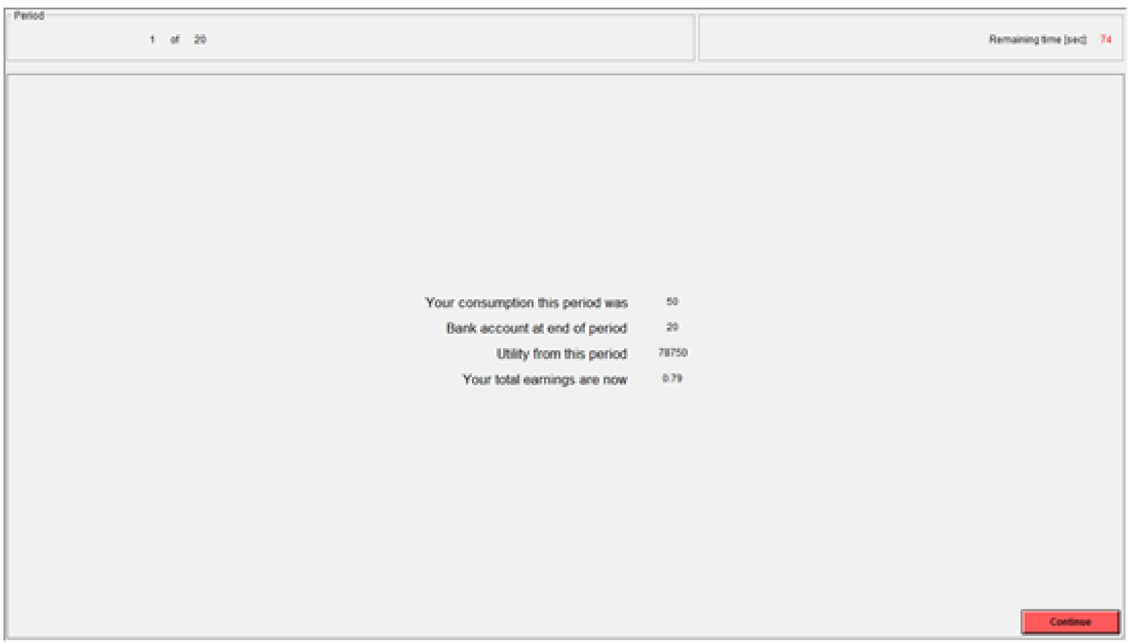


Figure 9: Review screen.

Once all subjects complete the first 20-period sequence, we will begin another 20-period sequence. The only difference between the first and second 20-period sequence is that the sequence of endowments (the income you receive at the beginning of each period) will be different. This is because the sequence is randomly drawn with equal probability from the closed interval of [60,80].

Payment:

Your payment today will consist of your $10 show-up fee, your earnings from the initial questionnaire (where you earn $.25 for each correct question), whatever you earn from your randomly implemented gamble, and your earnings from the two, 20-period sequences of decisions.

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. You can use the instructions to help answer these questions. *Your performance on this quiz does not affect your payoff.* 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 earn ______________ for each correct answer in the quiz. 2. Suppose it is period 5. Does the endowment you receive in period 5 depend on the endowment you received in period 4? ______________.

Does it instead depend on an endowment received in some earlier period (1, 2 or 3)? ______________.

3. Suppose you have 100 ECs in your bank account at the beginning of a period. Does this include your endowment for that period? ______________.

4. Suppose you have 100 ECs in your bank account at the beginning of a period. What is the maximum amount you can spend on consumption this period? ______________. What will be your bank account balance at the end of the period if you spend this maximum amount? ______________.

5. True or False: We will pay you for the decisions you make in both sequences? ______________

6. Suppose you earn 200 consumption points total. How much money do you earn? ______________.

7.7 Instructions for Pairs

Overview:

Welcome! You are here today to participate in an economic experiment involving the experimental simulation of an economy. If you read these instructions carefully and make appropriate decisions, you may earn a considerable amount of money that will be paid to you in cash immediately following the experiment.

We will pay each participant $10 for attending this experimental session. Throughout the experiment you can accrue additional earnings based on the decisions and predictions you make. You will earn points for each decision you make. Every 25 points you earn is worth an additional $1.

You are not allowed to communicate with other participants during this experiment. If you have any questions, the experimenter will be glad to answer them privately. If you have not done so already, please turn off your cell phone now. If you do not comply with these instructions, you will be excluded from the experiment and deprived of all payments aside from the minimum payment of $10 for attending.

Today's experiment consists of 3 sections.

Section 1 Instructions:

The first section has two parts. The first part of section one requires you to choose among a set of possible gambles. We will implement whichever gamble you choose and pay you based on the outcome of this gamble. The second part of section 1 will require you to answer a series of questions. We will pay you $.25 for each question you answer correctly. We will provide further instructions for section 1 on your screen whenever necessary.

The second section of today's experiment involves two 'sequences' of decision making. Each sequence consists of 20 periods. You will make a new decision in each of these periods. You will make these decisions using an experimental program displayed on the screen at your terminal. Your goal during the second section of today's experiment is to convert income into consumption points. Your income in this game is valueless until you convert it into consumption points. We will convert these consumption points into cash and pay you at the end of this experiment.

You will make your consumption decisions in each period with a partner. We will randomly assign you a partner during this experiment. You will be able to communicate with your partner using a chat feature. Your partners are fixed for the entirety of this experiment. That is, you will work with the same partner for both 20-period sequences.

The third section again requires you to choose among a set of possible gambles. However, you will be working with the same partner to make this decision. You will be able to communicate with your partner using a chat feature. We will implement whichever gamble you and your partner choose and pay you based on the outcome of this gamble. We will provide further instructions for section 3 on your screen whenever necessary.

Section 2 Instructions:

You and your partner are jointly endowed with experimental credits (ECs) at the beginning of each period. We refer to these ECs as income. The amount of income you and your partner receive in each period is determined randomly and will always be an amount between 60 and 80, inclusively. You may receive as income any number of ECs between 60 and 80 with equal probability. Income in each period is independent of whatever income you received before.

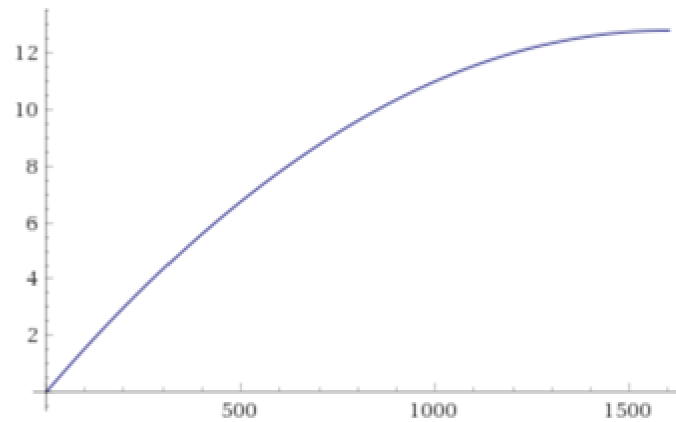
After randomly determining you and your partner's joint per-period income, the program will display this amount to you both and deposit this money automatically into your joint bank account. The program will also display the joint bank account balance (see Figure 1). This amount in your bank account represents your total wealth.

For example, suppose your joint endowment for a period is 70 ECs. You and your partner will both see this number. This means that together you must decide how to spend use these 70 ECs. To be clear, this would not mean that you have jointly gained 140 ECs.

You and your partner must decide in each period how much of your total wealth to convert into consumption points that period. Specifically, the number of points you and your partner earn in a single period is given by:

$$u(c_t) = [1600 * c_t - (1/2)c_t^2]\frac{1}{50}$$

Graphically:

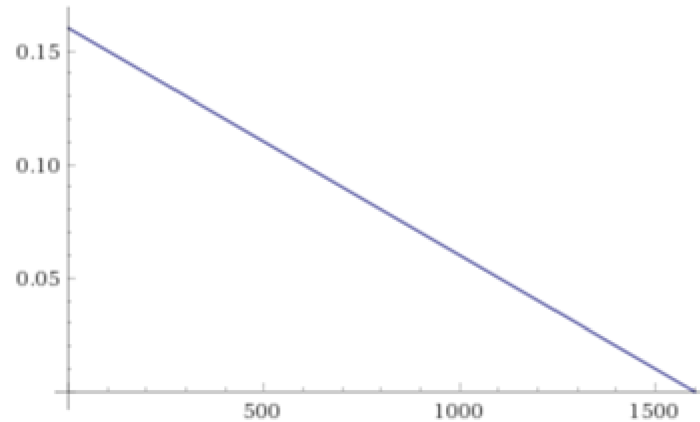


You can see from the graph above that each EC spent on consumption (X-axis) earns a positive, but diminishing, number of consumption points (Y-axis). Each EC that you spend within a period will earn you less consumption points than the previous EC spent in the same period. This is known as diminishing marginal returns.

Specifically, the rate at which you can convert wealth into consumption points is given by:

$$u'(c_t) = 16 - \frac{c_t}{50}$$

Graphically:



This graph shows you how many additional points you receive within a period (Y-axis) for spending a certain amount of wealth (X-axis).

ECs have no value in this experiment. Only consumption points have value. We convert consumption points to U.S. dollars at the rate of 25 points for $1.

You and your partner will splint income evenly. For example, if your joint consumption decisions lead to a payoff of $25 total, then you both receive $12.50.

Saving and borrow:

Saving:

You may save money in this experiment. Saving occurs automatically. If you spend an amount of ECs that is less than the amount of ECs in your bank account at the beginning of a period, this is called saving. Since we automatically deposit your per-period income into your bank account and all of your available income is stored in your bank account, saving requires no additional actions.

Any wealth that you do not use in a period for consuming will remain in your bank account and will be available for consuming in later periods. Note that your bank balance does not earn interest. Any money left in your account at the end of the 20th period of a sequence becomes worthless.

Borrowing:

You may borrow up to 60 credits in all periods except the last period. You cannot borrow in the last period because you are not allowed to end this game with a negative bank account balance.

Borrowing is also straightforward. If you wish to borrow money for consumption, simply add the amount of money you wish to borrow for consumption to your consumption decision. The program will always allow you to spend (except in the final period) an amount equal to whatever is in your bank account at the beginning of a period plus 60 ECs.

Saving and Borrowing example:

Suppose you have 100 ECs in your bank account at the beginning of period 2:

1. Suppose you spend 75 ECs on consumption. Then your bank account balance at the end of period 2 will be 25 ECs. Your bank account balance at the start of period 3 will be 25 ECs plus whatever endowment you receive for period 3. 2. Suppose you decide you want to spend 130 ECs. To do this, simply submit 130 ECs as your consumption decision (we discuss how to do this later in instructions). The program will allow you to spend the 130ECs and your bank account balance at the end of period 2 will be -30 ECs. Your bank account balance at the beginning of period 3 will be -30 ECs plus whatever endowment you receive for period 3.

Making a consumption decision:

We discuss two things in this section of the instructions. First, we discuss a tool available to you and your partner that will aid your consumption decision. We call this tool the consumption calculator. Second, we discuss how to submit a consumption decision.

Consumption Calculator:

We provide you with a consumption calculator to assist you when making a consumption decision. This is shown in Figure 1 below.

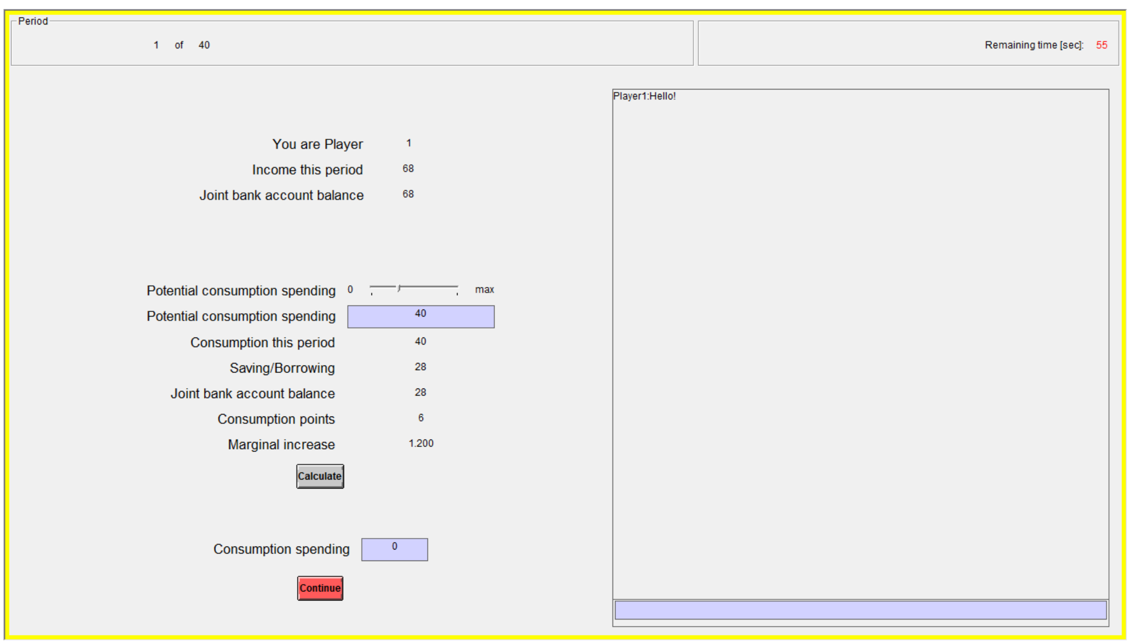


Figure 10: Decision screen for Pairs treatment.

The consumption calculator allows you to select a potential level of income you'd like to spend on consumption and shows you how much money you would save or borrow based on that decision, your resulting bank account balance, and the number of consumption points you would earn for spending that amount of income on consumption in that period.

You can choose a potential level of consumption income in two ways. First, you can move the slider (top line of the middle section of the screen in Figure 1) to some potential level of consumption spending. Doing this will cause all information to update automatically. Second, you can type a level of potential consumption spending into the box in the same section. Next, clicking the ‘calculate’ button in this section will cause all information to update based on whatever number you entered into the box.

Additionally, this calculator will show you the additional amount of consumption points you would earn if you decided to spend an additional EC in that period. This is called the marginal return to consumption. Recall, Each EC that you spend within a period will earn you less consumption points than the previous EC spent in the same period.

Both you and your partner have *independent* consumption calculators. This means that your partner does not automatically see information for potential levels of consumption spending that you check using your calculator and vice versa.

You and your partner can chat freely using the chat box picture on the right side of Figure 1. You should use this chat box to jointly agree upon a decision about how much of your joint income you should spend on consumption in each period.

Once you have reached an agreement using the chat box, you should both input your consumption spending decision and click continue. If you both input the same number, the program will proceed and you will jointly earn whatever amount of consumption points corresponds to your joint decision. If the numbers do not match, the program will not continue forward. You will receive a notification from the program whenever you input a number that does not match your partners.

Information:

As shown in Figure 1 above, you will always have information about your current period endowment and bank account balance whenever making a consumption decision. Furthermore, you will always have the consumption calculator available to help you understand how a potential level of consumption spending would impact your earnings and change your available bank account balance for spending in future periods. This is shown in Figure 2.

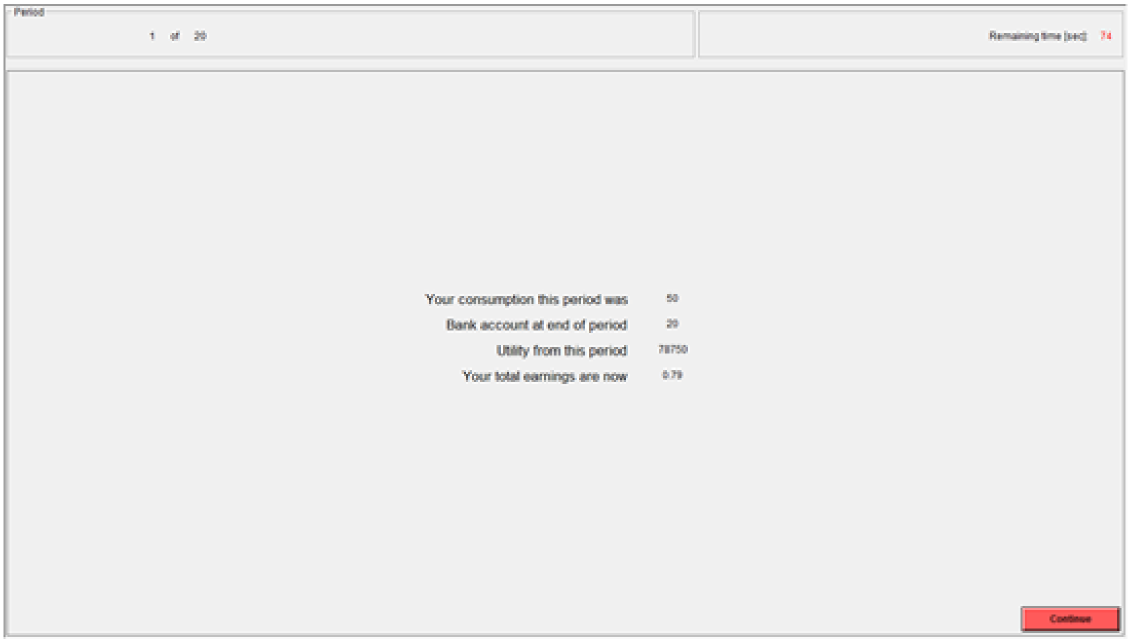


Figure 11: Review screen.

Additionally, we will complete each period (after you make a consumption decision) by providing a review screen that reminds you of how much income you spent on consumption in that period, your bank account balance at the end of that period, the amount of consumption points you earned in that period, and your total consumption points.

Once all subjects complete the first 20-period sequence, we will begin another 20-period sequence. The only difference between the first and second 20-period sequence is that the sequence of endowments (the income you receive at the beginning of each period) will be different. This is because the sequence is randomly drawn with equal probability from the closed interval of [60,80].

Payment:

Your payment today will consist of your $10 show-up fee, your earnings from the initial questionnaire (where you earn $.25 for each correct question), whatever you earn from both of your randomly implemented gamble, and your earnings from the two, 20-period sequences of decisions.

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. You can use the instructions to help answer these questions. Your performance on this quiz does not affect your payoff. 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 earn _______________ for each correct answer in the quiz.

2. Suppose it is period 5. Does the endowment you receive in period 5 depend on the endowment you received in period 4? _______________. Does it instead depend on an endowment received in some earlier period (1, 2 or 3)? _______________.

3. Suppose you have 100 ECs in your bank account at the beginning of a period. Does this include your endowment for that period? _______________.

4. Suppose you have 100 ECs in your bank account at the beginning of a period. What is the maximum amount you can spend on consumption this period? _______________. What will be your bank account balance at the end of the period if you spend this maximum amount? _______________.

5. True or False: We will pay you for the decisions you make in both sequences? True False.

6. If you and your partner together earn $30 for your joint consumption decisions, then you will personally earn how much? _______________.

7. Suppose you earn 200 consumption points total. How much money do you and your partner earn? _______________.

8. Does the marginal increase from an EC spent within a period earn you more or less consumption points than the previous EC spent in the same period?

7.8 Other Materials

CRT Questions:

1. A bat and a ball cost $1.10 in total. The bat costs $1.00 more than the ball. How much does the ball cost in cents?

2. If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets, in minutes?

3. In a lake there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake, in days?

4. In an athletics team, tall members are three times more likely to win a medal than short members. This year the team has won 60 medals so far. How many of these have been won by short athletes?

5. If John can drink one barrel of water in 6 days, and Mary can drink one barrel of water in 12 days, how long would it take them to drink one barrel of water together?

6. Jerry received both the 15th highest and the 15th lowest mark in the class. How many students are in the class?

Demographics Survey:

1. Select your gender. (Male, Female, Other?)

2. What is your age?

3. Which year in school are you? (Freshman, Sophomore, Junior, Senior, Graduate)

4. What is your major?

5. To the best of your knowledge, what is your GPA?

6. Approximately how much student loan debt do you have?

7. Approximately how much other debt do you have?

8. What income class were you in growing up, e.g. lower, middle, upper?

9. What is your current political affiliation?

Survey of Decisions:

1. What information did you use in making your consumption decisions?

2. Did you have a decision rule, if so, what was it?

3. Did you feel like you had enough time to make your decisions?

4. Do you believe it is good or bad to have debt?

5. Do you believe it is good or bad to have savings?

6. How well do you believe you performed on the consumption task? 25th percentile? 50th percentile? 75th percentile? 99th percentile?

Extra survey of decisons questions for Pairs treatment:

7. What was your communication strategy with your partner?

8. Did you tend to agree or disagree with your partner?

9. What was your strategy for overcoming disagreements?