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Abstract

This paper presents a nonparametric, revealed preference analysis of intertemporal consumption with risk. In an experimental setting, subjects allocate tokens over four commodities, consisting of consumption in two contingent states and at two time periods, subject to different budget constraints. With this data, one could test, using Afriat's Theorem and its generalizations, whether a subject's choices are consistent with utility maximization, and also utility maximization with various additional properties on the utility function. Our results broadly support a model where subjects maximize a utility function that is weakly separable across states but there is little support for weak separability across time. Our result sheds light on the source of the failure of the discounted expected utility model.

Keywords: risk preference, time preference, revealed preference, budgetary choice, Afriat's Theorem, experiment

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1 Introduction

Many important economic decisions involve agents choosing among alternatives that differ in both their risk and time properties. The canonical way of representing preferences in this context is to combine the expected utility and discounted utility models into what is known as the discounted expected utility (DEU) model, which evaluates the utility of a contingent consumption plan $(\widetilde{c}_1, \widetilde{c}_2, \widetilde{c}_3, ...)$ as

$$\sum_t \delta_t \mathbf{E}\left[u\left(\widetilde{c}_t\right)\right], \tag{1}$$

where $\widetilde{c}_t$ is the random consumption in period t and δ_t is the corresponding discount factor. With (additive) separability across both time periods and states, DEU has the great advantage of being a simple and tractable model which can deliver sharp conclusions in different applied contexts. However, this simplicity also means that the model cannot distinguish between an agent's attitude towards risk and his attitude towards intertemporal consumption. For this reason and others, alternative models have been proposed, which dispenses with separability either across states or across time (e.g., Kreps and Porteus, 1978; Selden, 1978; Epstein and Zin, 1989; Chew and Epstein,1990; and Halevy, 2008; see Section 1.1 for a more detailed discussion). Notably, some of these models have been shown to capture a broader domain of phenomena, such as the equity premium puzzle (Epstein and Zin, 1991).

In this paper, we design an experiment which will allow us to find out, using purely nonparametric methods, the source of the departure from the DEU model. In our experiment, subjects allocate experimental tokens to four commodities, which pay out in two states s_1 and s_2 and two time periods t_1 and t_2, as follows:

$$\begin{array}{ccc} & t_1 & t_2 \\ s_1 & c_{11} & c_{12} \\ s_2 & c_{21} & c_{22} \end{array}$$

The two states s_1 and s_2 are set to be equiprobable, while t_1 and t_2 are one week later and nine weeks later respectively. Subjects allocate 100 tokens by choosing $c = (c_{11}, c_{12}, c_{21}, c_{22})$ subject to the budget constraint

$$p_{11}c_{11} + p_{12}c_{12} + p_{21}c_{21} + p_{22}c_{22} \leq 100. \tag{2}$$

We present subjects with different budget sets by varying the price vector $p = (p_{11}, p_{12}, p_{21}, p_{22})$, with each subject making an allocation decision in a total of 41 budget sets. Eliciting preferences from budgetary decisions is becoming a fairly common experimental practice, but ours is the first experiment in which subjects choose among affordable alternatives where payoffs vary in two dimensions, i.e., in *both* state and time.

From each subject, we obtain a dataset with 41 observations, with each each observation i consisting of a price vector $p^i = (p_{11}, p_{12}, p_{21}, p_{22})$ and the corresponding choice $c^i = (c_{11}, c_{12}, c_{21}, c_{22})$ made by the subject at that price vector. Throughout the paper, we apply (nonparametric) revealed preference methods to test alternative hypotheses on a subject's utility function U defined on the contingent consumption plan $c \in \mathbb{R}^4_+$. At the most general, we ask whether the subject is maximizing some well-behaved (i.e., strictly increasing and continuous) utility function U. In other words, we ask whether there exists a function U such that the subject is choosing optimally given his budget; formally, at every observation i, we require $U(c^i) \geq U(c)$ for all c satisfying the budget constraint (2), with $p = p^i$. Afriat's Theorem (see Afriat (1967) and Varian (1982)) establishes that a data set $\mathcal{O} = \{(p^i, c^i)\}_{i=1}^{41}$ is consistent with this utility-maximization hypothesis if and only if it obeys GARP (the generalized axiom of revealed preference), a property which is computationally straightforward to check.

If the subject is maximizing discounted expected utility, then (with equiprobable states)

$$U(c_{11}, c_{12}, c_{21}, c_{22}) = \frac{1}{2}u(c_{11}) + \frac{1}{2}\delta u(c_{12}) + \frac{1}{2}u(c_{21}) + \frac{1}{2}\delta u(c_{22}). \tag{3}$$

for some increasing function u and $\delta \in (0, 1)$. DEU is a special case of a utility function that is *weakly separable across states*, which has the general form

$$U(c_{11}, c_{12}, c_{21}, c_{22}) = F(\upsilon(c_{11}, c_{12}), \widetilde{\upsilon}(c_{21}, c_{22})),$$

where υ ($\tilde{\upsilon}$) is the sub-utility function over consumption streams in state 1 (state 2) and F aggregates over the two sub-utilities. (In the DEU case, $\upsilon(c_{11}, c_{12}) = u(c_{11}) + \delta u(c_{12})$, $\tilde{\upsilon}(c_{21}, c_{22}) = u(c_{11}) + \delta u(c_{12})$ and F is the simple average between these two sub-utilities.) The DEU form is also a special case of a utility function that is *weakly separable across time*, which has the general form

$$U(c_{11}, c_{12}, c_{21}, c_{22}) = G(\omega(c_{11}, c_{21}), \widetilde{\omega}(c_{12}, c_{22})).$$

In this case, ω ($\tilde{\omega}$) is a sub-utility function over state-contingent consumption at date 1 (date 2) and the two sub-utilites are aggregated by the function G.

If a subject is a DEU maximizer, his dataset $\mathcal{O} = \{(p^i, c^i)\}_{i=1}^{41}$ will obey properties beyond GARP. In particular, the subject's choice of consumption stream in state 1 must maximize the sub-utility over consumption streams in state 1 that incur the same cost or less, and similarly for state 2. In other words, $c^i_{s_1} = (c^i_{11}, c^i_{12})$ must be optimal at price $p^i_{s_1} = (p^i_{11}, p^i_{12})$ in the sense that $v(c^i_{s_1}) \geq v(c_{11}, c_{12})$ for all (c_{11}, c_{12}) obeying $(p^i_{11}, p^i_{12})\cdot(c_{11}, c_{12}) \leq (p^i_{11}, p^i_{12})\cdot(c^i_{11}, c^i_{12})$. Therefore, if $\mathcal{O}$ is collected from a DEU maximizer, or more generally from a subject with a utility function weakly separable across states, the spliced data sets $\mathcal{O}_{s_1} = \{(p^i_{s_1}, c^i_{s_1})\}^{41}_{i=1}$ and $\mathcal{O}_{s_2} = \{(p^i_{s_2}, c^i_{s_2})\}^{41}_{i=1}$ will both obey GARP.

By a similar logic, if a data set is collected from a DEU maximizer or more generally from an agent with a utility function that is weakly separable across time, then GARP holds if $\mathcal{O}$ is spliced along the time dimension, i.e., $\mathcal{O}_{t_1} = \{(p^i_{t_1}, c^i_{t_1})\}^{41}_{i=1}$ and $\mathcal{O}_{t_2} = \{(p^i_{t_2}, c^i_{t_2})\}^{41}_{i=1}$ will both obey GARP, where $p^i_{t_1} = (p^i_{11}, p^i_{21})$ and $c^i_{t_1} = (c^i_{11}, c^i_{21})$.

When we test the data for these properties, we find that, in general, $\mathcal{O}$ obeys GARP and so does $\mathcal{O}_{s_1}$ and $\mathcal{O}_{s_2}$, but that is not true of $\mathcal{O}_{t_1}$ and $\mathcal{O}_{t_2}$. In other words, there is general support for utility maximization broadly defined and also for the existence of sub-utility functions defined on consumption streams, but there is weak support for sub-utility functions defined on contingent consumption. Furthermore, there is evidence that the sub-utility function on consumption streams is the same in both states, i.e., $v = \tilde{v}$ and also that this sub-utlity function exhibits impatience, i.e., one could find a rationalization of $\mathcal{O}_{s_1}$ such that $v(x, y) \geq v(y, x)$ whenever $x \geq y$. Testing for rationalizability with a utility function exhibiting impatience requires a strengthening of the GARP property (see Nishimura, Ok, and Quah (2017)).

These results suggest that, for most subjects, a utility function that is weakly across states but not necessarily across time captures their behavior well. Indeed, there is a generalization of Afriat's thoerem to test for rationalizabitliy with a weakly separable utility function (see Quah (2014)). Using this test, we find that 26% of the subjects satisfy both state and time separability (approximately), 50% of the subjects satisfy state separability but not time separability, 4% of the subjects satisfy time separability but not state separability, 11% of the subjects satisfy neither state separability nor time separability, the rest of 10% fail the overall GARP test and are not consistent with utility-maximization for the most general utility function U.

1.1 Related Literature

In the theoretical literature, alternative models of DEU have been proposed that relax either state or time separability, e.g., Kreps and Porteus (1978); Selden (1978); Epstein and Zin (1989); Chew and Epstein (1990); and Halevy (2008). Kreps and Porteus (1978) focuses on the *time neutrality* property of DEU, i.e., DEU predicts indifference between two contingent consumption plans that both deliver c_1 in period 1 and $\widetilde{c_2}$ in period 2, even though in one plan the uncertainty resolves at period 1 and in the other at period 2. In relaxing time neutrality, Kreps and Porteus (1978) obtains a recursive expected utility representation that is essentially time non-separable. Selden (1978) and Epstein and Zin (1989) focus instead on the non-distinction between risk preference and time preference in the DEU model. To illustrate, notice that DEU reduces to expected utility $\mathbf{E}[u(\widetilde{c})]$ for degenerate contingent consumption $\widetilde{c}$, and to discounted utility $\sum \delta_t u(c_t)$ for a deterministic consumption stream $(c_1, c_2, c_3, ...)$. Therefore, the same utility index u captures both the attitude towards risk and the attitude towards intertemporal substitution. The utility forms proposed in both Selden (1978) and Epstein and Zin (1978) disentangle risk preference from time preference, but Selden (1978) relaxes state separability while Epstein and Zin (1989) relaxes time separability. Follow-up models, including Chew and Epstein (1990) and Halevy (2008), attempt to distinguish risk preference from time preference by incorporating non-expected utility.

A number of recent experimental studies investigate various aspects of attitude towards intertemporal risks. Andreoni and Sprenger (2012a) propose an experimental design termed Convex Time Budget (CTB) to elicit time preference. In this experiment, subjects make allocation decisions between sooner and later payment. Andreoni and Sprenger (2012a) find that the utility index for time preference elicited using CTB is distinct from the utility index for risk elicited using price list. Relatedly, Abdellaoui et al. (2013) introduce a method to measure utility functions for risk preference and time preference separately, and find that the utility function under risk is more concave than the utility function over time. In another paper, Andreoni and Sprenger (2012b) consider CTB under a risky environment, in which there is a 50 percent chance of receiving the earlier payment and, independently, another 50 percent chance of receiving the later payment; they find that subjects are more responsive to changes of interest rate in the risky environment than under certainty. Based on these experimental results, Andreoni and Sprenger (2012a, b) conclude that risk preference is distinct from time preference. Epper and Fehr-Duda (2015) show theoretically that rank-dependent probability weighting (Halevy, 2008) can account for the key findings in Andreoni and Sprenger (2012b). Miao and Zhong (2015) also experimentally investigate intertemporal decision making and find support for a separation between attitudes towards risk and attitudes towards intertemporal substitution; their findings are broadly consistent with the models of Epstein and Zin (1989), Chew and Epstein (1990), and Halevy (2008). These experimental studies focus on the distinction between the utility index for risk aversion and intertemporal substitution, but they do not directly test for the separability of subjects' utility function across states and across time. The current study provides the first experimental test examining this issue.

The convex time budgets of Andreoni and Sprenger (2012a, b) is an instance in the experimental literature where budgetary choice decisions are employed to study preferences. Other instances include Andreoni and Miller (2001) and Fisman, Markovits and Kariv (2007), which study social preferences by considering modified dictator games in which the subjects allocate tokens between herself and anonymous recipients, with the value of each token varying across observations. Choi et al. (2007) study risk preferences by having subjects make portfolio decisions involving contingent consumption. Our study could be thought of as an extension of the Choi et al. (2007) experiment to one where risk and time preferences are studied in conjunction.

Whenever budgetary decisions are analysed, it is commonplace to appeal to Afriat's Theorem to study rationalizability or approximate rationalizability, the latter through the use of the critical cost efficiency index (Afriat, 1974). For example, Choi et al. (2015) find, in a large-scale experiment with household subjects, that the level of choice consistency with utility maximization, as measured by this index, is positively correlated to wealth. It is less common to go beyond Afriat's Theorem to use other revealed preference tests to evaluate the consistency of decision making with more specific models of utility maximization; examples of this include Polisson, Quah, and Renou (2015) for risk preference and Saito, Echenique and Imai (2015) for time preference. The use of revealed preferences tests beyond GARP is a feature of this paper.

1.2 Organization of the paper

Section 2 presents the experimental design. Since results in revealed preference analysis are used extensively in the paper, these are explained in some detail in Section 3. The results of the experiment are report in Section 4 and Section 5 concludes. There is also an Appendix with more detailed results.

2 Experiment Design

This section describes the design of our experiment, in which subjects make allocation decisions under different budget constraints. Specifically, we provide subjects with a budget of 100 experimental tokens which they can allocate over four date and state contingent commodities. A typical consumption bundle can be written as $c = (c_{11}, c_{12}, c_{21}, c_{22})$ where c_{st} refers to consumption in state s at time t. The two states, determined by a coin toss, are of equal probability; and the two time points are one week later and 9 weeks later.

The price vector $p = (p_{11}, p_{12}, p_{21}, p_{22})$ is obtained by having the price for each commodity randomly selected from the set $\{0.5, 0.8, 1, 1.25, 2\}$, with at least one price being equal to

1. This gives rise to 96 distinct price vectors. We randomly select 41 price vectors for each subject with one of them fixed to be the benchmark vector $(1, 1, 1, 1)$.

At the end of the experiment, each subject is paid according to one randomly selected decision task by tossing dice according to the Random Incentive Mechanism (RIM).[1] Subjects are informed to treat each decision as if it were the sole decision determining their payments. To control for preference for the timing of uncertainty resolution, all uncertainty is resolved at the end of the experiment. Once the decision task is selected and the state is realized, each subject is paid with an exchange rate of SGD 0.2 (about USD 0.15) per experimental token. To increase the credibility of payment, subjects are paid with post-dated checks that will not be honored by the local bank when presented prior to the date indicated. To further control for the potential difference in transaction cost at different time points (Andreoni and Sprenger, 2012a), subjects receive a minimum participation fee of SGD 12 (with SGD 6 for each payday). Experimental earnings are added to these minimum payments.

We note that the experiment in this study is based on monetary reward while in most models utility is derived from actual consumption. Reuben, Sapienza, and Zingales (2010) elicit discount factors for both monetary rewards and primary rewards of chocolate and find a positive and statistically significant relation between discount rates elicited using monetary and primary rewards. The observed correlation suggests that measurement through monetary reward might be ecologically valid. Augenblick, Niederle, and Sprenger (2013) study time preference over effort and show that the incentive for smoothing is higher for effort than for monetary reward. Readers can refer to Halevy (2014) for insightful discussions on the validity of using cash payment to elicit time preference. Notwithstanding these caveats, we posit that our overall approach would be applicable to the settings with actual consumptions.

A total of 103 undergraduate students are recruited as participants through an advertisement posted in the Integrated Virtual Learning Environment at the National University of Singapore. The experiment is conducted at the laboratory of the Center for Behavioral Economics at the National University of Singapore. Conducted by two of the authors and a research assistant, the experiment consists of four sessions with 20 to 30 subjects in each session. After the subjects arrive at the experiment venue, they are given the consent form approved by the Institutional Review Board of the National University of Singapore. Following that, general instructions are read aloud to the subjects, and several examples are demonstrated to them before they started making their decisions. The experimental instructions follow closely those in Andreoni and Sprenger (2012b) (See Appendix C for the Experimental Instructions). Most of our subjects complete the tasks within 30 minutes. At the end of the experiment, they approach the experimenters one by one, toss the dice and

[1]For the validity of RIM, readers can refer to Wakker (2007) for a detailed discussion.

receive payments in post-dated checks based on their choice. On average, the subjects are paid SGD 22.

3 Revealed Preference Analysis

In Section 3.1 we describe and explain the basic GARP condition that characterizes rationalizability with a well-behaved utility function. In Section 3.2 we consider further properties which we may require of a utility function rationalizing a dataset, and show how the GARP condition could be modified to check for rationalizability with utility functions having those properties.

3.1 GARP

We denote by $p^i = (p^i_{11}, p^i_{12}, p^i_{21}, p^i_{22})$ the price vector faced by the subject in decision problem i, and by $c^i = (c^i_{11}, c^i_{12}, c^i_{21}, c^i_{22})$ the bundle chosen by the subject. Thus the collection of a subject's decisions for all I decision problems can be written as

$$\mathcal{O} = \left\{(p^1, c^1), \ldots, (p^I, c^I)\right\}.$$

We shall refer to such a collection as a *dataset.* A utility function $U : \mathbb{R}^4_+ \to \mathbb{R}$ *rationalizes* the dataset $\mathcal{O}$ if, at each observation $i \in I$,[2]

$$U(c^i) \geq U(c) \text{ for all } c \in \mathbb{R}^4_+ \text{ s.t. } p^i \cdot c^i \geq p^i \cdot c.$$

This condition states that if a subject can afford c when choosing c^i, then it must be the case that the utility derived from c^i is weakly higher than that derived from c.

We refer to a utility function (or more generally any function defined on a subset of the Euclidean space) as *well-behaved* if it is continuous and strictly increasing. Afriat's Theorem (see Afriat (1967) and Varian (1982)) provides a necessary and sufficient condition under which a dataset can be rationalized by a well-behaved utility function. We shall now describe that test.

Let $\mathcal{C} = \{c^i\}_{i \in I}$ be the set of bundles chosen by the subject at some observation i. Given a dataset $\mathcal{O}$, if a subject chooses c^i when some c^j in $\mathcal{C}$ is affordable (i.e., $p^i \cdot c^i \geq p^i \cdot c^j$), then we say that c^i is *directly revealed preferred* to c^j and denote it by $c^i \succsim^* c^j$. If c^j is strictly cheaper than c^i ($p^i \cdot c^i > p^i \cdot c^j$), then we say that c^i is *directly strictly revealed preferred* to c^j and denote it by $c^i \succ^* c^j$. Lastly, let the *revealed preferred* relation be the transitive closure

[2]We shall abuse notation and use I to denote the number of observations as well as the set $\{1, 2, \ldots, I\}$.

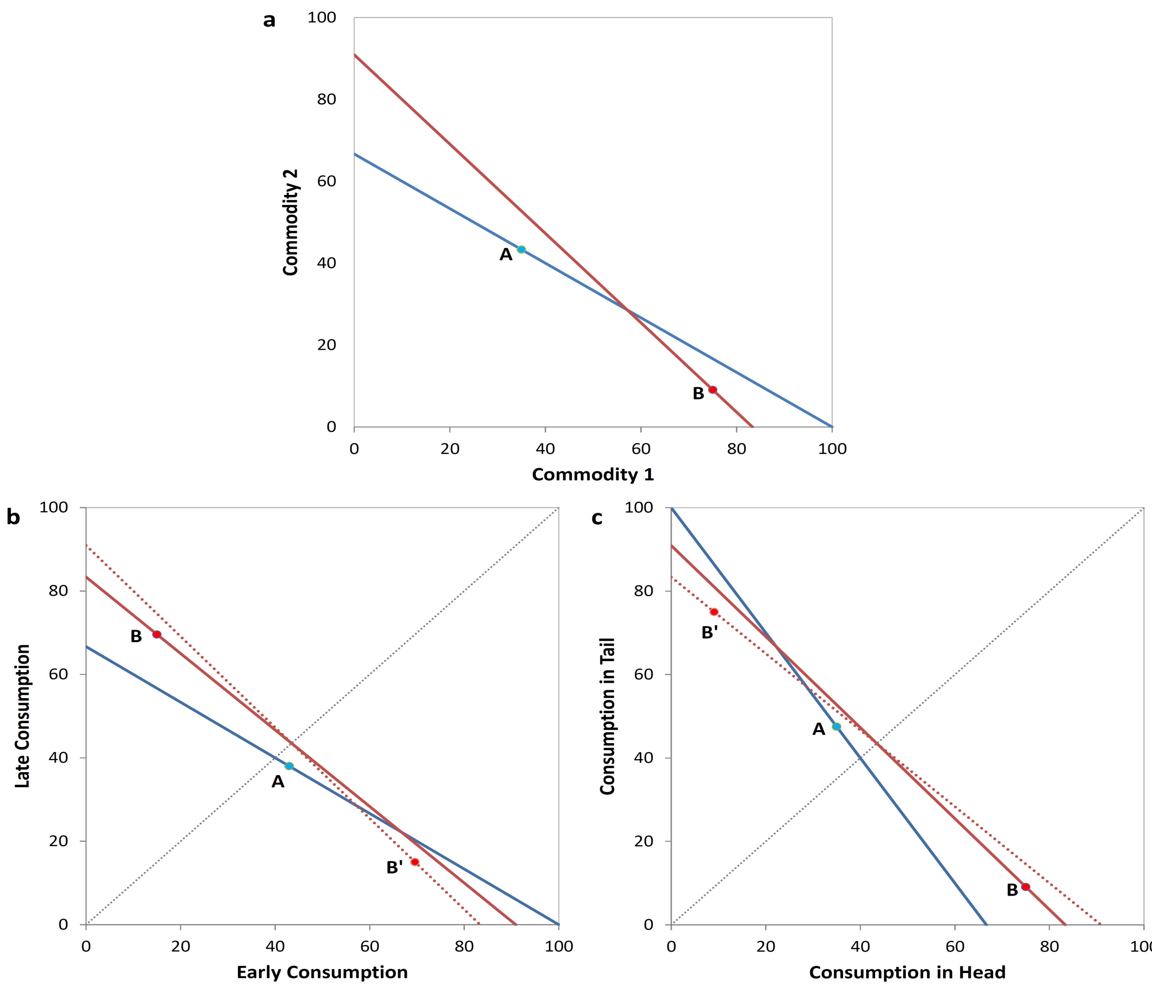

Figure 1: Illustration of violations of GARP, Impatience and Symmetry. *Fig 1.a depicts a violation of GARP, since A is revealed strictly preferred to B and B is revealed strictly preferred to A. GARP is not violated in Fig 1.b; however it is not consistent with optimization with an impatient utility function. B is revealed strictly preferred to A and A is also revealed strictly preferred to B under the impatience assumption, since B' is contained in the budget set when A is chosen and the impatient subject must prefer B' to B. In Fig 1.c, GARP is not violated, but the data is not compatible with maximization of a symmetric utility function. B is revealed preferred to A and, under symmetry A is revealed preferred to B (because A is revealed preferred to B').*

of $\succsim^*$, denoted as $\succsim^{**}$.[3] A dataset $\mathcal{O}$ satisfies the *generalized axiom of revealed preference* (GARP) if the following holds:

$$\text{for all } c^i \text{ and } c^j,\ c^i \succsim^{**} c^j \text{ implies } c^j \not\succ^* c^i. \tag{4}$$

Figure 1.a depicts a violation of GARP involving two observations. It is not difficult to show

[3] In detail, $c^i \succsim^{**} c^j$ if we can find $i_1, \ldots, i_K$ such that $c^i \succsim^* c^{i_1} \succsim^* c^{i_2} \succsim^* \ldots \succsim^* c^{i_K} \succsim^* c^j$.

that any dataset that can be rationalized by a well-behaved utility function (indeed, by any locally nonsatiated preference) must satisfy GARP; the substantive part of Afriat's Theorem establishes that GARP is also *sufficient* for a dataset to be rationalized by a well-behaved utility function.

GARP tests provide 0/1 results, i.e., a subject is either consistent or inconsistent with maximizing a specific utility function. However, a subject may behave roughly in accordance with utility maximization but for some reason such as inattention and measurement error, the subject does not choose the optimal bundle on all occasions. A popular approach to measure departures from rationality to use the *critical cost efficiency index* (CCEI) developed in Afriat (1972). This index, which ranges from 0 to 1, is a measure of the efficiency with which a subject allocates his budget. Formally, a subject has a CCEI of $e \in [0, 1]$ if e is the largest number such that there is a well-behaved utility function U with

$$U(c^i) \geq U(c) \text{ for all } c \in \mathbb{R}^4_+ \text{ s.t. } p^i \cdot c^i \geq e\, p^i \cdot c, \text{ for all } i \in I. \tag{5}$$

A CCEI of 1 indicates that a subject is perfectly utility-maximizing. A CCEI less than 1, say 0.95, indicates that there is a well-behaved utility function that approximately rationalizes the data in the sense that there is a utility function for which the chosen bundle c^i (at every observation i) is preferred to any bundle that is more than 5% cheaper than c^i (at the prevailing price vector p^i).

Approximate rationalizability at some coefficient e (in the sense given by (5)) can be tested using a modified version of GARP, in which the revealed preference relation $\succsim^*_e$ is defined as follows: $c^i \succsim^*_e c^j$ if $p^i \cdot c^i \geq e\, p^i \cdot c^j$. In an analogous way, one could define $\succ^*_e$, the transitive closure $\succsim^{**}_e$ and the no-cycling condition (4). Such a condition is necessary and sufficient for rationalizability at that coefficient (see Afriat (1972)).

3.2 More revealed preference tests

The basic GARP test could be extended in various ways to test for more stringent conditions on the rationalizing utility function. We confine our discussion here to those properties which must be satisfied by any subject who maximizes a discounted expected utility function. It follows that a rejection of any of these properties implies a rejection of the discounted expected utility model.

Property 1: State Separability. A utility function U satisfies state separability if there are well-behaved functions $F : \mathbb{R}^2 \to \mathbb{R}$, $\upsilon, \widetilde{\upsilon} : \mathbb{R}^2_+ \to \mathbb{R}$, such that

$$U(c_{11}, c_{12}, c_{21}, c_{22}) = F(\upsilon(c_{11}, c_{12}), \widetilde{\upsilon}(c_{21}, c_{22})). \tag{6}$$

State separability implies that the consumption stream in one state can be ordered independently of what is obtained in the other state. Therefore, if two bundles give the same consumption stream in (for example) state 2, then altering that stream will not change the preferred bundle, i.e.,

$$\begin{array}{ccc} & t_1 & t_2 \\ s_1 & x & y \\ s_2 & z & w \end{array} \succ \begin{array}{ccc} & t_1 & t_2 \\ s_1 & x' & y' \\ s_2 & z & w \end{array} \Rightarrow \begin{array}{ccc} & t_1 & t_2 \\ s_1 & x & y \\ s_2 & z' & w' \end{array} \succ \begin{array}{ccc} & t_1 & t_2 \\ s_1 & x' & y' \\ s_2 & z' & w' \end{array}$$

Property 2: Time Separability. A utility function U satisfies time separability if there are well-behaved functions $G : \mathbb{R}^2 \to \mathbb{R}$, $\omega, \widetilde{\omega} : \mathbb{R}^2_+ \to \mathbb{R}$, such that

$$U(c_{11}, c_{12}, c_{21}, c_{22}) = G(\omega(c_{11}, c_{21}), \widetilde{\omega}(c_{12}, c_{22})). \tag{7}$$

In this case, the ranking over two bundles with the same contingent consumption at (say) date 1 will not be altered if the date 1 contingent consumption is changed, i.e.,

$$\begin{array}{ccc} & t_1 & t_2 \\ s_1 & x & y \\ s_2 & z & w \end{array} \succ \begin{array}{ccc} & t_1 & t_2 \\ s_1 & x & y' \\ s_2 & z & w' \end{array} \Rightarrow \begin{array}{ccc} & t_1 & t_2 \\ s_1 & x' & y \\ s_2 & z' & w \end{array} \succ \begin{array}{ccc} & t_1 & t_2 \\ s_1 & x' & y' \\ s_2 & z' & w' \end{array}$$

For a data set to be rationalizable by a utility function that is weakly separable across states, it is clear that GARP should be satisfied by $\mathcal{O}$, and it should also be satisfied when the data is restricted to each state; in other words, $\mathcal{O}_{s_1} = \left\{\left(p^i_{s_1}, c^i_{s_1}\right)\right\}_{i\in I}$ (where $p^i_{s_1} = (p^i_{11}, p^i_{12})$ and $c^i_{s_1} = (c^i_{11}, c^i_{12})$) and $\mathcal{O}_{s_2} = \left\{\left(p^i_{s_2}, c^i_{s_2}\right)\right\}_{i\in I}$ must both obey GARP. However, these three conditions together are *not* sufficient to guarantee weak separability.

Necessary and sufficient conditions for weak separability can be found in Quah (2014). We shall now describe that test, focusing on the case of state separability. First, we must find a complete and transitive relation, $\succsim_{s_1}$ on $\mathcal{C}_{s_1} = \{c^i_{s_1}\}_{i\in I}$ that extends the revealed preference and revealed strict preference relations on $\mathcal{C}_{s_1}$,[4] and another complete and transitive relation on $\mathcal{C}_{s_2} = \{c^i_{s_2}\}_{i\in I}$ that extends the revealed preference and revealed strict preference relations $\mathcal{C}_{s_2}$. Based on $\succsim_{s_1}$ and $\succsim_{s_2}$, we then construct a revealed preference relation on $\mathcal{C}$ such that c^i is revealed preferred to c^j if there exist $c^k_{s_1} \in \mathcal{C}_{s_1}$ and $c^\ell_{s_2} \in \mathcal{C}_{s_2}$ obeying the following conditions: (i) $(p^i_{s_1}, p^i_{s_2}) \cdot (c^i_{s_1}, c^i_{s_2}) \geq (p^i_{s_1}, p^i_{s_2}) \cdot (c^k_{s_1}, c^\ell_{s_2})$; (ii) $c^k_{s_1} \succsim_{s_1} c^j_{s_1}$; and (iii) $c^\ell_{s_2} \succsim_{s_2} c^j_{s_2}$. We say that c^i is revealed strictly preferred to c^j if either the inequality in (i) is strict, or either of the preferences in (ii) and (iii) are strict. Quah (2014) shows that if $\succsim_{s_1}$ and $\succsim_{s_2}$ could be found so that the resulting revealed relations admit no cycles in the sense of (4),

[4] The complete and transitive relation $\succsim_{s_1}$ *extends* the revealed preference relations if $c^i_{s_1} \succsim_{s_1} (\succ_{s_1})\, c^j_{s_1}$ if $c^i_{s_1}$ is revealed preferred (revealed strictly preferred) to $c^j_{s_1}$.

then the data is rationalizable by a utility function that is weakly separable across states.[5] (It is clear that this condition is also necessary.)

If a subject has a utility function that is weakly separable across states, then it would be natural to expect the sub-utility functions (which are defined on consumption streams over time) to exhibit impatience. This means that given a larger quantity x and a smaller quantity y, an impatient subject would prefer the larger quantity early and the smaller quantity later.

Property 3: Impatience. $x \geq y$ implies $\upsilon(x, y) \geq \upsilon(y, x)$, and $\widetilde{\upsilon}(x, y) \geq \widetilde{\upsilon}(y, x)$.

Similar to the test for weak separability, the test for this property involves strengthening the revealed preference conditions and then testing for the absence of cycles. We focus our discussion on consumption streams in state 1. For $c^i_{s_1}$ and $c^j_{s_2}$ in $\mathcal{C}_{s_1}$, we say that $c^i_{s_1} = (c^i_{11}, c^i_{12})$ is revealed preferred to $c^j_{s_1} = (c^j_{11}, c^j_{12})$ if either (i) $p^i_{s_1} \cdot c^i_{s_1} \geq p^i_{s_1} \cdot c^j_{s_1}$ or (ii) $p^i_{s_1} \cdot c^i_{s_1} \geq p^i_{s_1} \cdot (c^j_{12}, c^j_{11})$ and $c^j_{12} > c^j_{11}$. In addition, $c^i_{s_1}$ is revealed strictly preferred to $c^j_{s_1}$ if either (ii) holds or the inequality in (i) is strict. With these modified definitions of revealed preference, it is straightforward to check that the no-cycling condition (4) is necessary for rationalization by a well-behaved utility function υ exhibiting impatience; furthermore, this condition is also sufficient for rationalization by a utility function with these properties (see Nishimura, Ok, and Quah (2017)). Figure 1.b depicts a dataset with two observations that obeys GARP but cannot be rationalized with an impatient utility function.

In the case where there is weak separability across time, the sub-utility functions ought to be symmetric since the two states are equiprobable in our experiment.

Property 4: Symmetry. $\omega(x, y) = \omega(y, x)$ and $\widetilde{\omega}(x, y) = \widetilde{\omega}(y, x)$, for any x, $y \in \mathbb{R}_+$.

To explain the test for this property, we focus our discussion on contingent consumption at date 1. Let $\mathcal{C}_{t_1} = \{c^i_{t_1}\}_{i \in I}$, where $c^i_{t_1} = (c^i_{11}, c^i_{21})$. For $c^i_{t_1}$ and $c^j_{t_1}$ in $\mathcal{C}_{t_1}$, we define $c^i_{t_1}$ as revealed preferred to $c^j_{t_1}$ if either (i) $p^i_{t_1} \cdot c^i_{t_1} \geq p^i_{t_1} \cdot c^j_{t_1}$ or (ii) $p^i_{t_1} \cdot c^i_{t_1} \geq p^i_{t_1} \cdot (c^j_{21}, c^j_{11})$. In addition, $c^i_{t_1}$ is revealed strictly preferred to $c^j_{t_1}$ if either (i) or (ii) holds with strict inequality. With these modified definitions of revealed preference, it is straightforward to check that the no-cycling condition (4) is necessary for rationalization by a well-behaved and symmetric utility function ω; less obviously, this condition is also sufficient (see Nishimura, Ok, and Quah (2017)). Figure 1.c gives an example of a dataset with two observations that obeys GARP but is not rationalizable with a symmetric utility function.

Lastly, it would be natural to hypothesize that any sub-utility over consumption streams is state independent, in the sense that $\upsilon = \widetilde{\upsilon}$, and that any sub-utility over contingent consumption would be time-invariant, in the sense that $\omega = \widetilde{\omega}$,

[5] Notice that this test is computationally more demanding than the GARP test because in principle one needs to go through all the possible extensions of the revealed preference relations and check for cycles before one could definitively reject weak separability.

Property 5: State-Independent Time Preference. $\upsilon = \widetilde{\upsilon}$.

Property 6: Time-Invariant Risk Preference. $\omega = \widetilde{\omega}$.

Property 5 can be tested by pooling $\mathcal{O}_{s_1}$ and $\mathcal{O}_{s_2}$ into a single data set and then checking if it is rationalizable, either with a well-behaved utility function or a well-behaved and impatient utility function. Similarly, time-invariance can be tested by pooling $\mathcal{O}_{t_1}$ and $\mathcal{O}_{t_2}$.

Lastly, we should mention that even though throughout this subsection we have confined our discussion to testing for exact rationalizability, it is possible to modify these tests to measure the critical cost efficiency index when exact rationalizability fails. The approach is broadly the same as that (described at the end of Section 3.1) for the standard GARP test.

4 Results

4.1 Aggregate Behavior

This subsection provides a brief summary of aggregate behavior. Figure 2 plots the average allocation of tokens for each of the four commodities under each price.[6] Two patterns arise. First, the average allocation is lower when the price is higher, suggesting that the law of demand is satisfied in the aggregate level. Second, at any given price, the allocation to the early time point is larger than that to the late time point, which is indicative evidence that subjects are on average impatient.

We further conduct regression analyses with the tokens allocated to each commodity as dependent variable and the prices for all the commodities as independent variable. We apply a Tobit regression model with censoring at both 0 and 100, given the concern of corner choices. From the results reported in Table 1 below, we observe that the tokens allocated to each commodity is negatively affected by its own price, and positive affected by the price of the other three commodities. Moreover, the cross-price effect is stronger if the two commodities are within same time period, compared to when they are within the same state. This suggests that the motive for diversification across states is stronger than the motive for smoothing across time points.

One common issue with convex budget design is the prevalence of corner choices. For example, Chakraborty et al. (2016) examine the external consistency and internal consistency of convex time budget experiments. In particular, they find substantial violation of wealth monotonicity, demand monotonicity, and impatience for subjects making interior choices.

[6]This is computed as the simple average across all observations and all subjects, without regard to the other prevailing prices.

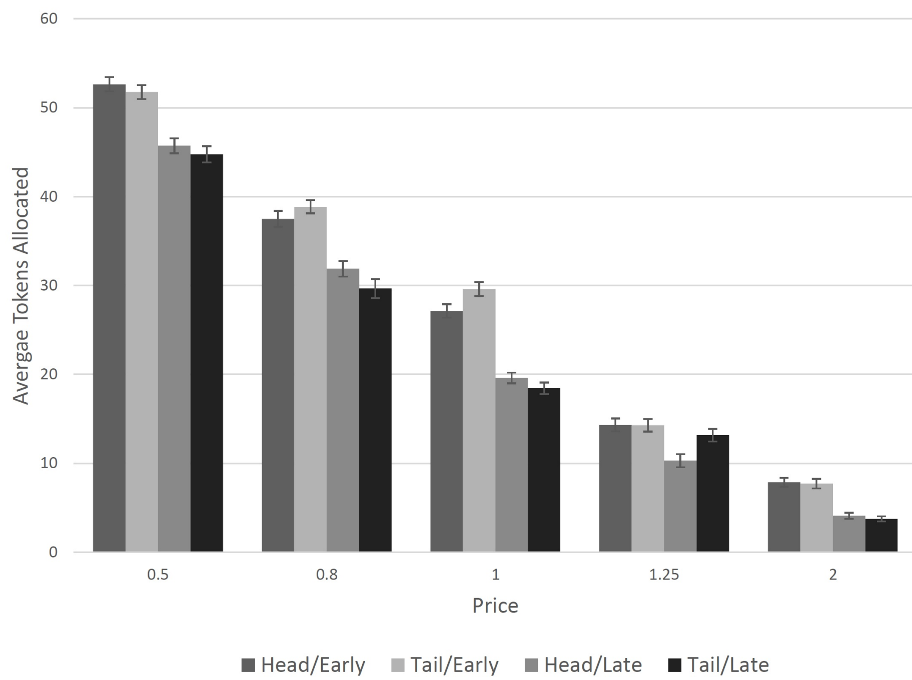

Figure 2: Average Tokens Allocated to Each Commodity. *Average tokens are calculated by pooling all subjects' choices, and plotted for each price and each of the four commodities.*

In our setting, an observation (p^i, c^i) is classified as a corner choice if the subject allocates 0 token to at least one commodity. We find that on average 76.7 percent of the subjects' choices are corner for a given price vector, 49 percent of the subjects make corner choices for all price vectors, and 91 percent of the subjects make at least one corner choice in the 52 price vectors. We separate the analysis for those with and without corner choices in Appendix B (Table B1, B2), and find that our main observations remain intact.

4.2 Revealed Preference Analysis

In this subsection, we report the results of the revealed preference tests for the properties identified in Section 3.2. As we have pointed out, all of the properties listed there must hold if the agent is maximizing a discount expected utility function. The most basic tests concern the existence of sub-utility functions, either defined over dated consumption (conditional on a state) or contingent consumption (at a given date).

First, we focus on the existence and behavior of sub-utility functions in each state. Note that the existence of these sub-utility functions is necessary (though not sufficient) for rationalization with a state separable utility function (of the form (6)). To be specific, we test if there are sub-utility functions υ $(\widetilde{\upsilon})$ rationalizing the datasets $\mathcal{O}_{s_1}$ $(\mathcal{O}_{s_2})$. Table 2 reports the results of these tests. At the CCEI level of 0.95, around 85 percent of the subjects have a

Table 1: Regression Analysis on Price Effect.

	Head/Early allocation	Tail/Early allocation	Head/Late allocation	Tail/Late allocation
Head/Early Price	**-38.831*** **	3.902***	31.237***	2.367**
	(3.872)	(1.425)	(2.584)	(1.157)
Tail/Early Price	3.660***	**-38.384*** **	4.640***	31.198***
	(1.205)	(3.497)	(1.458)	(2.715)
Head/Late Price	24.757***	3.517***	**-40.866*** **	1.928
	(2.138)	(1.300)	(4.447)	(1.302)
Tail/Late Price	1.924**	23.524***	3.750***	**-39.549*** **
	(0.862)	(1.821)	(1.305)	(4.317)
constant	30.120***	28.292***	9.147**	12.055***
	(2.846)	(3.237)	(3.737)	(3.401)
Observations	4,223	4,223	4,223	4,223
Pseudo R-squared	0.0659	0.0689	0.0701	0.0745

Table 2: Impatience and State-Independent Time Preference.

		CCEI 1	CCEI 0.99	CCEI 0.95	CCEI 0.90
Head	Well-Behaved	0.689	0.796	0.854	0.912
	Impatience	0.670	0.767	0.845	0.893
Tail	Well-Behaved	0.650	0.806	0.864	0.903
	Impatience	0.641	0.757	0.825	0.874
Pooled	State-Independence	0.553	0.709	0.825	0.883
	State-Ind. with Impatience	0.544	0.650	0.786	0.845

well-behaved utility function in state Head and similar proportion in state Tail; if impatience is imposed on the utility function, the pass rate drops (as it must) but very modestly. (Recall from Section 3.2 that the existence of well-behaved sub-utility function in state k can be ascertained by testing GARP on $\mathcal{O}_{s_k}$ and the existence of a well-behaved and impatient sub-utility function in that state can be ascertained by testing a stronger version of GARP.) We also repeat the tests pooling the data in the two states, in order to test for the existence of a state independent sub-utility function; in this case, the pass rate is around 82 percent and dropping slightly to 79 percent when impatience is imposed.[7]

Table 3: Symmetry and Time-Invariant Risk Preference.

		CCEI 1	CCEI 0.99	CCEI 0.95	CCEI 0.90
Early	Well-Behaved	0.485	0.621	0.718	0.816
	Symmetry	0.194	0.262	0.379	0.408
Late	Well-Behaved	0.272	0.350	0.408	0.456
	Symmetry	0.155	0.175	0.214	0.262
Pooled	Time-Independence	0.146	0.204	0.282	0.340
	Time-Ind. with Symmetry	0.097	0.146	0.184	0.233

When a subject has an overall utility function that is weakly separable across time (see (7)), he or she would have a sub-utility function at each date. This means that there are sub-utility functions ω ($\widetilde{\omega}$) rationalizing the datasets $\mathcal{O}_{t_1}$ ($\mathcal{O}_{t_2}$). Table 3 reports the results of the revealed preference tests at each time point. At the CCEI level of 0.95, 72 percent of all subjects exhibit behavior rationalizable by a well-behaved utility function at the Early time point, with the corresponding figure at the Late time point being 41 percent. These numbers drop to 38 percent and 21 percent respectively after imposing symmetry. To check for the existence of a time-invariant sub-utility function, we pool the observations (for each subject) at the two time points into a single data set; in this case, 28 percent are rationalizable with a well-behaved utility function, and the figure drops to 18 percent if symmetry is imposed.

It is clear from Tables 2 and 3 that while there is strong support for the existence of sub-utility functions over consumption streams, the evidence in favor of the existence of sub-utility functions over contingent consumption (at each date) is a lot weaker. Table 4 reinforces these findings by comparing the pass rates for each test with its power. The latter is measured in two ways. In the first way, we generate datasets (each consisting of 41 observations) using random allocation decisions in which the tokens sum up to 100. In the second way, we first pool the decisions made by all subjects in the experiment and then generate datasets (of 41 observations each) by sampling from that set. Notice that for datasets randomly generated according to the first method, the pass rate is essentially zero at the

[7] In Table A3 in the Appendix, we provide the exact CCEI of each subject.

Table 4: Power Test.

		Exp-Data	Rdm-Sampled	Rdm-Generated
Head	Well-Behaved	0.854	0.218	0.001
	Impatience	0.845	0.203	0.000
Tail	Well-Behaved	0.864	0.256	0.000
	Impatience	0.825	0.218	0.000
H&T Pooled	Well-Behaved	0.825	0.040	0.000
	Impatience	0.786	0.035	0.000
Early	Well-Behaved	0.718	0.410	0.000
	Symmetry	0.379	0.083	0.000
Late	Well-Behaved	0.408	0.290	0.000
	Symmetry	0.214	0.016	0.000
E&L Pooled	Well-Behaved	0.282	0.035	0.000
	Symmetry	0.184	0.000	0.000

Note. The table displays the pass rates (at CCEI 0.95) among experimental data, randomly sampled data (using subject choices) and randomly generated data. The experimental data consists of 103 datasets (from 103 subjects). For the randomly sampled data and randomly generated data, estimated pass rates are obtained from more than 10000 generated datasets in each case.

0.95 CCEI. For datasets randomly generated according to the second method, the pass rates are higher but still low when compared against the pass rate (among subjects). Selten (1991) proposes using the difference between the experimental pass rate and the pass rate from randomly generated data as a measure of a model's *predictive power*.[8] Notice that all the models (whether they involve state or time separability) *do* have predictive power in the sense that the true pass rate exceeds the pass rates of the randomly generated data. Furthermore, the state-separable hypothesis with state independence and impatience is obviously superior in predictive power to the time-separable hypothesis with date independence and symmetry, since $0.786 - 0.035 > 0.184 - 0.000$.

Table 5: GARP and Separability.

	CCEI 1	CCEI 0.99	CCEI 0.95	CCEI 0.90
Well-Behaved	0.631	0.757	0.903	0.971
State Separability	0.456	0.553	0.757	0.874
Time Separability	0.165	0.194	0.301	0.369

So far we have only checked whether datasets are consistent with the existence of sub-utility functions, but have not actually tested whether each subject's dataset is rationalizable by a weakly separable utility function (either of the state-separable form (6) or the time-separable

[8]Selten (1991) provides an axiomatization of this index. A model's predictive power is high if its pass rate is high and it delivers sharp predictions in the sense that the pass rate for randomly generated data is low.

form (7)), which requires the recovery, not just of sub-utility functions, but also of an aggregator function. Table 5 displays the results of implementing the rationalizability test for weakly separable utility functions proposed in Quah (2014). Notice that both state-separable and time-separable utility functions are special cases of well-behaved utility functions and therefore the pass rate of the latter (which exceeds 90 percent at CCEI of 0.95) must be higher than the other two. However, while 75 percent of all subjects display behavior consistent with a state separable utility function, the corresponding figure for time separable utility is only 30 percent.

Table 6: Individual Type Analysis (pass rates at CCEI 0.95)

Well-behaved	State separable	Time separable	# of subjects
Pass	Pass	Pass	27
Pass	Pass	Fail	51
Pass	Fail	Pass	4
Pass	Fail	Fail	11
Fail	Fail	Fail	10

This disparity is in some ways even more starkly displayed in Table 6, which counts the number of subjects who pass/fail the three models (at CCEI of 0.95). Notice that while 51 subjects are consistent with the state-separable model but not the time-separable model, only four subjects are consistent with the time-consistent model but not the state-separable model. So the usefulness of the model in explaining subject behavior appears to be very modest and certainly pales in comparison with the state-separable model.

5 Conclusion

We conduct an experiment to elicit preferences of subjects over risky consumption streams. Using recently developed revealed preference tests, we check for the consistency of subject behavior with a variety of preference hypotheses. Our results broadly support the hypothesis that intertemporal preferences under risk are separable across states, but there is little evidence to support separability across time. This is the source of the failure of the discounted expected utility model to explain subject behavior. Furthermore, we find that the sub-utility functions over consumption streams are state independent and exhibit impatience.

Broadly speaking, our framework and testing methods can be applied to analyze preferences in other contexts where the pattern of separability is a central issue. For example, in the case of social preferences in risky environments (Fudenberg and Levine, 2012; Saito, 2013; Brock, Andreas, and Ozbay, 2013), one important question is whether and how the decision maker trades off between ex ante and ex post fairness concerns; ex ante fairness would suggest a preference that is separable across individuals, while ex post fairness suggests a preference that is separable across states.

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Appendix: Supplementary Tables

Table A1: Price Effect with only Interior Choices.

	Head/Early allocation	Tail/Early allocation	Head/Late allocation	Tail/Late allocation
Head/Early Price	**-9.247*** **	3.149***	5.900***	0.198
	(1.802)	(1.014)	(1.214)	(0.924)
Tail/Early Price	-0.105	**-8.904*** **	3.084***	5.925***
	(0.937)	(1.552)	(0.776)	(1.259)
Head/Late Price	5.730***	1.683*	**9.986*** **	2.572***
	(1.259)	(0.993)	(1.693)	(0.830)
Tail/Late Price	1.440*	7.251***	1.144	**-9.836*** **
	(0.762)	(1.550)	(0.706)	(1.598)
constant	27.803***	21.167***	24.621**	26.409***
	(2.015)	(2.353)	(1.997)	(2.218)
Observations	984	984	984	984
Pseudo R-squared	0.210	0.248	0.236	0.242

Table A2: Price Effect with only Corner Choices.

	Head/Early allocation	Tail/Early allocation	Head/Late allocation	Tail/Late allocation
Head/Early Price	**-61.781*** **	4.484**	51.419***	4.053**
	(7.105)	(2.067)	(2.728)	(1.782)
Tail/Early Price	5.488***	**-59.966*** **	8.861***	54.769***
	(1.787)	(6.305)	(2.516)	(2.587)
Head/Late Price	36.298***	4.855**	**-97.729*** **	-1.250
	(2.782)	(1.901)	(8.924)	(2.014)
Tail/Late Price	3.229**	31.691***	8.534***	**-102.425*** **
	(1.334)	(2.336)	(2.213)	(9.176)
constant	31.427***	33.974***	13.811**	27.887***
	(3.792)	(4.936)	(5.498)	(6.056)
Observations	3,239	3,239	3,239	3,239
Pseudo R-squared	0.0965	0.0967	0.128	0.147

Table A3: Power Test (at CCEI 0.95 and 0.90)

		Exp-Data	Rdn-Sampled	Rdn-Generated
Head	Well-Behaved	0.854	0.218	0.001
		(0.912)	(0.423)	(0.007)
	Impatience	0.845	0.203	0.000
		(0.893)	(0.396)	(0.001)
Tail	Well-Behaved	0.864	0.256	0.000
		(0.903)	(0.411)	(0.008)
	Impatience	0.825	0.218	0.000
		(0.874)	(0.377)	(0.000)
H&T Pooled	Well-Behaved	0.825	0.040	0.000
		(0.883)	(0.154)	(0.000)
	Impatience	0.786	0.035	0.000
		(0.845)	(0.140)	(0.000)
Early	Well-Behaved	0.718	0.410	0.000
		(0.816)	(0.657)	(0.007)
	Symmetry	0.379	0.083	0.000
		(0.408)	(0.178)	(0.000)
Late	Well-Behaved	0.408	0.290	0.000
		(0.456)	(0.455)	(0.009)
	Symmetry	0.214	0.016	0.000
		(0.262)	(0.028)	(0.000)
E&L Pooled	Well-Behaved	0.282	0.035	0.000
		(0.340)	(0.144)	(0.000)
	Symmetry	0.184	0.000	0.000
		(0.233)	(0.001)	(0.000)

Note. This table is a longer version of Table 4 in the main part of the paper. It displays the passing rates among experimental data, randomly sampled data (using subject choices) and randomly generated data. The experimental data consists of 103 datasets (from 103 subjects). For the randomly sampled data and randomly generated data, estimated pass rates are obtained from more than 10000 generated datasets in each case. The percentage in each row without the brackets is the pass rate at CCEI 0.95, and the percentage in brackets is the pass rate at CCEI 0.90.

Table A4: Detailed CCEI Results.

	Overall	Head		Tail		H&T Pooled		Early		Late		E&L Pooled	
	W-B	W-B	Imp	W-B	Imp	W-B	Imp	W-B	Sym	W-B	Sym	W-B	Sym
Subject 1	0.97	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80	0.80
Subject 2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80	0.80
Subject 3	0.87	0.74	0.74	0.95	0.95	0.74	0.74	1.00	0.80	0.80	0.80	0.80	0.80
Subject 4	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.50	0.80	0.50
Subject 5	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 6	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.80	0.80	0.80	0.80
Subject 7	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 8	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80
Subject 9	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 10	0.98	1.00	1.00	1.00	1.00	1.00	1.00	0.84	0.80	0.80	0.80	0.80	0.80
Subject 11	1.00	1.00	0.97	1.00	1.00	1.00	0.97	1.00	1.00	1.00	0.99	1.00	0.99
Subject 12	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 13	1.00	1.00	1.00	0.98	0.98	0.98	0.98	0.91	0.80	0.80	0.80	0.80	0.80
Subject 14	1.00	1.00	1.00	0.99	0.93	0.99	0.93	0.99	0.83	1.00	1.00	0.99	0.83
Subject 15	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 16	1.00	1.00	1.00	0.93	0.93	0.93	0.93	0.80	0.80	0.85	0.80	0.80	0.80
Subject 17	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.83	0.80	0.80	0.80
Subject 18	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.91	0.40	0.91	0.40
Subject 19	0.97	0.91	0.91	0.90	0.90	0.90	0.90	0.91	0.83	0.85	0.80	0.85	0.80
Subject 20	1.00	1.00	1.00	1.00	1.00	0.99	0.99	0.80	0.80	1.00	0.80	0.80	0.80
Subject 21	0.95	0.92	0.92	1.00	1.00	0.92	0.92	0.84	0.76	1.00	0.80	0.84	0.76
Subject 22	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80
Subject 23	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80
Subject 24	0.99	1.00	1.00	1.00	0.93	1.00	0.93	0.98	0.98	1.00	0.98	0.94	0.94
Subject 25	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.98	0.98	0.98	0.98	0.98
Subject 26	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80
Subject 27	0.94	0.79	0.79	0.88	0.84	0.78	0.78	0.96	0.70	0.70	0.65	0.70	0.65
Subject 28	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	1.00	0.80	0.80	0.80
Subject 29	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80
Subject 30	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 31	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80
Subject 32	0.99	0.99	0.99	1.00	1.00	0.97	0.97	1.00	0.80	0.87	0.80	0.87	0.80
Subject 33	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 34	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80
Subject 35	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.82	0.80	0.82	0.80
Subject 36	1.00	1.00	1.00	1.00	0.80	1.00	0.80	1.00	1.00	0.80	0.80	0.80	0.80
Subject 37	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80
Subject 38	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.80	0.80	0.80	0.80
Subject 39	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80
Subject 40	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80
Subject 41	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80
Subject 42	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80
Subject 43	1.00	1.00	1.00	0.99	0.99	0.99	0.99	1.00	0.87	0.80	0.80	0.80	0.80
Subject 44	1.00	0.99	0.99	0.99	0.99	0.99	0.99	1.00	0.87	0.80	0.80	0.80	0.80
Subject 45	1.00	1.00	1.00	0.98	0.98	0.98	0.98	0.97	0.97	1.00	0.91	0.97	0.91
Subject 46	0.88	0.83	0.83	0.80	0.80	0.80	0.80	1.00	1.00	1.00	0.64	0.96	0.64
Subject 47	0.99	0.98	0.98	1.00	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Subject 48	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80
Subject 49	1.00	0.90	0.80	1.00	1.00	0.90	0.80	1.00	0.80	0.80	0.80	0.80	0.80
Subject 50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.89	0.80	0.80	0.80
Subject 51	1.00	1.00	1.00	0.97	0.97	0.97	0.97	1.00	0.80	1.00	0.80	1.00	0.80
Subject 52	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.85	0.80	0.80	0.80
Subject 53	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.91	0.87	0.87	0.87	0.87
Subject 54	0.98	0.86	0.72	0.90	0.90	0.86	0.72	0.94	0.82	0.92	0.80	0.87	0.80
Subject 55	1.00	0.95	0.95	1.00	1.00	0.95	0.95	0.91	0.80	0.80	0.80	0.80	0.80

Table A4 continued.

	Overall	Head		Tail		H&T Pooled		Early		Late		E&L Pooled	
	W-B	W-B	Imp	W-B	Imp	W-B	Imp	W-B	Sym	W-B	Sym	W-B	Sym
Subject 56	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 57	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	1.00	0.80	0.80	0.80
Subject 58	0.94	0.78	0.78	0.85	0.85	0.78	0.78	0.80	0.71	0.84	0.80	0.80	0.71
Subject 59	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.90	0.80	0.80	0.80
Subject 60	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	1.00	0.80	1.00	0.80
Subject 61	1.00	1.00	1.00	1.00	1.00	0.96	0.96	0.89	0.89	0.80	0.80	0.80	0.80
Subject 62	0.98	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.92	1.00	1.00	0.98	0.92
Subject 63	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 64	0.97	1.00	0.91	1.00	1.00	0.94	0.91	0.94	0.80	0.95	0.80	0.80	0.80
Subject 65	1.00	0.97	0.97	1.00	1.00	0.97	0.97	0.80	0.80	0.81	0.80	0.80	0.80
Subject 66	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80	0.80
Subject 67	0.97	0.92	0.92	0.94	0.84	0.92	0.84	0.91	0.84	0.89	0.79	0.89	0.79
Subject 68	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	1.00	0.80	0.80	0.80
Subject 69	0.92	0.80	0.60	0.87	0.87	0.60	0.60	0.80	0.80	1.00	0.92	0.79	0.75
Subject 70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 71	0.91	0.91	0.91	0.91	0.91	0.89	0.89	0.80	0.62	0.91	0.80	0.80	0.62
Subject 72	0.99	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.80	1.00	0.80	0.98	0.80
Subject 73	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.88	0.97	0.88	0.97	0.88
Subject 74	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80
Subject 75	0.99	0.98	0.98	1.00	1.00	0.98	0.98	1.00	1.00	1.00	1.00	1.00	1.00
Subject 76	1.00	1.00	1.00	1.00	0.82	1.00	0.82	1.00	0.89	1.00	0.50	0.87	0.50
Subject 77	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 78	0.94	0.80	0.76	0.88	0.87	0.80	0.76	0.90	0.87	0.98	0.92	0.90	0.87
Subject 79	1.00	1.00	1.00	0.97	0.97	0.97	0.97	1.00	0.80	0.80	0.80	0.80	0.80
Subject 80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.92	0.82	1.00	0.64	0.92	0.64
Subject 81	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80
Subject 82	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.80	0.80	0.80	0.80
Subject 83	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 84	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 85	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.80	1.00	0.80
Subject 86	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.64	1.00	0.80	0.92	0.64
Subject 87	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80
Subject 88	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80
Subject 89	0.98	1.00	1.00	0.98	0.98	0.98	0.98	1.00	0.95	0.97	0.94	0.97	0.94
Subject 90	0.97	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.80	0.80	0.80	0.80	0.80
Subject 91	0.89	0.73	0.73	0.82	0.82	0.73	0.73	0.92	0.87	0.82	0.82	0.82	0.82
Subject 92	1.00	1.00	0.96	1.00	1.00	1.00	0.96	0.98	0.80	0.83	0.80	0.82	0.80
Subject 93	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80
Subject 94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80
Subject 95	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.91	0.91	0.91	0.91	0.91
Subject 96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.64	0.80	0.64
Subject 97	0.91	0.89	0.80	0.89	0.63	0.79	0.63	0.62	0.40	0.87	0.67	0.62	0.40
Subject 98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.95	1.00	1.00	1.00	0.95
Subject 99	0.96	0.91	0.87	0.82	0.82	0.82	0.82	0.95	0.89	0.80	0.69	0.80	0.69
Subject 100	0.98	1.00	1.00	0.86	0.86	0.86	0.86	0.83	0.80	0.82	0.80	0.80	0.80
Subject 101	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Subject 102	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	1.00	0.80	0.80	0.80
Subject 103	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.80	0.80	0.80	0.80	0.80