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TIME CONSISTENCY: STATIONARITY AND TIME INVARIANCE

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TIME CONSISTENCY: STATIONARITY AND TIME INVARIANCE

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A sequence of experiments documents static and dynamic "preference reversals" between sooner-smaller and later-larger rewards, when the sooner reward could be immediate. The theoretically motivated design permits separate identification of *time consistent*, *stationary*, and *time invariant* choices. At least half of the subjects are time consistent, but only three-quarters of them exhibit stationary choices. About half of subjects with time inconsistent choices have stationary preferences. These results challenge the view that present-bias preferences are the main source of time inconsistent choices.

KEYWORDS: Time discounting, diminishing impatiences, intertemporal preferences.

1. INTRODUCTION

THE PAST TWENTY YEARS have seen a surge of interest in time inconsistent preferences. Mostly, this has been motivated by psychological experiments and introspection that have suggested the existence of "present-bias": a decision maker prefers smaller immediate reward to a larger delayed reward, but when she is asked about her preferences between these two alternatives when both are equally shifted into the future, her preferences are reversed. Although there is no inconsistency per se in her answers, this behavior has been taken to suggest that when the decision maker will be asked to update her choices in the future, she will generally deviate from her ex ante plans.

Our goal in the present study is to perform a dynamic preference reversal experiment. As such, one is required to extend the standard framework of preferences over temporal payments to a dated collection of such preferences. This extension allows us to formally define three distinct properties. *Stationarity* implies that ranking of temporal payments depends only on the time distance and payment distance between the alternatives. *Time invariance* assumes that the decision maker evaluates each temporal payment relative to the evaluation pe-

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riod. A decision maker is *time consistent* if all her temporal preferences agree on the ranking of alternatives. We show that any two properties imply the third. As a consequence, if preferences are time invariant, then a decision maker is time consistent if and only if her preferences are stationary. Since our goal is to understand the dynamic structure of temporal preferences, these three components must be measured simultaneously.

We use a classroom as a field: it is an environment in which transaction costs are minimal and the risk that the experimenter will default on his future commitments is easier to eliminate. Each subject is asked a series of incentive compatible questions with a goal to estimate three numbers: the minimal delayed amount that she is willing to substitute today for an immediate payment; the minimal delayed amount that she is willing to substitute today for future payment; the minimal delayed amount that she is willing to substitute in the future for future payment. These three measures allow the experimenter to view all three dimensions of the dynamic decision problem described above.

The main analysis classifies the subjects according to their choices into several preference classes, without committing to a specific functional representation in each. We find that more than half of the subjects are time consistent, but only three-quarters of them exhibit stationary choices. Moreover, about half of subjects with time inconsistent choices have stationary preferences. These results proved to be extremely robust over varying stakes and different incentive systems.

What is the source of time varying preferences? We point to two possible sources. The first is implicit risk: the present is immediate but also certain, while every future reward is inherently uncertain. The subjective perception of the future may lead a decision maker to hold nonstationary but time consistent preferences (Sozou (1998), Azfar (1999), Halevy (2005)). The second is demand for liquidity: if a decision maker does not fully anticipate her future constraints, which are generically stochastic, there is very little reason to expect she will be time invariant. The data seem to be consistent with these rationalizations for time varying preferences; but even after accounting for them, the gap between stationarity and time consistency remains substantial.

The paper is organized as follows: Section 2 presents the experimental design. It covers two experiments that differ mainly in the incentives employed (to differentiate, we term the last experiment "robustness treatment"). Section 3 builds the theoretical background necessary for the identification used in the analysis conducted in Section 4. Section 5 concludes with discussion of the results. The main body of the paper reports two experiments conducted in 2010 and 2013. An earlier experiment with smaller sample size and smaller stakes (but very similar results) was conducted a year earlier. For completeness, we report the results of the earlier experiment in Appendix C in the Supplemental Material (Halevy (2015)).

2. DESIGN

Subjects in the main experiment were first year students at the University of British Columbia, enrolled in five different tutorials of "Principles of Economics." The robustness treatment included three additional sections. The students in these sections were required to attend tutorials regularly (weekly), as part of the course requirements. This allowed the experimenters[2] to meet them without imposing additional cost ("transaction cost") on the subjects. The recurrent structure allowed easy payment during future meetings and facilitated the dynamic structure of the experiment: subjects could be asked to make similar (in a sense to be defined shortly) choices at two different dates that will reveal the dynamic structure of their preferences. In an effort to establish early trust, students received the consent form 48 hours prior to their participation in the experiment (through the class's web site).[3] In the main experiment, each tutorial was divided into two waves, which completed the experiment in a one week lag. In the robustness treatment, the whole section performed the experiment simultaneously (as a single wave).

Each subject was given four choice lists (CL):[4] two with sooner payments of \$10 and two with sooner payments of \$100. In each line of a choice list, the subject was asked to choose between the sooner payment (of \$10 or \$100, respectively) and a one week delayed payment that varied between \$9.90 and \$11 (in a 10 cents step) and \$99 and \$110 (in a \$1 step), respectively. For two of the lists (one with \$10 and one with \$100 sooner payments), the sooner payment was to be paid immediately, and the other two lists had a sooner payment to be paid in four (five in the robustness treatment) weeks.[5]

In the main experiment, subjects were informed that in 4 weeks they will be asked to choose again between immediate and delayed (by a week) payments, and the week 0 choice or the week 4 choice (that concerns the tradeoff between payments on week 4 and week 5) will be implemented with equal probability—making both decisions incentive compatible.

In the robustness treatment, subjects were only informed that the experiment has a second part, which will take place in 5 weeks. They were not informed what would be included in the second part, but it was made clear that in order to be paid for it, they must complete the second part of the experi-

[2]The experiments in each section were conducted by different groups of research assistants. The author never interacted directly with the subjects in order not to create any "demand effect."

[3]This was a lesson from the first experiment, in which trust was established gradually.

[4]Instructions for the experiments can be found in Appendices A and B in the Supplemental Material.

[5]Notice that, in all lists, the lowest delayed payment was lower than the sooner payment. This treatment was introduced in the 2010 experiment, in order to eliminate possible framing which suggests that future payment should be higher than the present payment. Also, in 2009, all lists had early payment of \$10 and delayed payment varied between \$10 and \$12 in steps of \$0.20.

ment.[6] On week 5, the subjects were asked to choose in similar choice lists in which every choice was between a payment of \$100 (\$10) in week 5 (immediately) and amounts varying between \$99 (\$9.90) and \$110 (\$11) in week 6. The payment depended only on week 5 choices, irrespective of week 0 decisions.

Although subjects in each wave of the main experiment were not present when subjects in the other wave made their choices, subjects in Wave 2 of the main experiment witnessed some subjects in Wave 1 being paid in week 1. This is the only important distinction between the two waves. The logic behind this design was to suggest that the experimenter will not default and to decrease the (subjective) implicit risk associated with delay.

Denote by x_1 (or y_1) the switching point from an immediate payment of \$100 (or \$10) to a delayed payment (List 1). x_2 (or y_2) denotes the switching point from an earlier payment of \$100 (or \$10) to a delayed payment, when the earlier payment occurs in 4 weeks (5 weeks in the robustness treatment—List 2). $x_{2.1}$ (or $y_{2.1}$) denotes the switching point from an earlier payment of \$100 (or \$10) to a delayed payment, when the earlier payment is immediate, and takes place on week 4 (week 5 in the robustness treatment—List 2.1).[7] That is, the data collected from each subject consist of six switching points $(x_1, x_2, x_{2.1}, y_1, y_2, y_{2.1})$. Figure 1 visualizes the timeline of the main experiment.

In designing the experiment, it became apparent that providing proper incentives to choices in both List 2 and List 2.1 is a challenging task.[8] There were three design options: paying according to both lists ("pay all"); not disclosing to subjects on week 0 that they will be given an opportunity to choose again and implementing the latter choice ("pay last decision without prior dis-

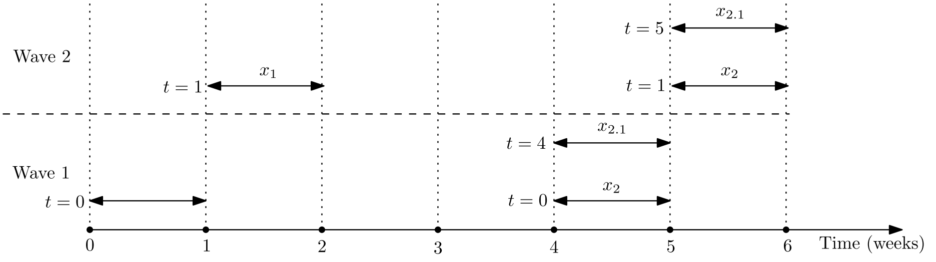

FIGURE 1.—Timeline of the main experiment.

[6]The exact language used was: "You must be present in the discussion group meeting in 5 weeks and complete the second part of the experiment in order to be paid for it."

[7]In case a subject chose all earlier payments, we take the switching point to be equal to the highest delayed payment plus \$1 or \$0.1, respectively.

[8]See Ainslie and Haendel (1983), Sayman and Öncüler (2009), Harrison, Lau, and Rutström (2005), Giné, Goldberg, Silverman, and Yang (2013), Read, Frederick, and Airoldi (2012) for alternative approaches.

closure"); disclosing the whole protocol on week 0, and randomly incentivize both lists ("pay one"). Each alternative has its drawbacks. The first causes possible wealth effects and permits the subject to smooth her payments in weeks 4 and 5. For example, a subject may choose a later payment in List 2 and an earlier payment in List 2.1 just to equate the payments across time. The second alternative has nice properties: x_2 may be viewed as a commitment choice and $x_{2.1}$ is elicited under certainty. However, it causes the implementation to be borderline inconsistent with the instructions and information provided to subjects in week 0.[9] This led us to adopt the third alternative in the main experiment, although it has an important theoretical drawback: under the third design, the subject faces a lottery between week 0 and week 4 choices. Therefore, in choosing x_2 (y_2) and $x_{2.1}$ ($y_{2.1}$), she may integrate the two into a single lottery. By choosing similarly on the two lists, the subject is able to hedge the risk introduced by the random incentive system (RIS). Although this use of lotteries is common in experimental economics,[10] and may be justified by isolation, it is important to note that this is an empirical question. In an effort to make it difficult to integrate List 2 and List 2.1, and to guarantee that the subject decides on the two lists in isolation, List 2 was not available to the subject when she made her choices in List 2.1 during week 4. Beyond the risk that a subject will integrate the two choice lists, providing the prior decisions to the subject may provoke consistent choices in List 2.1 (e.g., if a subject does not want to seem inconsistent to an experimenter). Our design eliminates this problem, since the experimenter present in the room does not know the choices the subject made in List 2, and only one of the lists will be viewed by the experimenter to determine the payment.[11] In the robustness treatment, we implemented the second alternative ("pay last decision without prior disclosure"), in order to test if subjects do not isolate in the main experiment and equate $x_{2.1}$ to x_2 (and appear time consistent) only to hedge the experimental risk.

From each section included in the main experiment (which had, on average, 30 students), and for each time horizon, one student from each wave was paid according to her choices from the lists with an early payment of \$100 (i.e., 4 students per section), while the rest of the students were paid according to their choices made in the choice lists with an early payment of \$10. Similarly,

[9]Economic experiments try to minimize such design based on the rationale that once a subject is surprised, it is impossible to model what she is reacting to: does she believe the experimenter anymore? Could she be offered more choices in the future that she was not informed about? Is the payment viewed as safe as it was before? Is the experimenter offering additional choices because the original choices did not conform to the experimenter's expectations?

[10]Even in the choice lists, only one choice out of the 12 is randomly implemented.

[11]If a subject memorizes her choices in List 2, and chooses in List 2.1 based on this recollection, this may serve as an internal commitment device. Naturally, in a behavioral experiment, we cannot observe such a process, but the approach developed below that is based on revealed choices would classify such a subject as consistent.

in each section of the robustness treatment (that had, on average, 24 subjects), 4 students were paid according to their choices in the lists with a sooner payments of \$100 (two in the choice list with an immediate payment in week 0 and two in the choice list with an immediate payment in week 5). In all treatments, the random selection of students to be paid according to the lists with an early payment of \$100, was performed only after choices in all relevant lists were made. The random line from each choice list to be implemented was determined individually for each subject by throwing a 12 sided die, and the list to be implemented in week 4 of the main experiment was determined by a coin toss (individually), after the subjects made their choices in week 4 between payments in week 4 and week 5.

One hundred forty-nine subjects completed part 1 of the main experiment, of which 130 completed part 2. Ten subjects had multiple switching points, and three subjects chose all later rewards (implying negative time preference). Seventy-two subjects completed part 1 of the robustness treatment, of which 63 completed part 2. Four subjects had multiple switching points. The analysis reported below focuses on the remaining 117 subjects in the main experiment (of which 43 were in Wave 1 and 74 in Wave 2), and 59 subjects in the robustness treatment.[12]

3. THEORETICAL BACKGROUND

Let the pair (ξ, t) represent a payment of $\$\xi$ at time t, where $\xi \in \Re$ and $t \geq 0$. Let $\{\succsim_t\}_{t=0}^{\infty}$ be a sequence of complete and transitive binary relations, defined over temporal payments. $\succsim_t$ represents the decision maker's (DM) preferences over temporal payments at time t.[13] $\{\succsim_t\}_{t=0}^{\infty}$ should be viewed as rationalizing the DM's choices over temporal payments. As such, it is impossible to disentangle many possible cognitive processes that give rise to the same choices. Let $\sim_t$ be the symmetric part of $\succsim_t$, and $\succ_t$ be the asymmetric part of $\succsim_t$.[14]

[12]Inclusion of the other subjects did not change any of the results. That is, subjects who did not complete part 2 were not significantly different in their answers to part 1 from subjects who completed part 2. Moreover, any criteria of inclusion of subjects with multiple switching points did not change significantly the results. In the main experiment, subjects were informed in advance that if they will be scheduled to be paid and they missed their tutorial, they can pick up their payment from the Economics department main office. In the robustness treatment, subjects were required to answer part 2 of the experiment in order to be paid for it.

[13]Intentionally, we do not specify the stochastic process (possibly subjective) governing temporal payments, which may affect the DM's perception and evaluation of the temporal lotteries. That is, we are not interested here in the source for choices (as in Halevy (2008)), but in revealed choices. Moreover, we can easily extend $\succsim_t$ to be defined over sequences of payments, without affecting the main insight used for the experimental identification.

[14]The definitions below are stated in the indifference mode for exposition simplicity. With natural monotonicity assumptions, such as: if $\psi > \xi$ and $s > t$, then $(\psi, s) \succ_t (\xi, s)$, and if $t < s < s'$, then $(\xi, s) \succ_t (\xi, s')$, it is easy to see how to derive the asymmetric part from $\succsim_t$. Alternatively, the definitions below could be stated using weak preference.

DEFINITION 1: $\succsim_t$ is *stationary* if, for every $0 \leq t, t', \xi, \psi \in \Re$, and $\Delta_2, \Delta_1 \geq 0$:

$$(\xi, t + \Delta_1) \sim_t (\psi, t + \Delta_2) \iff (\xi, t' + \Delta_1) \sim_t (\psi, t' + \Delta_2).$$

Stationarity is identified as the property of preferences studied in the decision theoretic literature (Koopmans (1960), Fishburn and Rubinstein (1982)) and tested in the standard static experiment: under stationarity, the ranking of two temporal payments at time t depends only on the "payment distance" (ξ vs. ψ) and the relative delay of the two payments ($\Delta_2 - \Delta_1$). The ranking does not depend on the distance from t, the evaluation period. As such, stationary preferences preclude static preference reversals. The sequence $\{\succsim_t\}_{t=0}^{\infty}$ is stationary if $\succsim_t$ is stationary for every t.

DEFINITION 2: $\{\succsim_t\}_{t=0}^{\infty}$ are *time invariant* if, for every $t, t' \geq 0$, $\xi, \psi \in \Re$, and $\Delta_2, \Delta_1 \geq 0$:

$$(\xi, t + \Delta_1) \sim_t (\psi, t + \Delta_2) \iff (\xi, t' + \Delta_1) \sim_{t'} (\psi, t' + \Delta_2).$$

Time Invariance relates the DM's preferences at time t and at time t': by itself, it does not impose restrictions on the structure of preferences at any given time, but only implies that preferences are not a function of calendar time. If preferences are time invariant, only time relative to the evaluation period matters. In other words, temporal payments are evaluated relative to a "stopwatch time."[15]

DEFINITION 3: $\{\succsim_t\}_{t=0}^{\infty}$ exhibit *time consistency* if, for every $t, t' \geq 0$, $\xi, \psi \in \Re$, and $\Delta_2, \Delta_1 \geq 0$:

$$(\xi, t + \Delta_1) \sim_t (\psi, t + \Delta_2) \iff (\xi, t + \Delta_1) \sim_{t'} (\psi, t + \Delta_2).$$

Time Consistency requires that the ranking of temporal payments does not change as the evaluation perspective changes from t to t'. As such, it relates $\succsim_t$ to $\succsim_{t'}$ in a way that will imply that a DM will not have an incentive to deviate ex post (say at time t') from her ex ante plan of time t. Time consistency precludes dynamic preference reversals.[16]

It is evident that the three properties of preferences are pairwise independent, but the following proposition highlights the relation between them.

PROPOSITION 4: *Any two of the three properties*: *Stationarity*, *Time Invariance*, *and Time Consistency*, *imply the third*.

[15]This terminology was suggested to me by Peter Wakker.

[16]Note that no separability restrictions are imposed on preferences in this paper. Blackorby, Nissen, Primont, and Russell (1973), Johnsen and Donaldson (1985) imposed separability restrictions together with related axioms.

PROOF: Stationarity and Time Invariance imply Time Consistency: $(\xi, t+\Delta_1) \sim_t (\psi, t+\Delta_2)$ if and only if (by time invariance) $(\xi, t'+\Delta_1) \sim_{t'} (\psi, t'+\Delta_2)$ if and only if (by stationarity) $(\xi, t+\Delta_1) \sim_{t'} (\psi, t+\Delta_2)$.

Stationarity and Time Consistency imply Time Invariance: $(\xi, t+\Delta_1) \sim_t (\psi, t+\Delta_2)$ if and only if (by time consistency) $(\xi, t+\Delta_1) \sim_{t'} (\psi, t+\Delta_2)$ if and only if (by stationarity) $(\xi, t'+\Delta_1) \sim_{t'} (\psi, t'+\Delta_2)$.

Time Consistency and Time Invariance imply Stationarity: $(\xi, t+\Delta_1) \sim_t (\psi, t+\Delta_2)$ if and only if (by time invariance) $(\xi, t'+\Delta_1) \sim_{t'} (\psi, t'+\Delta_2)$ if and only if (by time consistency) $(\xi, t'+\Delta_1) \sim_t (\psi, t'+\Delta_2)$. *Q.E.D.*

Proposition 4 highlights the fact that time invariance has been an implicit assumption in most of the literature (especially recent behavioral studies), and the implication of this assumption: understanding time inconsistent behavior has focused on the stationarity assumption. One of the goals of the current study is to investigate this theoretical and empirical view.

Proposition 4 allows us to identify directly each subject's preferences from the switching points $(x_1, x_2, x_{2.1})$ as defined in Section 2.

FACT 5: *The following identification follows directly from the definitions*:
(1) *If preferences are stationary*, *then* $x_2 = x_1$.
(2) *If preferences are time invariant*, *then* $x_{2.1} = x_1$.
(3) *If preferences are time consistent*, *then* $x_{2.1} = x_2$.

Static present bias (quasi-hyperbolic discounting, diminishing impatience) imply $x_2 < x_1$, so the subject is more impatient for immediate payments than to distant payments. Dynamic preference reversals consistent with diminishing impatience imply that $x_2 < x_{2.1}$, so the subject was patient when she contemplated distant payoffs but she becomes impatient when the distant rewards become immediate. Only when $x_{2.1} = x_1$ (choices are time invariant) do the two concepts coincide.

REMARK 6: In reporting the results, we pursue two approaches of interpreting choices made in the choice lists. The first assumes that a choice made between two alternatives on a specific line represents strict preference. This implies that the identification restriction in Fact 5 holds with equality. The second approach assumes that a choice represents only weak preference. As a result, if a subject switches between an immediate payment of \$100 to a later payment of x_1 in List 1, one can only infer that $(x_1, 1) \succsim_0 (100, 0)$ and assuming monotonicity and transitivity: $(x_1+1, 1) \succ_0 (100, 0)$. If $x_2 = x_1 + 1$ in List 2, then $(x_1+1, 5) \succsim_0 (100, 4)$. The asymmetric part of the latter together with the symmetric part of the former are consistent with stationary preferences. Therefore, if the interpretation of choices is of revealing weak preference, it is easy to see that $|x_2 - x_1| \leq 1$, $|x_{2.1} - x_1| \leq 1$ and $|x_{2.1} - x_2| \leq 1$ are still consistent with stationarity, time invariance, and time consistency, respectively.

4. RESULTS

4.1. *Aggregate Results*

Although this is not the main focus of the study, this subsection reports statistics for the aggregate distribution of subjects. The results are reported in Table I.[17]

Choices are approximately stationary as there is no significant difference between x_1 and x_2.[18] Average choices are inconsistent with the time invariance assumption: subjects are, on average, more impatient for a one week delay when asked at week 4 (or week 5 in the robustness treatment) than when asked at week 0.[19] The evidence for time inconsistency is mixed: for high stakes, $x_{2.1}$ is slightly higher than x_2 (in both treatments), but the difference is insignificant at 5%. However, for small stakes, $y_{2.1}$ is significantly higher than y_2 in the main experiment, but not in the robustness treatment. Consistent with previous findings on the magnitude effect, subjects are less impatient for high stakes than for low stakes.

4.2. *Distribution of Responses*

The main focus of the current study is the heterogeneity of choices among subjects.[20] We define five classes and study the distribution of choices among them. It is important to emphasize that no parametric functional form is utilized and therefore the classification is based on the properties of preferences

TABLE I
AGGREGATE STATISTICS

	Average			*p*-Value	
Variable	Main	Robustness	H_0	Main	Robustness
x_1	103.684	103.271	$x_1 = x_2$	0.063678	0.8929
x_2	104.214	103.203	$x_1 = x_{2.1}$	0.000389	0.0232
$x_{2.1}$	104.923	104.407	$x_2 = x_{2.1}$	0.067159	0.0662
y_1	10.591	10.624	$y_1 = y_2$	0.976429	0.6289
y_2	10.591	10.598	$y_1 = y_{2.1}$	0.000865	0.2175
$y_{2.1}$	10.721	10.686	$y_2 = y_{2.1}$	0.000589	0.1299

[17]There are no significant differences between the two waves of the main experiment in any of the variables (smallest p-value for the six differences in variables is 0.306). Therefore, the results reported in Table I pool both waves.

[18]In the main experiment, there is very mild evidence for increasing impatience, but it is insignificant at 5%.

[19]In the robustness treatment, the null hypothesis of time invariance in low stakes cannot be rejected.

[20]Other approaches to study heterogeneity estimate variation within a parametric family or the usage of a mixture model.

discussed in the previous section: stationarity, time invariance, and time consistency.

The main results are reported in Table II. Although we report separate classifications based on the \$100 lists ($x_1, x_2, x_{2.1}$) and the \$10 lists ($y_1, y_2, y_{2.1}$), the discussion below focuses on the \$100, as similar patterns emerge from the lower stakes.

Interpreting choices made in the choice lists as expressing strict preference, almost 48% of subjects in the main experiment made time consistent choices ($x_2 = x_{2.1}$). Of them, 35% show time invariant choices ($x_1 = x_2 = x_{2.1}$) and almost 13% exhibit non-stationary but consistent choices ($x_1 \neq x_2 = x_{2.1}$). The proportions in the robustness treatment are similar: 42% of subjects are time consistent; of them, 37% made time invariant and stationary choices. Interpreting choices as expressing weak preferences, these numbers are even higher: almost 60% of subjects in the main experiment and 56% in the robustness treatment made choices that can be rationalized as time consistent.

The remaining subjects are time inconsistent. In the main experiment, we find that 12 of them (10% of the 117 subjects) have time invariant but non-stationary preferences ($x_1 = x_2 \neq x_{2.1}$), and only 3 of them exhibit static present-bias choices ($x_2 < x_1 = x_{2.1}$). In the robustness treatment, the proportion is similar: 6 out of 59 (5 exhibit present bias). Twice as many subjects (25 subjects in the main experiment and 12 in the robustness treatment) exhibit stationary but time varying preferences ($x_1 = x_2 \neq x_{2.1}$). These subjects are time inconsistent, but the static experiment alone does not provide sufficient information to observe their inconsistency.[21]

Out of 51 subjects in the main experiment (25 in the robustness treatment) with non-stationary preferences, 22 subjects (15 in the robustness treatment), which is 43% (60%), exhibit choices consistent with static present-bias. Out of 61 subjects in the main experiment (34 in the robustness treatment) with time inconsistent preferences, 37 subjects (22 in the robustness treatment), which is 61% (65%), exhibit choices consistent with dynamic present-bias (insignificantly different from 0.5 at 10% using a binomial test).[22]

Only minor differences emerged between the main experiment and the robustness treatment: the relative proportion of subjects who made non-stationary but time consistent choices is lower in the robustness treatment. Although the proportion of subjects who made time invariant but non-stationary

[21] These proportions do not change drastically in either treatment when interpreting choices as representing weak preferences.

[22] With weak preferences: out of 37 subjects in the main experiment (22 in the robustness treatment) with non-stationary preferences, 14 subjects (13 in the robustness treatment), which is 38% (59%), made choices consistent with static present-bias. Out of 47 subjects in the main experiment (26 in the robustness treatment) with time inconsistent preferences, 29 subjects (18 in the robustness treatment), which is 62% (69%), made choices consistent with dynamic present-bias. This proportion is insignificantly (at 5%) different from 0.5 using a binomial test (p-values equal 0.1439 and 0.0755, respectively).

TABLE II

CLASSIFICATION OF SUBJECTS

	$100								$10							
	Strict Preferences				Weak Preferences				Strict Preferences				Weak Preferences			
	Main		Robustness		Main		Robustness		Main		Robustness		Main		Robustness	
	#	%	#	%	#	%	#	%	#	%	#	%	#	%	#	%
Time Invariant Stationary ($x_1 = x_2 = x_{2.1}$)	41	35.04	22	37.29	56	47.86	27	45.76	43	36.75	24	40.68	62	52.99	35	59.32
Time Invariant Non-Stationary[a] ($x_2 \neq x_1 = x_{2.1}$)	12 (3)	10.25	6 (5)	10.17	11 (3)	9.40	7 (5)	11.86	8 (5)	6.83	6 (5)	10.17	10 (7)	8.55	5 (3)	8.47
Time Varying Stationary[b] ($x_1 = x_2 \neq x_{2.1}$)	25 (18)	21.36	12 (10)	20.34	24 (18)	20.51	10 (8)	16.95	32 (21)	27.35	11 (9)	18.64	27 (19)	23.08	10 (6)	16.95
Non-Stationary Consistent[c] ($x_1 \neq x_2 = x_{2.1}$)	15 (8)	12.82	3 (1)	5.08	14 (4)	11.97	6 (3)	10.17	19 (8)	16.24	5 (2)	8.47	13 (5)	11.11	4 (0)	6.78
Time Varying Non-Stationary Inconsistent[d]	24 (11, 16)	20.51	16 (9, 7)	27.12	12 (7, 8)	10.26	9 (5, 5)	15.25	15 (5, 9)	12.82	13 (5, 6)	22.03	5 (2, 4)	4.27	5 (4, 4)	8.47
Total	117	100	59	100	117	100	59	100	117	100	59	100	117	100	59	100

[a] In brackets: number of subjects whose choices are consistent with present bias.

[b] In brackets: number of subjects whose choices are consistent with dynamic present bias.

[c] In brackets: number of subjects whose choices are consistent with static present bias.

[d] In brackets: number of subjects whose choices are consistent with (static present bias, dynamic present bias).

choices is similar (10–15%), the share of present-bias subjects within this group is slightly higher in the robustness treatment. These small differences may be a result of conducting the experiment during different years, of eliminating the waves, of eliciting x_2 and $x_{2.1}$ as commitment choices instead of employing random incentive as in the main experiment, or of simple sampling variation. Crucially, the robustness treatment demonstrates that the high frequency of time consistent choices is not due to the fact that subjects integrated their choices (concerning payments during week 4 or week 5) made in week 0 and in week 4.

4.3. *Associations*

The previous section demonstrated that the commonly assumed property of time invariance may not be justified empirically. Time varying preferences blur the identification of stationarity with time consistency. It is important to test whether the association between stationarity and time invariance on the one hand, and time consistency on the other hand, is present in the data.

The first row of the tables contained in Table III[23] reveals that the association between time consistency and stationarity was not strong in the first wave, but is tight in the second wave and in the robustness treatment.[24] For example, 52% (68%) of subjects who made stationary choices in wave 1 (2) of the main experiment were time consistent, but only 33% (27%) of subjects who made non-stationary choices in the respective waves were time consistent. In the robustness treatment, the respective proportions are 65% and 12%. Another measure that summarizes the tables is the proportion of subjects whose choices either satisfy both stationarity and time consistency, or are neither time consistent nor stationary. While in wave 1 this proportion is only 58%, it increases to 70% in wave 2 and is 75% in the robustness treatment.[25]

The second row of tables included in Table III documents a very strong association between time invariance and time consistency, in both waves of the main experiment and in the robustness treatment. For example, 68% (82%) of subjects who made time invariant choices in wave 1 (2) of the main experiment were time consistent, but only 25% (22.5%) of subjects who made time varying choices in these waves were time consistent. In the robustness treatment, these proportions are 79% and 10%, respectively. The proportions of subjects whose choices either satisfy both time invariance and time consistency, or are neither time consistent nor time invariant are 72% (80%, 85%) in wave 1 (wave 2, robustness treatment).

[23]We report associations based on x_1, x_2, $x_{2.1}$. Similar patterns are found for y_1, y_2, $y_{2.1}$.

[24]This pattern of weak association in wave 1 and tight association in wave 2 was found in the first experiment conducted in 2009 (see Table C.III in Appendix C in the Supplemental Material) as well.

[25]All proportions above are based on choices as revealing strict preferences. See the numbers in brackets reported in Table III for choices revealing weak preferences. The proportions do not change substantially.

TABLE III

TIME CONSISTENCY, STATIONARITY, AND TIME INVARIANCE: ASSOCIATIONS[a]

Main Experiment—Wave 1

Stationarity

		Yes	No	
TC	Yes	13 (17)	6 (4)	19 (21)
	No	12 (12)	12 (10)	24 (22)
		25 (29)	18 (14)	43

Strict (weak) p-value: 0.351 (0.104)

Time Invariance

		Yes	No	
TC	Yes	13 (17)	6 (4)	19 (21)
	No	6 (6)	18 (16)	24 (22)
		19 (23)	24 (20)	43

Strict (weak) p-value: <0.01 (<0.001)

Main Experiment—Wave 2

Stationarity

		Yes	No	
TC	Yes	28 (39)	9 (10)	37 (49)
	No	13 (12)	24 (13)	37 (25)
		41 (51)	33 (23)	74

Strict (weak) p-value: 0.001 (0.008)

Time Invariance

		Yes	No	
TC	Yes	28 (39)	9 (10)	37 (49)
	No	6 (5)	31 (20)	37 (25)
		34 (44)	40 (30)	74

Strict (weak) p-value: <0.0001 (<0.0001)

Robustness Treatment

Stationarity

		Yes	No	
TC	Yes	22 (28)	3 (6)	25 (34)
	No	12 (9)	22 (16)	34 (25)
		34 (37)	25 (22)	59

Strict (weak) p-value: 0.00005 (0.0004)

Time Invariance

		Yes	No	
TC	Yes	22 (27)	3 (7)	25 (34)
	No	6 (7)	28 (18)	34 (25)
		28 (34)	31 (25)	59

Strict (weak) p-value: <0.0001 (0.00014)

[a]Numbers in tables are for choices revealing strict (weak in brackets) preferences.

Numbers below tables are p-values of Fisher exact tests for association between the respective properties in the table above assuming choices reveal strict (weak in brackets) preferences.

Stationarity measured by $x_1 = x_2$ ($|x_1 - x_2| \leq 1$) for choices revealing strict (weak) preferences.

Time consistency measured by $x_{2.1} = x_2$ ($|x_{2.1} - x_2| \leq 1$) for choices revealing strict (weak) preferences.

Time invariance measured by $x_1 = x_{2.1}$ ($|x_1 - x_{2.1}| \leq 1$) for choices revealing strict (weak) preferences.

5. DISCUSSION

We investigated the association between static and dynamic preference reversals in an incentivized environment, without a front end delay. The design permits identification of immediacy effect, while trying to minimize future transaction costs. We find that at least 50% of the subjects are time consistent, and that about a quarter of them have non-stationary preferences. On the other hand, both non-stationary and time varying preferences account for time inconsistent choices.

5.1. *Possible Behavioral Rationalizations*

There are two behavioral patterns that account for a substantial part of time varying choices observed in the experiment. About 10% of all subjects (and more than 20% of subjects with time varying choices) made non-stationary but time consistent choices. Their choices can be rationalized by models that incorporate subjective implicit risk into the decision maker's considerations (Sozou (1998), Azfar (1999), Halevy (2005)).[26] For example, a subject may not trust the experimenter initially, but, conditional on the payment be available in 4 weeks, may be willing to delay another week—leading to diminishing impatience but time consistent choice. Alternatively, a student may suspect that the probability of not attending a tutorial increases as the term approaches its end, leading to increasing impatience. If her initial forecast proves correct after 4 weeks, she will not revise her choices and be time consistent. Interestingly, about half of the non-stationary and consistent subjects belong to each group.

A second channel that may lead to time varying preferences relies on liquidity demands of subjects. For example, a subject who has no cash at hand and possible limited access to credit may become very impatient when the prize is monetary. The data seem to support this interpretation: out of 25 subjects in the main experiment who chose all immediate payments in either List 1 or List 2.1 when the immediate payment was $100, only 4 (6 assuming choices reveal weak preferences) exhibited time invariant choices. That is, out of 64 (50 assuming weak preferences) subjects who had time varying choices, about one third chose all immediate payments in one of the two lists.[27,28]

[26]A related, but different, point was made by Noor (2009), Ambrus, Ásgeirsdóttir, Noor, and Sándor (2014) who studied the effect of expected income on elicited temporal tradeoffs, assuming subjects integrate experimental rewards with exogenous income.

[27]Twenty-one and 19 subjects assuming strict and weak preferences, respectively. Similar pattern emerges from the robustness treatment: 11 subjects chose all immediate payments in List 1 or List 2.1 with an immediate payment of $100; only 2 of them (3 assuming weak preferences) made time invariant choices. The remaining 9 (8 assuming weak preferences) comprise about one third of the 31 or 25 subjects with time varying preferences, assuming choices reveal strict or weak preferences, respectively.

[28]In the lower stakes lists, the picture is even more extreme: in the main experiment, 52 subjects exhibited extreme impatience. Thirty of them (17 assuming weak preferences) made time varying

The distribution of the 25 subjects who exhibited extreme impatience in the main experiment (chose all immediate payments either in List 1 or List 2.1) reveals that 10 of them (40%) had stationary preferences but were time inconsistent, 3 chose all earlier payments on all three lists (therefore were stationary and time consistent), only one made time invariant and non-stationary choices (hence was not time consistent), and 2 others were time consistent but their preferences were not stationary. Assuming that this group of subjects is motivated mainly by liquidity (cash) constraints, the proportion of time consistent choices within the remaining subjects increases to 55.4% (51 out of 92 subjects). When choices reveal only weak preference, the share of subjects who made choices that can be rationalized as time consistent among the not extremely impatient subjects increases to 68.5% (63 out of 92 subjects). The proportion of non-stationary but time invariant choices remains around 12% (11 out of 92). Interestingly, out of 37 subjects who exhibited dynamic present-bias in the main experiment, 18 were among the subjects who exhibited extreme impatience (72% of the 25).[29] Among subjects who do not exhibit extreme impatience, stationarity and time invariance are found to be tightly associated with time consistency ($p < 0.001$ for both), while among subjects who made extremely impatient choices, only time invariance is associated with time consistency ($p = 0.016$).[30]

Even after accounting for implicit risk and liquidity constrained subjects, there remains a substantial group of subjects who made stationary but time inconsistent choices. Fifteen out of the 53 (13 out of 64 when choice reveals weak preference) subjects with stationary choices who did not exhibit extreme short-term impatience in the main experiment were time inconsistent. They account for 36.6% (44.8%) of time inconsistent subjects who are not liquidity constrained.[31]

5.2. *Consistency With Other Experimental Findings*

Do the findings reported in the current study constitute an outlier within the experimental literature on present bias?

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choices. These subjects account for around 40% of subjects with time varying preferences (66 or 46 subjects assuming choices reveal strict or weak preferences, respectively). In the robustness treatment, extreme impatience (27 subjects) accounts for about one half of subjects with time varying choices in the $10 lists (15 out of 29 subjects assuming strict preferences, and 9 out 19 subjects assuming weak preferences).

[29]Similar patterns emerge from the robustness treatment.

[30]The 11 extremely impatient subjects in the robustness treatment do not permit powerful statistical tests. For the subjects who did not exhibit extreme impatience, both stationarity and time invariance were significantly associated with time consistency (p-values smaller than 1% for both).

[31]The proportions in the robustness treatment are extremely similar: restricting the sample to subjects who did not exhibit extreme impatience (48 subjects), 31 made stationary choices (34 assuming weak preferences) and 10 (8) of them made time inconsistent choices. They account for 38.4% (44.5%) of time inconsistent subjects who are not liquidity constraint.

In trying to implement time preference experiment, experimental economists had to overcome two practical obstacles: first, the present is certain while any future payment is subject to some subjective risk (Halevy (2005)). Second, immediate payments involve minimal transaction cost while any future payment will usually require higher cost of cashing the payment (Benhabib, Bisin, and Schotter (2010)). In order to overcome these difficulties, a front-end-delay (FED) is typically used: a small delay (between one day and one week) is introduced to all rewards. The results from such static experiments (Andersen, Harrison, Lau, and Rutström (2008), Andreoni and Sprenger (2012a)) do not provide conclusive evidence, and are usually consistent with exponential discounting as well as with quasi-hyperbolic models.

Some researchers argue that only primary rewards should be used to experimentally elicit time preferences, since models of intertemporal preferences study the substitution between utility flows, not between monetary payments. We refer an interested reader to Halevy (2014), which presents our perspective of this line of reasoning with relation to the current study. Augenblick, Niederle, and Sprenger (2014) have recently reported that aggregate time inconsistency is found when deciding over effort, whereas decisions over money are time consistent. However, we believe that the difference may be attributed to their experimental design. Indeed, the decision environment over effort is not held constant: while ex ante decisions are made in the lab, subsequent decisions are made online.[32] Furthermore, their main effort treatment employs asymmetric probabilistic Convex Time Budgets (CTB, Andreoni and Sprenger (2012a)),[33] which have been shown by Andreoni and Sprenger (2012b) to be sensitive to risk conditions.[34] As such, these probabilistic incentives alone may lead to time inconsistency.[35]

Many other well known studies conform to parts of the picture portrayed in the current work. Ashraf, Karlan, and Yin (2006) found that 28% of subjects in their hypothetical study exhibited present-bias, and these preferences correlated with take-up of commitment saving accounts. Duflo, Kremer, and Robinson (2011) reported 31–41% of diminishing impatience choices. Kaur,

[32]Even in their replication study Augenblick, Niederle, and Sprenger (2014) required subjects who made online decisions over monetary payments to arrive to the lab to collect their payments within a short time window, while subjects who made online decisions over the allocation of effort were not required to visit the lab until the end of the experiment.

[33]Chakraborty, Calford, Fenig, and Halevy (2014) discussed the challenge in interpreting interior choices made in Andreoni and Sprenger (2012a) as reflecting only intertemporal preferences.

[34]Both Cheung (2015) and Miao and Zhong (2015), who replicated and extended their findings, reported significant differences between the aggregate allocations even when the risks governing early and late payments are positively correlated, as implemented in the Augenblick, Niederle, and Sprenger (2014) design.

[35]In their between-subject replication study, the latter asymmetry was eliminated but then the difference between the aggregate ex ante and subsequent effort allocations is significant only at high interest rates, which might be challenging to reconcile with their structural assumptions of present bias and convex effort cost.

Kremer, and Mullainathan (2010) documented 35% take-up of commitment pay-schemes. Giné, Karlan, and Zinman (2010) found 11% take-up of commitment saving accounts to stop smoking. Meier and Sprenger (2015) studied time invariance (stability) among low income U.S. tax filers. Their findings on stability of preferences are comparable to ours (although they used FED). Andreoni and Sprenger (2012a) used CTB with small FED and reported that 17% of subjects exhibit diminishing impatience. Epper, Fehr-Duda, and Bruhin (2011) found that 54% of subjects exhibit diminishing impatience; Coller, Harrison, and Rutström (2012) used a finite mixture model and found that 41% of the aggregate response could be accounted for by a quasi-hyperbolic model. Giné et al. (2013) employed asymmetric probabilistic CTB (with monetary rewards) in a dynamic field study in Malawi and found only limited evidence for hyperbolic discounting. Andersen, Harrison, Lau, and Rutström (2014) reported almost no support for the quasi-hyperbolic model, which led them to reconsider the strength of the existing experimental evidence for this model. In an independent longitudinal study, Read, Frederick, and Airoldi (2012) found no evidence for hyperbolic discounting.

In conclusion, our findings fall within the range of existing studies, although most of them are missing crucial dimensions that are essential for studying the multifaceted structure of temporal preferences.

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