Reference dependence in intertemporal preferences

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Reference Dependence in Intertemporal Preference*

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Abstract

Dynamic structures in intertemporal choices offer multiple channels through which reference dependence can occur. We examine intertemporal reference dependence when using choice lists to elicit time preference over outcome sequences. Reference point effects can arise endogenously within an outcome sequence and exogenously from the experimental environment of the choice list. We show that estimated discount factors in the choice list are biased by both kinds of reference points, and propose a model to jointly account for both. Our experimental design with outcome sequences also enables us to jointly estimate the discount factor and utility curvature. We further discuss the implications for recent developments in the measurement of intertemporal preference.

Keywords: intertemporal preference, reference dependence, choice list, experiment

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1. Introduction

Many of our choices involve trade-offs between present and future rewards. Consider, for example, the debate between impulsive buying versus saving: One enjoys instant gratification from impulsive buying but worries about potentially insufficient savings for retirement. The decision can be further influenced by taking reference of one's own purchasing behaviour in the past and that of peers at the moment. This paper systematically examines the role of reference dependence in intertemporal choice.

Given the dynamic feature of intertemporal choices, the channels through which the reference effect comes into play can be multifarious. Loewenstein and Prelec (1993) show that people generally prefer an intertemporal sequence that improves over time, although positive time preference would suggest a preference for a decreasing sequence. A possible explanation is that people take the past outcome as a reference point, so that the increasing sequence is viewed as a sequence of gains and is preferred over a decreasing one. Henceforth, in this paper, taking past consumption as a reference point is referred to as *endogenous* reference dependence. Another stream of the literature examines reference effects that are generated by the choice environment. Loewenstein (1988) observes that the willingness to pay to speed up consumption from future to present is less than the willingness to accept to delay the same consumption from present to future. This suggests that evaluation of the same consumption can be affected by the choice frames and contexts that shift the reference point. We refer to this type of reference point as *exogenous* reference dependence. Here we provide the first joint evaluation of both endogenous and exogenous reference points.

We examine the reference dependence in the setting of the widely used choice-list elicitation method. Choice lists consist of ordered sets of binary choices, with each row in the list representing one choice. A common structure is that one option is kept fixed on one side of the list (henceforth referred to as *fixed option*), and options vary from row to row on the other side of the list (henceforth referred to as *varying options*). Varying options usually range from worse to better, compared with the fixed option. Subjects choose between the fixed option and a varying option in each row and switch their choice at the point at which the varying option changes from worse to better. The midpoint between the two options where the choice switches is taken as the indifference value of the fixed option.

The fixed option in the choice list can plausibly be viewed as an exogenous reference point in each choice. We focus on two-period outcome sequences, denoted (c_0, c_1), which deliver c_0 now and c_1 later, and implemented two types of outcome sequences as the fixed option: *present-oriented* $(x, 0)$, which delivers x now and 0 later, and *future-oriented* $(0, y)$, which delivers 0 now and y later. In general, a reference point is favored relative to its alternatives because of loss aversion—that is, the cons are weighted more relative to the pros. We therefore hypothesize that a present-oriented fixed option enhances impatience, resulting in a downward-biased discount factor. When the fixed option is future-oriented, subjects will be more patient, resulting in an upward-biased discount factor. Consequently, intransitivities will result when we compare preference relations elicited by present-oriented fixed options with those elicited by future-oriented fixed options.

To examine endogenous reference dependence, we implemented four types of choices, using combinations of increasing or decreasing-sequence varying options with a present-oriented or future-oriented fixed option in a choice pair. The four types are PI (*P*resent-oriented fixed option versus *I*ncreasing varying option), PD, FI, and FD (*F*uture-oriented fixed option versus *D*ecreasing varying option). Given that increasing sequence would be undervalued relative to decreasing sequence, we hypothesize that when we elicit an indifference value of a present-oriented fixed option from the varying options, an upward-biased discount factor is induced in PI compared to PD. Reversely, a downward-biased discount factor is induced in FI compared to FD. We conduct an experiment to test these predictions.

When we fit the discounted utility (DU) model assuming linear utility at the individual level, we observe systematic differences in the elicited discount factors that support both the exogenous and endogenous reference effects. Choices involving the present-oriented fixed option yield an average discount factor of 0.85 over 6 months, while choices involving the future-oriented fixed option yield an average discount factor of 0.95. We also observe preference intransitivity in a majority of the subject's choices. These results support the exogenous reference effect.

When separately estimating the increasing and decreasing trends, an average discount factor of 0.91 resulted from choices that involve a present-oriented fixed option and increasing varying options, while a lower average discount factor of 0.74 resulted from choices that involve a present-oriented fixed option and decreasing varying options. By contrast, when the fixed option is future-oriented, the observation is reversed: The average discount factor is 0.93 with increasing varying options and 0.96 with decreasing varying options. This provides support for the endogenous reference effect.

In addition, choices over outcome sequences enable us to jointly estimate the utility curvature and discount factor. We structurally estimate the DU model at both the individual and aggregate level and find that the estimated utility curvature is close to linearity. The observed systematic differences in the elicited discount factors are biased in the same way as what we observe with a linear utility function. Finally, we further estimate a model that combines both exogenous and endogenous reference-dependent effects and find that a substantial proportion of subjects exhibit both reference effects. Overall, in the setting of choice list, we provide experimental evidence in support for both endogenous and exogenous reference dependence in intertemporal choice.

2. Related Literature

In this section, we briefly review and discuss some related literature including reference dependence and intertemporal choice. Moreover, we also discuss our contribution to the elicitation of time preferences and multiattribute decision making.

Reference Dependence. Reference dependence is a central concept in behavioral economics. Markowitz (1952) pioneered the concept and Kahneman and Tversky (1979) carried it forward, showing that the status quo as reference point underlies a wide range of behavioral anomalies in decision making under risk. This has yielded fruitful developments in recent decades.[1] For instance, Köszegi and Rabin (2006, 2007) model personal expectation as a reference point. Some theories incorporate reference dependence implicitly. For example, the disappointment-aversion model (Bell, 1985; Loomes and Sugden, 1986; Gul, 1991), in which disappointment and elation are defined relative to the certainty equivalent, can be viewed as taking the certainty equivalent as an endogenously formed reference point within the lottery. Also, in regret theory (Bell, 1982; Loomes and Sugden, 1982), the outcomes of alternative options are compared,

[1] Numerous anomalies have been documented in both experimental and empirical research in support of reference dependence (e.g., Kahneman, Knetsch and Thaler, 1991; Camerer et al, 1997; Fehr and Goette 2007; Baillon et al. 2020). Recent studies examine the notion of expectation as reference point (e.g., Abeler et al., 2011; Ericson and Fuster, 2011; Gill and Prowse, 2012; Heffetz and List, 2014; Gneezy et al. 2012; Masatlioglu and Raymond, 2016; Freeman, 2019).

and gain is referred to as "rejoice" and loss as "regret," which can be regarded as modelling reference points exogenously in the given choice context. Whereas reference dependence has been widely examined for risk, its investigation has been limited with respect to time preference.

Intertemporal Choice. Experimental studies have been conducted to understand the role of reference points in intertemporal settings, some of which investigate how intertemporal choice is affected by exogenous contexts and frames. Loewenstein (1988) observes that subjects ask for more to delay the receipt of a videocassette recorder from now to a year later and pay less to speed up its receipt immediately instead of a year later. He contends that a delay or speed-up frame endogenously gives rise to different reference points. Moreover, an important related notion in the literature is sign dependence whereby the explicit frame of gains and losses—positive outcomes negative outcomes—can also shape reference dependence. Shelley (1993) extends Loewenstein's findings and observes a reverse pattern when outcomes are framed as being negative. These observations are related to the literature on the willingness-to-pay and willingness-to-accept gap (Plott and Zeiler 2005; Isoni, Loomes, and Sugden 2011). However, these studies all use direct matching, which is known to be hampered by biases whereby reference outcomes are often explicitly stated. Nowadays, choice lists are almost exclusively used to avoid those biases. One novelty of our experiment is that we demonstrate reference dependence in choice lists, even though they do not involve explicit framings that readily induce perceptions of reference points.

Relatedly, Frederick and Read (2002) show that implicit discount rates are higher when subjects report a future reward to be indifferent to a specific present reward, than when they report a present reward to be indifferent to a specific future reward. This study is similar to ours in its implementation of the present-oriented fixed option versus the future-oriented fixed option. The effect observed by Frederick and Read may be partially caused by the attribute trade-off effect (Delquie, 1993), whereby direct trade-offs between two attributes X and Y are biased depending on whether X is traded off against Y or Y is traded off against X. The two reward periods for present and future can be regarded as two different attributes by Frederick and Read. However, our implementation of present versus future serves different purposes from those of Frederick and Read. In our paper, the reference effect is manifested through the difference between the choice of a varying option compared with either a present-oriented fixed option or a future-oriented fixed option, in which no direct trade-offs are made (see our experimental design Section 3 for details). Also, whereas it is either the present or the future that causes the effect in Frederick and Read's study, in our setting the fixed option in the choice list is the reference point in the choice context.

Tversky, Slovic, and Kahneman (1990) obtain intertemporal preference reversals by comparing a pricing task and a choice task. They attribute the preference reversals to procedural variance, in which payoffs are weighted more in pricing than in the choice task. Freeman et al. (2016) also show that different elicitation procedures induce different discounting behaviour, leading to preference reversals or intransitivity. Our paper is not affected by such differences, because we use the same elicitation method of choice lists throughout. The observed preference reversals in our study can thus be clearly attributed to the reference effect, without confounding due to procedural variance.

Our study is also related to some theories whereby reference dependence is modelled implicitly or explicitly. In habit formation models (Stigler and Becker, 1977; Constantinides, 1990; Wathieu, 1997), the utility of current consumption is affected by past consumption, which can be regarded as reference dependence (Baucells and Sarin, 2010). Stigler and Becker (1977) argue that such preferences are endogenously formed and can account for changes in behavior that seemingly deviate from normative standards. Baucells et al. (2018) propose range- and sign-dependent utility for uncertain cash flows, which introduces reference points in the choice context and jointly accounts for a range of behavioral phenomena. Building on these general models, our framework provides a simple way to organize and interpret the experimental observations. Our findings contribute to criticism of the additive separability assumed in classical discounting (Barro and King, 1984), because we demonstrate clear interactions between different timepoints in the outcome sequences.

Elicitation of Time Preference. In choice list elicitations, the options on one side of the list are often kept fixed, while the options on the other side vary from row to row. It has recently been suggested that when subjects make decisions across each row on the choice list, they tend to view the fixed option as the reference point. For example, for the elicitation of risk preference, Sprenger (2015) shows that the fixed option on the choice list could be taken as a reference point.[2] In this regard, by eliciting time preference, we are the first to manipulate the exogenous reference point as the fixed option in the choice list. Our findings provide clear evidence that decision makers regard the fixed option in the choice list as a reference point, which confirms the corresponding biases in the elicited time preference and the observed preference reversals. This contributes to the understanding of the observed higher discount rate elicited using a choice list, as well as the intertemporal subadditivity. Section 7 elaborates on these points.

Elicitation of the utility curvature over time has been extensively debated in recent experimental literature. In the elicitation of time preference, subjects usually make binary choices between receiving a smaller payment s_0 at a sooner time t_o and a larger payment l_1 at later time t_1. Based on the discounted utility model, $D(t_o)u(s_0) = D(t_1)u(l_1)$, such behavioral data cannot jointly identify the parameters of the discount factor and utility curvature. This issue has been addressed in several studies using various approaches. Abdellaoui et al. (2010) measure intertemporal utility independently of the discount function. Andreoni and Sprenger (2012) use the convex time budget (CTB) to elicit time preference with joint identification of the discount factor and utility curvature under the discounted utility model. Abdellaoui et al. (2013) also separately elicit utility curvatures for the time and risk domains and report that the utility curvature is almost linear in the time domain and concave in the risk domain. Attema et al. (2010) use time-trade-off sequences to elicit the discount function in an entirely utility-free manner. Montiel Olea and Strzalecki (2014) provide an axiomatization for quasi-hyperbolic discounting with the use of annuity compensations that enables measurement of the discount factor independent of the utility curvature over time. Attema et al. (2016) propose the direct trade-odd method to elicit the discount factor without utility. We add to the literature on the estimation of utility curvature by eliciting preference relations for outcome sequences $(x_0, x_1) \sim (y_0, y_1)$ in the choice list elicitation.

Multiattribute decision making. Tversky and Kahneman (1991) examine loss aversion in the riskless and multiattribute setting, in which the gain-loss utility is additive across attributes. Their notion of multiattribute loss aversion is applied to analysis brand choice (Hardie et al, 1993), and to examine the price and seating occupancy in the performing arts industry (Tereyagoglu et al., 2018). In our intertemporal setting with two periods, one may view the

[2] Relatedly, Hershey and Schoemaker (1985) observe that the elicitation of risk preference is sensitive to whether certainty equivalence or probability equivalence is used in the experiment.

outcome in each time point as an attribute. In this regard, the *exogenous* reference dependence can then be interpreted as a form of multiattribute utility in the intertemporal choice, and the observed endogenous reference dependence provides evidence for the interactions between attributes.

3. Experimental Design

3.1. The choice list design

Our experiment considers the choice of outcome sequences $(c_{0,}c_1)$, whereby the timing of consumption is always the present and 6 months from now. Therefore, timepoints are not expressed in notation. Table 1, taken from our experimental instructions, illustrates the choice list design. Each row presents a binary choice between two outcome sequences, and there are 20 choices in the list. The outcome sequence on the right-hand side is kept fixed as $(45, 0)$ from top to bottom and is referred to as the fixed option. The options on the left-hand side improve from top to bottom in the form of $(5, x)$, with x varying from 40 to 59. We collectively call these options the varying options. Decision makers are directed to mark their choice of either the left (L) or right option (R) for each row in the middle column. The midpoint at which the switch from right to left occurs is recorded as the switching value. If a subject does not switch in the list, we record the value as if the subject switched at the boundary value of the list.[3]

In Table 1, the fixed option (45, 0) in the choice list grants the outcome 45 at present and nothing in 6 months, and therefore is a present-oriented sequence. The varying options in Table 1 grant a positive outcome in both periods. We call this type of sequence, in the form of (c_0, c_1) with $c_0 > 0$ and $c_1 > 0$, a *spread* sequence. The spread sequence is an increasing sequence if $c_0 < c_1$ and a decreasing sequence if $c_0 > c_1$. Table 1 uses increasing spread sequences as the varying option.

Moreover, for varying options (c_0, c_1), we vary either only the early outcome c_0 or only the late outcome c_1 in the list. The list of varying options in which the early outcome c_0 varies and

[3] For instance, if a subject chose as shown in Table 1, the switching value is recorded as 56.5. If a subject always chose the left option, the value 39.5 is recorded; if a subject always chose the right option, the value 59.5 is recorded.

the late outcome c_1 is fixed is referred to as the *early-varying* list. Conversely, when the early outcome c_0 is fixed and the late outcome c_1 varies, we call the list the *late-varying* list. Table 1 is an example of a late-varying list. To counterbalance, we constructed the varying options so that half are early-varying and the other half late-varying.

Table 1. An Illustrative Example of the Choice List

Row	Left Option		DECISION		Right Option	
	Today	6 months			Today	6 months
1	\$5	\$40	L ☐	R ☑	\$45	\$0
2	\$5	\$41	L ☐	R ☑		
3	\$5	\$42	L ☐	R ☑		
4	\$5	\$43	L ☐	R ☑		
⋮	⋮	⋮	L ☐	R ☑		
⋮	⋮	⋮	L ☐	R ☑		
17	\$5	\$56	L ☐	R ☑		
18	\$5	\$57	L ☑	R ☐		
19	\$5	\$58	L ☑	R ☐		
20	\$5	\$59	L ☑	R ☐		

Note. This table presents an example in which subjects choose between the left option and the right option for each of the 20 rows and report their choices in the middle column.

The two attributes of varying options (increasing or decreasing by early- or late-varying) lead to four different compositions: increasing and late-varying (IL), decreasing and late-varying (DL), increasing and early-varying (IE), and decreasing and early-varying (DE). The IL-type spread outcome sequence takes the form $(10, \mathrm{x})$ with $\mathrm{x} \in \{90, 92, \ldots, 128\}$. Similarly, DL takes the form $(90, \mathrm{x})$ with $\mathrm{x} \in \{10, 12, \ldots, 48\}$; IE is $(\mathrm{x}, 10)$ with $\mathrm{x} \in \{90, 92, \ldots, 128\}$; and DE is $(\mathrm{x}, 90)$ with $\mathrm{x} \in \{10, 12, \ldots, 48\}$.

Table 2 below presents all choice parameters for all 21 choice lists. The second column indicates the type of choice list. Taking choice list 1 in Table 2 as an example, the abbreviation PF means that the choices in the list are always between a present-oriented (P) fixed option and future-oriented (F) varying options. That is, in choice list 1, the choice type is PF, where $\mathrm{P} = (100, 0)$ is the fixed option and the future-oriented outcome sequences in the form of $\mathrm{F} = (0, \mathrm{x})$ are the varying options, where $\mathrm{x} \in \{100, 102, \ldots 138\}$. The PS/FS choice list types mean that the choices are between a P/F fixed option and a spread outcome sequence (S) as the varying option.

3.2. Recruitment and procedure

A total of 101 undergraduate students at the National University of Singapore (NUS) were recruited. The experiment was conducted in five sessions. After arriving at the experimental venue, subjects signed the consent form approved by the NUS Institutional Review Board. General instructions were read aloud, followed by a demonstration of several examples. Subjects were then instructed to complete the decision problems in the 21 choice lists (see Online Appendix C for experimental instructions). The order of choice lists was completely randomized.

Table 2. Summary of Outcome Sequences in the Experiment

No.	Choice	Fixed option	Varying options
1	*PF*	P (100, 0)	F (0, 100),….,(0, 138)
2	*PS*	P (100, 0)	S_{IL} (10, 90), …., (10, 128)
3	*PS*	P (100, 0)	S_{DL} (90, 10), ….,(90, 48)
4	*PS*	P (100, 0)	S_{IE} (10, 90), …., (48, 90)
5	*PS*	P (100, 0)	S_{DE} (90, 10), …., (128, 10)
6	*FS*	F_1 (0, 102)	S_{IL} (10, 90), …., (10, 128)
7	*FS*	F_1 (0, 102)	S_{DL} (90, 10), ….,(90, 48)
8	*FS*	F_1 (0, 102)	S_{IE} (10, 90), …., (48, 90)
9	*FS*	F_1 (0, 102)	S_{DE} (90, 10), …., (128, 10)
10	*FS*	F_2 (0, 112)	S_{IL} (10, 90), …., (10, 128)
11	*FS*	F_2 (0, 112)	S_{DL} (90, 10), ….,(90, 48)
12	*FS*	F_2 (0, 112)	S_{IE} (10, 90), …., (48, 90)
13	*FS*	F_2 (0, 112)	S_{DE} (90, 10), …., (128, 10)
14	*FS*	F_3 (0, 122)	S_{IL} (10, 90), …., (10, 128)
15	*FS*	F_3 (0, 122)	S_{DL} (90, 10), ….,(90, 48)
16	*FS*	F_3 (0, 122)	S_{IE} (10, 90), …., (48, 90)
17	*FS*	F_3 (0, 122)	S_{DE} (90, 10), …., (128, 10)
18	*FS*	F_4 (0, 132)	S_{IL} (10, 90), …., (10, 128)
19	*FS*	F_4 (0, 132)	S_{DL} (90, 10), ….,(90, 48)
20	*FS*	F_4 (0, 132)	S_{IE} (10, 90), …., (48, 90)
21	*FS*	F_4 (0, 132)	S_{DE} (90, 10), …., (128, 10)

Note. This table summarizes the 21 choice lists used in the experiment for the corresponding tasks (2nd column), fixed options (3rd column), and varying options (4th column).

Each subject received a SG$10 (about US$8 at the time of the experiment) flat payment for their participation, plus a payment based on one randomly selected choice. All payments were made via check instead of cash. Each subject received first $5 of the $10 show-up fee on the day of the experiment and $5 six months later, to ensure that the transaction cost was kept constant across different time points. In addition, one subject in each session was randomly selected to receive a choice-based real payment, which was determined by the outcome of one randomly selected decision they made. Once the additional real payment was determined for this randomly selected subject, it was added to the show-up fee and the total amounts were written on the check for the corresponding dates. Thus. the experimenter always issued subjects two checks: One for the amount received on the day of the experiment and the other for the amount to be received 6 months later. The banking policy in Singapore stipulates that a check cannot be cashed before the specified due date. This ensured that the subject could not expedite the delayed payment described in the decision problems.

4. Theoretical Framework and Predictions

In this section we present the theoretical framework with the discounted utility model and two forms of reference dependence, and derive their theoretical predictions for our experimental setting. Here we will focus on the two-period setting as in our experimental design.

4.1. Discounted utility

The most popular model in intertemporal choice is the discounted utility (*DU*) model, axiomatized by Koopmans (1960) for sequences over discrete time periods. The DU of (c_0, c_1) is

$$DU(c_0, c_1) = u(c_0) + \delta u(c_1), \tag{1}$$

where u is the *utility function* and δ $(\delta > 0)$ is the *discount factor*. Since DU assumes that the utility is purely determined by the consumption in each period and is time separable, the prediction of DU is straightforward, as summarized below.

Prediction DU: (A) The discount factor is the same for different choice lists; (B) Choice behavior satisfies transitivity.

4.2. Endogenous reference effect

The outcome sequence in our experiment allows us to manipulate the endogenous reference effect whereby consumption at period 0 is taken as a reference point. Relative to consumption at period 0, a better future consumption is perceived as a gain and a worse consumption as a loss. This reference dependence effect is endogenized within the outcome sequence itself, and we refer to it as *endogenous reference dependence* (EnRD). Building on previous models (e.g., Köszegi and Rabin, 2006, 2007; Baucells and Sarin, 2010), we propose a simple utility function for EnRD:

$$U_{EnRD}(c_0, c_1) = u(c_0) + \delta u(c_1) + \mu_{EnRD}(c_0, c_1) \quad (2)$$

$$\mu_{EnRD}(c_0, c_1) = \begin{cases} 0 & if \;\; c_1 \geq c_0 \\ (\gamma - 1)\delta\big(u(c_1) - u(c_0)\big) & if \;\; c_1 < c_0 \end{cases}$$

We keep the DU core in the EnRD specification. On top of DU, we introduce an additive part of the endogenous gain-loss utility $\mu_{EnRD}(c_0, c_1)$ to capture the endogenous reference effect, in which the difference between future consumption and present consumption $(u(c_1) - u(c_0))$ influences overall evaluation of the sequence. The weight for the gain-loss utility equals 0 for gains and $(\gamma - 1)$ for losses. We assume that the weight for the gain-loss utility is $(\gamma - 1)$, namely, present consumption is viewed as a reference point when one evaluates future consumption. The $(\gamma - 1)$ captures whether the decision maker weights gains differently from losses. Loss aversion results when $\gamma > 1$.[4]

EnRD satisfies transitivity, because $U_{EnRD}(x_0, x_1) > U_{EnRD}(y_0, y_1)$ and $U_{EnRD}(y_0, y_1) > U_{EnRD}(z_0, z_1)$ implies $U_{EnRD}(x_0, x_1) > U_{EnRD}(z_0, z_1)$. We next consider the implications of EnRD for our experimental setting. We provide the intuition below and the detailed proof in Online Appendix B1.

Consider an indifference relation $C = (c_0,\ c_1) \sim R = (r_0,\ r_1)$, and true representation of the preference is subject to endogenous reference, $U_{EnRD}(c_0,\ c_1) = U_{EnRD}(r_0,\ r_1)$. We will

[4] Here we assume the weight for gains is zero, so that this simplified function allows us to identify the parameters in the structural estimation. If we use the specification similar to that of Köszegi and Rabin (2006, 2007), the predictions are the same; see Online Appendix B2 for details.

explain how the inferred discount factor is biased if we mistakenly fit DU to the indifference and set $DU(c_0, c_1) = DU(r_0, r_1)$. EnRD preferences value a decreasing sequence less than DU preferences, given the sensation of losses from $c_1 - c_0$; but an increasing sequence is evaluated the same between EnRD and DU. When choosing between a present-oriented fixed option and increasing varying options, subjects would value the former less and the latter the same. Consequently, they would report a smaller indifference point in the varying option and behave as if they were more patient. If we use DU to estimate the discount factor, it would be biased upward. By contrast, for choices between the present-oriented fixed option and the decreasing varying options, since both options are valued less by EnRD, the inferred discount factor is less biased.

Similarly, when subjects choose between the future-oriented fixed option and decreasing varying options, they value the former the same and the latter less. Consequently, they would report a higher indifference point in the varying option and behave as if they were more patient. When we use DU to make inference, the inferred discount factor would be upward-biased. For choice lists with a future-oriented fixed option and increasing varying options, since both options are valued the same, the inferred discount factor is not biased.

To sum, we have the following predictions for preference with EnRD.

Prediction EnRD: (A) For choice lists with a present-oriented fixed option, the inferred discount factor is bigger when the varying option is increasing than when it is decreasing. For choice lists with a future-oriented fixed option, the inferred discount factor is bigger when the varying option is decreasing than when it is increasing. (B) Choice behavior satisfies transitivity.

4.3. Exogenous reference effect

The choice list design in our experiment allows us to manipulate the exogenous reference point, generated by using the decision context as the fixed option in the choice list. More specifically, when decision makers evaluate varying options $C = (c_0, c_1)$ in the choice list, they consider $R = (r_0, r_1)$—the fixed option—as the exogenous reference point. Because the reference dependence effect is exogenously given by the choice list, we call this *exogenous reference* *dependence* (ExRD). To accommodate the intuition of ExRD, we propose a simple utility function as follows. [5]

$$U_{ExRD}(C|R) = u(c_0) + \delta u(c_1) + \mu_{ExRD}(c_0, r_0) + \delta \mu_{ExRD}(c_1, r_1) \tag{3}$$
$$\mu_{ExRD}(c_i, r_i) = \begin{cases} 0 & if\ c_i \geq r_i \\ (\lambda - 1)(u(c_i) - u(r_i)) & if\ c_i < r_i \end{cases}$$

Here the utility in ExRD has two components: the DU component to capture consumption utility and the exogenous gain-loss utility μ_{ExRD}. The exogenous gain-loss utility compares consumption at each period with the corresponding reference consumption at the same period. Similar to the specification in EnRD, we assume that the gain-loss utility weight for each period equals 0 for gains, and the sensation of losses $u(c_i) - u(r_i)$ is weighted by $\lambda - 1$. Here $\lambda > 1$ captures loss aversion.

We provide the intuition underlying the predictions of ExRD below and the detailed proof in Appendix B1. If the fixed option is taken as the reference, the fixed option would be evaluated more than how it would be evaluated under DU, and the subjects would state a higher indifference point in the varying option. When the fixed option or the reference is present-oriented, subjects would behave as if they were more impatient and the inferred discount factor using DU would be downward-biased. Conversely, when the fixed option is future-oriented, subjects would behave as if they were more patient, and the inferred discount factor would be biased upward and thus greater.

ExRD can lead to violations of transitivity. Our experiment consists of three types of choices (PF, PS, and FS) to elicit three types of indifference relations between (1) $P{\sim}F$, a present-oriented fixed option and a future-oriented varying option; (2) $P{\sim}S'$, a present-oriented fixed option and a spread varying option; and (3) $F{\sim}S''$, a future-oriented fixed option and a spread varying option. ExRD would lead decision makers to report a higher indifference point relative to the fixed option, and thus F, S'' and S'' are all inflated by the reference effect. Note that S'' is further "inflated" based on the "inflated" F, so $S'' > S'$. This reflects the intuition of

[5] Although models have been proposed for decisions under risk, only recently has the idea of exogenous reference been extended to intertemporal choices by range- and sign-dependent utility (Baucells et al., 2018). The range- and sign-dependent utility allows an additional subjective survival probability for future outcomes. In our experiment, for simplicity, we assume there is no uncertainty embedded in future outcomes.

stairway to heaven illustrated by Baucells et al. (2018). Thus, transitivity is violated in the sense of $F \sim S'' \succ S' \sim P \sim F$.

To sum, we have the following predictions for preference with ExRD.

Prediction ExRD: (A) The inferred discount factor is downward-biased for choice lists with a present-oriented fixed option and upward-biased for choice lists with a future-oriented fixed option. (B) Choice behavior violates transitivity in the direction in which the elicited indifference spread sequence relative to the future-oriented fixed option dominates those indifferent to the present-oriented fixed option.

4.4. A combined model

Finally, we consider a combined model to jointly capture both EnRD and ExRD. One natural approach is to have an additive utility for different components as follows:

$$U_{Com}(C|R) = u(c_0) + \delta u(c_1) + \mu_{EnRD}(c_0, c_1) + \mu_{ExRD}(c_0, r_0) + \delta \mu_{ExRD}(c_1, r_1) \quad (4)$$

$$\mu_{EnRD}(c_0, c_1) = \begin{cases} 0 & if \;\; c_1 \geq c_0 \\ (\gamma - 1)\delta(u(c_1) - u(c_0)) & if \;\; c_1 < c_0 \end{cases}$$

$$\mu_{ExRD}(c_i, r_i) = \begin{cases} 0 & if \; c_i \geq r_i \\ (\lambda - 1)(u(c_i) - u(r_i)) & if \; c_i < r_i \end{cases}$$

The first component is DU to capture consumption utility. The second component is the gain-loss utility for EnRD, and the third component is the gain-loss utility for ExRD. In in the online Appendix B1, we show the predictions of EnRD and ExRD in isolation continue to hold in the combined model. In the results section, we estimate the parameters of the combined model.

5. Data Analysis Methods

5.1. Intransitive patterns

This subsection explains how we examine preference transitivity. From the experimental choices, we can directly observe two indifference relations: a future-oriented sequence $F(0, x)$ that is indifferent to the present-oriented fixed option $P(100, 0)$ and a spread sequence $S'(y_0, y_1^P)$ that is indifferent to $P(100, 0)$. If we know the preference relation between $F(0, x)$ and $S'(y_0, y_1^P)$, we can directly observe whether transitivity is violated.

In our experiment, we observe indifference relations to four future-oriented fixed options ((0, 102), (0, 112), (0, 122), and (0, 132)), in the form of $(0, 102) \sim (y_0, y_{11}^F)$, $(0, 112) \sim (y_0, y_{12}^F)$, $(0, 122) \sim (y_0, y_{13}^F)$, $(0, 132) \sim (y_0, y_{14}^F)$. Since $F(0, x)$ is elicited from PF choices and would vary from person to person, it is likely that $F(0, x)$ is not one of the four future-oriented sequences implemented in the FS choices. Therefore, we will extrapolate the indifference sequence to $F(0, x)$. We conduct the extrapolation from the four pairs of FS indifference relations observed from the experiment. A linear relationship is fitted between $X = (102, 112, 122, 132)$ and $Y = (y_{11}^F, y_{12}^F, y_{13}^F, y_{14}^F)$, such that $Y = \beta_1 X + \beta_0$. Based on a linear relationship, we can infer $y_1^F = \beta_1 x + \beta_0$ such that $F(0, x) \sim S''(y_0, y_1^F)$. Since we directly observe $P(100, 0) \sim F(0, x)$ and $F(100, 0) \sim S'(y_0, y_1^P)$, we can test the violation of transitivity by comparing y_1^F with y_1^P.

We use Subject 70 as an example to illustrate the extrapolation. We observe that Subject 70 is indifferent between $P(100{,}0) \sim F(0{,}111)$ and $P(100{,}0) \sim S'(10{,}99)$. Given that $F(0{,}111)$ is not one of the four future-oriented fixed options implemented in the experiment, we cannot observe the subject's preference of $F(0{,}111)$. Instead, we observe the indifference relations: (0,102)~(10,93), (0,112)~(10,101), (0,122)~(10,113), and $(0{,}132) \sim (10{,}123)$. Given that X is fixed at $X = (102{,}112, 122, 132)$ and we observe Y from her choices as $Y = (93, 101, 113, 123)$, the fitted regression line is Y=1.02X-11.84. To find the corresponding Y when X is 111 as in $F(0{,}111)$, substituting $X = 111$ into the regression line yields $Y = 1.02 * 111 - 11.84 = 101.38$. Hence, we obtain $F(0{,}111) \sim S''(10, 101.38)$, which gives rise to an intransitive circle of $F(0{,}111) \sim S''(10, 101.38) \succ S'(10{,}99) \sim P(100{,}0) \sim F(0{,}111)$. Here we use the increasing, late-varying options (IL) as an example. A similar analysis can be applied to the other types (DL, IE, and DE) of varying options. Appendix A3 further illustrates the extrapolation analysis.

5.2. DU model assuming linear utility

We estimate the discount factor under DU with linear utility. The indifferent preference between two sequences $(x_0, x_1) \sim (y_0, y_1)$ can be represented as $u(x_0) + \delta u(x_1) = u(y_0) + \delta u(y_1)$. If we assume that the utility function is linear, we can directly calculate the discount factor as $\delta = (x_0 - y_0)/(y_1 - x_1)$ for each indifference revealed in the experiment. We perform this computation for every list completed by each subject.

To examine the prediction of the exogenous reference effect on the elicited discount factor, we test whether the discount factors δ^F calculated from F-choice lists (i.e., those that feature future-oriented fixed options) are higher than those δ^P from P-choice lists. For each subject, one δ^F is obtained by averaging the discount factors calculated from all F-choice lists completed by that subject; similarly, one δ^P is obtained by averaging the estimates from all P-choice lists. Because our design includes 5 P-choice lists and 16 F-choice lists, our inference relies on the assumption that decision errors are stable across lists and do not vary substantially between the P-choice and F-choice lists. Nevertheless, should the choice errors vary across the choice lists, it would be difficult for us to separate reference dependence preferences from choice errors. But we compare the two types of choices using signed ranked test, and believe this statistical test can help account for some of the decision errors. We reported the value of δ^P and δ^F as well as the statistical comparison between the two in the result section.

To check the endogenous reference effect on the elicited discount factor, we look at whether the choices that involve the increasing or the decreasing sequence produce discount factors biased in different directions. That is, for each subject, a discount factor δ^{FI} is obtained as the average of the discount factors calculated from this subject's answers to the FI choice lists (i.e., the choice lists featuring an F- fixed option versus I- increasing varying options). Similarly, a discount factor δ^{FD} is obtained from the FD lists, and so is δ^{PI} from PI choice lists and δ^{PD} from PD choice lists. We examine whether $\delta^{FI} < \delta^{FD}$ and $\delta^{PI} > \delta^{PD}$ as predicted.

The drawback of this method is that we rely on the indifference value that is obtained only if subjects switch preferences in the choice list. Although we record the indifference value in non-switching lists as the boundary value, this is potentially more problematic if we use this value to calculate the discount factor than if we use it to infer the choice pattern. Thus, we report, in Section 6.2, the discount factors estimated from choice lists in which subjects switch. That is, for a subject who switches preferences in all 21 choice lists, 21 discount factors will be calculated. For a subject who switches in 15 lists and does not switch in the remaining 6 lists, 15 discount factors will be calculated. We report the discount factors calculated from all lists in Appendix A. Whether or not we include the non-switching lists does not change the overall results.

5.3. Structural estimation

We conduct structural estimation of DU for the discount factor and utility curvature jointly. Following the DU specification in equation (1), a binary choice between two outcome sequences $(x_0, x_1) \succcurlyeq (y_0, y_1)$ gives

$$U(x_0, x_1) = u(x_0) + \delta u(x_1) \geq U(y_0, y_1) = u(y_0) + \delta u(y_1)$$

Let utility function u follow the power utility family specification, and the utility of a positive outcome x is

$$u(x) = \begin{cases} x^{\alpha}, & \alpha > 0 \\ \ln(x), & \alpha = 0 \\ -x^{\alpha}, & \alpha < 0 \end{cases} \tag{5}$$

When $\alpha = 1$, the utility function is linear. The common finding in the literature is $\alpha < 1$. That is, utility is concave.

The choice probability of choosing (x_0, x_1) over (y_0, y_1) is given by

$$\mathrm{P}(x_0, x_1, y_0, y_1, w) = \emptyset(\frac{U(x_0, x_1) - U(y_0, y_1)}{\mu}) \tag{6}$$

where $\emptyset$ is the cumulative normal distribution, U is the model to be estimated, μ is a noise term, and w represents the set of preference parameters in U. We used the maximum log likelihood approach to optimize our estimates, which maximize the log sum of the choice probability of all N choices:

$$max \sum_{n=1}^{N} \ln P(x_0, x_1, y_0, y_1, w) \tag{7}$$

With these specifications, we can jointly estimate the utility parameter and the discount factor from the binary choices subjects made in the choice lists. We perform the estimation at the individual level ($N = 420$: 21 choice lists per subject × 20 choices in each choice list). That is, to estimate DU for each subject, three parameters (the utility parameter α, discount factor δ, and error term μ) will be estimated. This approach allows us to include the non-switching data, because indifference is not essential in this type of estimation. We still removed three subjects who did not switch in all 21 lists, since in that case the estimation cannot converge on any sensible parameters. Therefore, the results reported in Section 6.3 are based on 80 subjects.

We examine whether the estimated discount factors are biased in a way that is consistent with the predictions. First, we examine the differences between discount factors elicited in F- and P- choices for each individual. To structurally estimate and compare the discount factor for the both types of choices at once, we include a dummy variable I_{F-P} that assigns the numeric value 0 to P- choices and 1 to F- choices. Four parameters were estimated for each subject: the utility parameter, α; the discount factor for P- choices, δ_P; the discount factor for the difference between F- and P- choices, $I_{F-P} * \delta_{F-P}$; and the error term μ. The discount factor for F- choices δ_F can be computed by δ_P+δ_{F-P}.

Second, to separately estimate discount factors for increasing/decreasing varying options, we introduced three dummy variables. The three dummy variables categorize the choice data into four groups, FI, FD, PI and PD, thus allowing us to estimate four discount factors δ_{FI}, δ_{FD}, δ_{PI}, δ_{PD} for each individual at the same time.

Finally, we also conduct the structural estimation at the individual level for the reference dependence models of EnRD and ExRD and the combined model outlined in the theory section. Compared with the DU specification, EnRD adds one additional parameter γ to capture endogenous loss aversion, ExRD adds one additional parameter λ to capture exogenous loss aversion, and the combined model adds both γ and λ.

In addition to individual estimation, we also perform the estimation at the aggregate level. That is, we take the 83 subjects' choice data as one representative agent and estimate one set of parameters based on data on all choices. We pool the 83 subjects' 420 choices to maximize the aggregate choice probability of choosing (x_0, x_1) over (y_0, y_1), which is given by

$$\sum_{1}^{83} \sum_{1}^{420} \ln P(x_0, x_1, y_0, y_1, w) \qquad (8)$$

We run the aggregate estimation for three model specifications of DU. The first specification follows the DU model, whereby three parameters (the utility, discount factor, and error term) are estimated. The second specification estimates two separate discount factors for F- and P-

choices instead of a sole discount factor, as in the first specification. The third specification estimates four discount factors for FI, FD, PI, and PD choices. We also estimate the EnRD, ExRD, and combined model at the aggregate level. Because the aggregate results paint a picture similar to that based on the individual analysis, we report them in Appendix A2.

6. Results

This section examines the behavioral patterns revealed by the experiment and compares them with the predictions of reference dependence.[6] We first examine violations of transitivity and check whether the direction of violations is consistent with the theoretical prediction. Second, we follow the traditional approach to estimate the discount factor by assuming linear utility. Third, we parametrically estimate the discount factor jointly with the utility parameter using DU. Lastly, we conduct structural estimations using the combined model.

6.1. Overview and intransitive patterns

Table 3 lists the median indifference relations for all 21 choice lists. At the median level, subjects report indifference between the present-oriented fixed option $(100, 0)$ and the future-oriented sequence $(0, 109)$, consistent with positive discounting, that is, they value future consumption less than present consumption.

Given the median indifference $F(0, 109) \sim P(100, 0)$, we need to find the sequence S'' that is indifferent to F: $(0, 109)$ to determine whether S'' is indifferent to the spread sequence S' that is indifferent to $P(100, 0)$. Table 4 shows the extrapolated S'' that is indifferent to F: $(0, 109)$ in the first column. The last column shows that the spread sequence S' is not equivalent to S'' in all four cases (IL, DL, IE, DE). This shows that transitivity is violated, which supports the effect of exogenous reference dependence. The difference between S' and S'' is much smaller in the increasing outcome sequences (IL and IE) than in the decreasing outcome sequences (DL and DE), which supports endogenous reference dependence.

[6] In the experiment, 101 subjects each completed 21 choice lists, and 18 subjects switched more than once in at least one choice list. Those 18 subjects' responses were removed from all results reported in the results section. The overall observations were not affected with the 18 subjects' responses included in the analysis.

Table 3. Median Switching Points

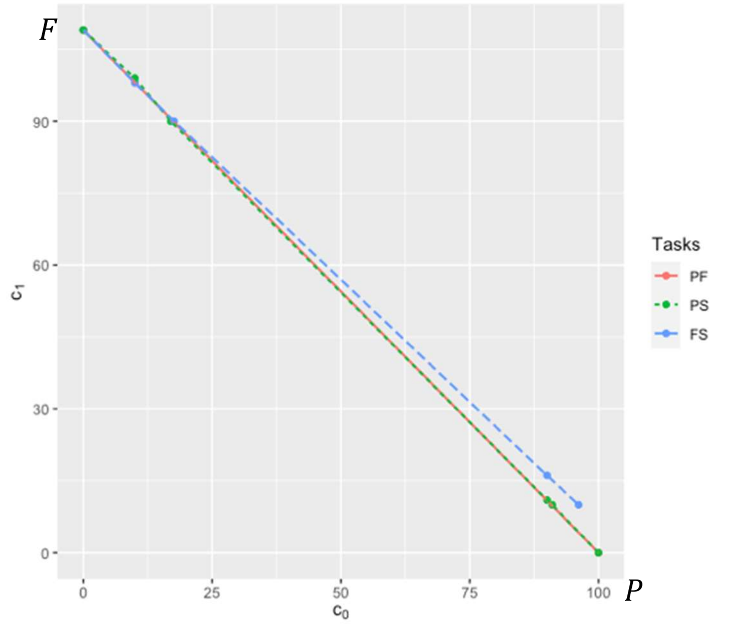
#. choice list	Median		Fixed option		Choice
	Now	6 mon	Now	6 mon	
1	0	109	100	0	PF
2	10	99	100	0	PS_{IL}
3	90	11	100	0	PS_{DL}
4	17	90	100	0	PS_{IE}
5	91	10	100	0	PS_{DE}
6	10	91	0	102	FS_{IL}
7	90	9	0	102	FS_{DL}
8	11	90	0	102	FS_{IE}
9	89	10	0	102	FS_{DE}
10	10	101	0	112	FS_{IL}
11	90	19	0	112	FS_{DL}
12	21	90	0	112	FS_{IE}
13	99	10	0	112	FS_{DE}
14	10	111	0	122	FS_{IL}
15	90	27	0	122	FS_{DL}
16	29	90	0	122	FS_{IE}
17	107	10	0	122	FS_{DE}
18	10	121	0	132	FS_{IL}
19	90	37	0	132	FS_{DL}
20	39	90	0	132	FS_{IE}
21	117	10	0	132	FS_{DE}

Table 4. Indifferent Circles at Aggregate Median Level

$S''_{IL}(10,\mathbf{98})\sim F(0,109)$	$F(0,109)\sim P(100,0)$	$P(100,0)\sim S'_{IL}(10,\mathbf{99})$	$S'_{IL} > S''_{IL}$
$S''_{DL}(90,\mathbf{16})\sim F(0,109)$		$P(100,0)\sim S'_{DL}(90,\mathbf{11})$	$S'_{DL} < S''_{DL}$
$S''_{IE}(\mathbf{18},90)\sim F(0,109)$		$P(100,0)\sim S'_{IE}(\mathbf{17},90)$	$S'_{IE} < S''_{IE}$
$S''_{DE}(\mathbf{96},10)\sim F(0,109)$		$P(100,0)\sim S'_{DE}(\mathbf{91},10)$	$S'_{DE} < S''_{DE}$

Figure 1 visualizes the aggregate median indifference relations as indifference curves. The indifference $F(0,109)\sim P(100,0)$ is represented by the straight red line connecting the points $(0,109)$ and $(100,0)$, with the x-axis presenting the outcome at today, c_0, and the y-axis representing the outcome in 6 months, c_1.

Figure 1. Indifference Curves Based on Median Data



The indifference curves (red straight line and green dotted line) show that involve the present-oriented fixed option overlap well with each other. A gap occurs between the F- indifference curve (blue dashed line) and the two P- indifference curves. This suggests that different fixed options would induce different behavioral patterns, because a shift of reference can turn gains into losses and vice versa, giving rise to preference reversal. Here, the outcome sequence over two periods can be seen as an option of two attributes. Hence, we share features similar to those in the analysis of Tversky and Kahneman (1991, Figure 3). In Tversky and Kahneman, option y and option x are evaluated from a reference point r or s, with reference r yielding a steeper indifference curve between y and x. In our case, F and P are evaluated with F or P taken as the reference, and $F \sim_P P$ implies $F \succ_F P$, such that the indifference curve is steeper when evaluated from F than P. As we observe that there is a great deal of heterogeneity at the individual level, we provide the indifference curves for each subject in Online Appendix A.

We conducted the extrapolation for each subject to determine their preference circles $P \sim F$, $P \sim S'$, and $F \sim S''$ and tested whether S' is different from S''. Table 5 below presents the proportion of intransitivity at the individual level. In addition to pervasive intransitivity, majority of subjects exhibit systematic patterns $S'' > S'$, consistent with the prediction of ExRD. We also calculated the difference $S'' - S'$, and include the median difference in the third row.

Table 5. Summary of Inconsistent Patterns

Inconsistent pattern	$S''_{IL} \succ S'_{IL}$	$S''_{DL} \succ S'_{DL}$	$S''_{IE} \succ S'_{IE}$	$S''_{DE} \succ S'_{DE}$
Percentage	51.8%	74.7%***	74.7%***	61.4%*
Median difference ($)	0.59	8.94	7.35	0.59

Note. Summary percentages of 83 subjects with predicted inconsistent patterns. We examine whether the proportion is different from 50% by conducting a binomial test. ****p*-value <0.01, ***p*-value <0.05, **p*-value <0.1

Table 6. Summary of Inconsistent Patterns with $2 Imprecision Interval

Inconsistent pattern	IL	DL	IE	DE
$S'' \succ S'$	25.3%	66.3%***	67.5%***	32.5%
$S'' \sim S'$	36.1%	18.1%	16.9%	24.1%
$S'' \prec S'$	38.6%	15.7%	15.7%	43.4%

Note. Summary percentages of 83 subjects with predicted inconsistent patterns with $2 imprecision interval. We examine whether the proportion of $S'' \succ S'$ is different from $S'' \prec S'$ using a chi-square test. ****p*-value <0.01, ***p*-value <0.05, **p*-value <0.1

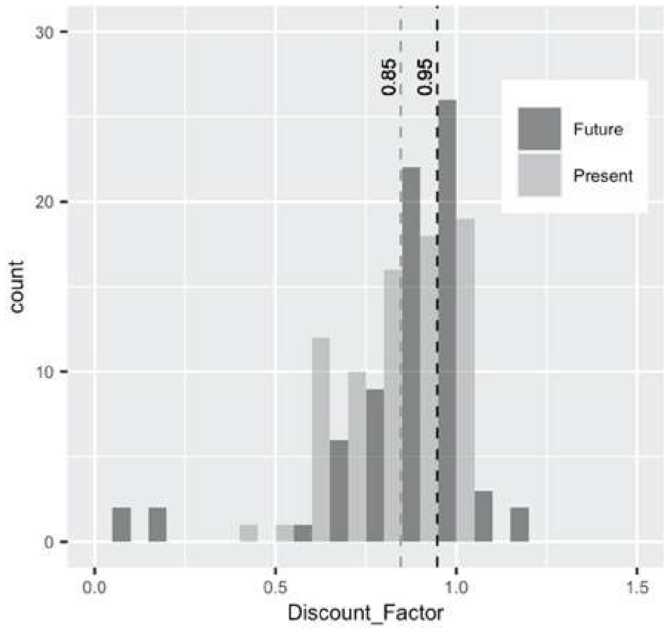
The results in Table 5 are based on the extrapolation using linear regression. In this regard, we assume that errors have zero mean. Because preference reversal hypothesis is directional in the sense of systematic patterns $S'' > S'$, the linear regression exercise is unlikely to be biased in favor of our hypothesis. In addition, we relax the zero-mean assumption and allow $2 imprecision interval. Table 6 reports an inconsistent pattern based on a $2 imprecision interval. That is, as long as the absolute difference between S''_{IL} and S'_{IL} is within $2, we will record the preference relation as $S''_{IL} \sim S'_{IL}$. We continue to observe systematic patterns $S'' > S'$ for two out of the four spread sequences.

6.2. Discount factor estimated with linear utility

This section reports the results of the calculated discount factor with utility assumed linear. Based on the discount factor calculated from each choice list and for each subject, we observe that the median discount factor over the 6-month period is 0.93.

Figure 2 presents, side by side, the histograms of all individual discount factors elicited from the F- and P- choices. The median discount factors of P- and F- choices are 0.85 and 0.95, respectively (Wilcoxon signed-rank test, $p < 0.001$). If we look at individual estimates from F- and P- choices, 75% of subjects have higher F- discount factors than their P- discount factors, and 20% of subjects exhibit the opposite pattern. The nonparametric result shows that F-choices consistently produce higher discount factors than P-choices. This confirms our prediction of ExRD, whereby the fixed option is viewed as the reference point resulting in more patience.

Figure 2. Individual Discount Factors Elicited from F- and P- Choices



Note. The reference line indicates the group median.

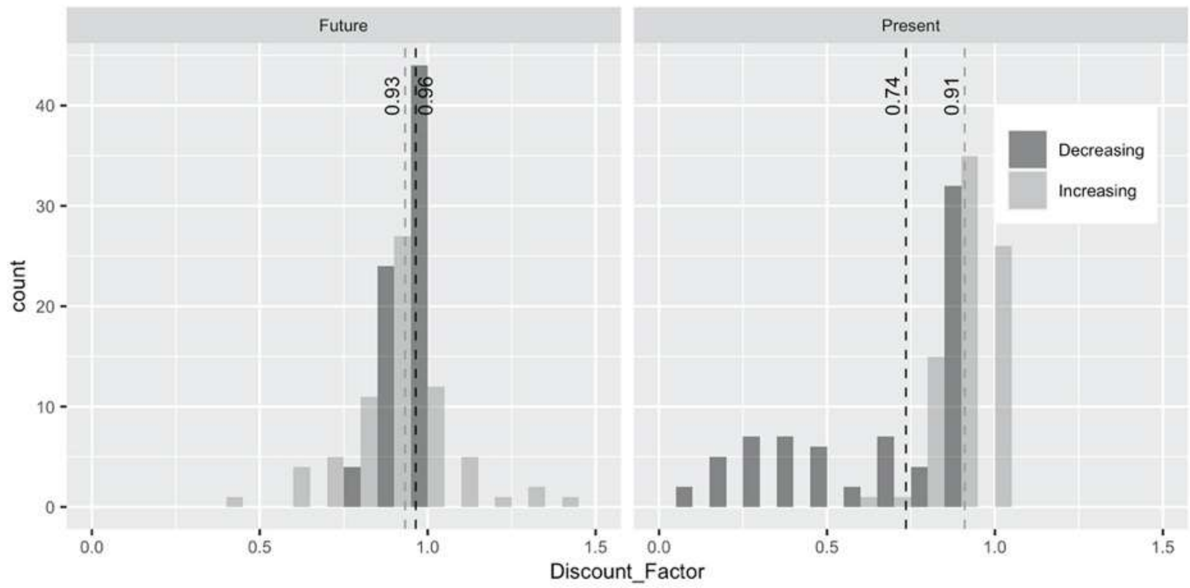
Figure 3 plots the individual estimates, in which the increasing and decreasing sequence are contrasted for both F- and P- choices. The median discount factor of FI ($\delta_{FI} = 0.93$) is smaller than that of FD ($\delta_{FD} = 0.96$) (Wilcoxon signed-rank test, p = 0.013), and the median discount factor of PI ($\delta_{PI} = 0.91$) is greater than PD ($\delta_{PD} = 0.74$) (Wilcoxon signed-rank test, $p <$ 0.001).[7] If we compare the estimates within each subject, 59% of subjects exhibit $\delta_{FI} < \delta_{FD}$, and 77% of subjects exhibit $\delta_{PI} > \delta_{PD}$. All comparisons demonstrate that the inferred discount factors are consistent with the prediction of EnRD.

Our results so far confirm both exogenous and endogenous reference effects. We further examine each subject separately to see whether their inferred discount factors for the four

[7] Estimated discount factors do not differ for different varying options. See Appendix A1 for details.

conditions are jointly consistent with the predictions of ExRD and EnRD. We observe that 33% of subjects exhibit patterns consistent with both ExRD and EnRD, 42% of subjects exhibit patterns only consistent with ExRD, 16% of subjects exhibit patterns only consistent with EnRD, and remaining 10% of subjects exhibit patterns consistent with neither EnRD nor ExRD.

Figure 3. Individual Discount Factors Elicited from FI, FD, PI, and PD Choices



Note. The reference line indicates the group median.

6.3. Discount factor estimated jointly with utility function

Figure 4 presents all subjects' discount factors parametrically estimated for their F- and P- choices in which the medians are indicated by the reference lines (see Table A1 for both aggregate and individual estimates). The median utility parameter is 0.99—almost linear—the median discount factor of F- choices is 0.95, and the median discount factor of P- choices is 0.91 (Wilcoxon signed-rank test, p < 0.01). Individually, 69% of subjects have a greater discount factor elicited from F- choices than P- choices, consistent with the prediction of ExRD.

We also separately estimate discount factors for increasing/decreasing sequences for each subject's choice data, testing the prediction of EnRD. The median utility parameter is 1.00. For the discount factors, δ_{FI} is smaller than δ_{FD} (Wilcoxon signed rank test, p = 0.02) and δ_{PI}

exceeds δ_{PD} (Wilcoxon signed rank test, p = 0.12).[8] Estimates of discount factors are plotted in Figure 5, and again reference lines indicate the medians. 59% of subjects exhibit $\delta_{FI} < \delta_{FD}$ and 67% exhibit $\delta_{PI} > \delta_{PD}$.

Figure 4. Individual Parametric Discount Factors Elicited from F- and P- Choices

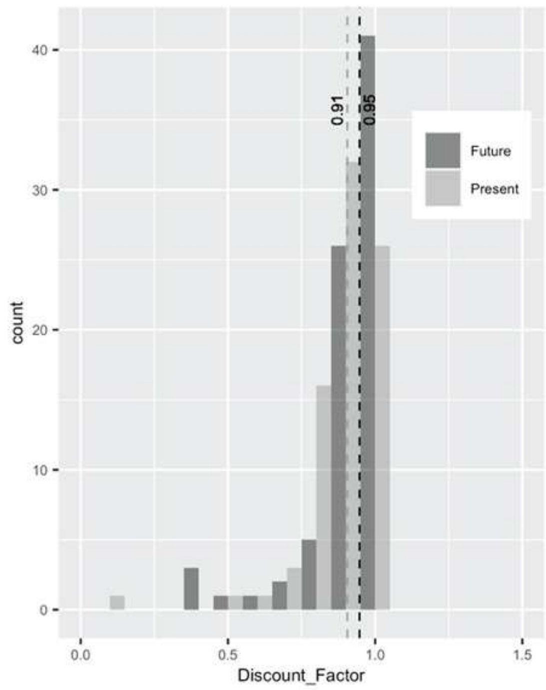
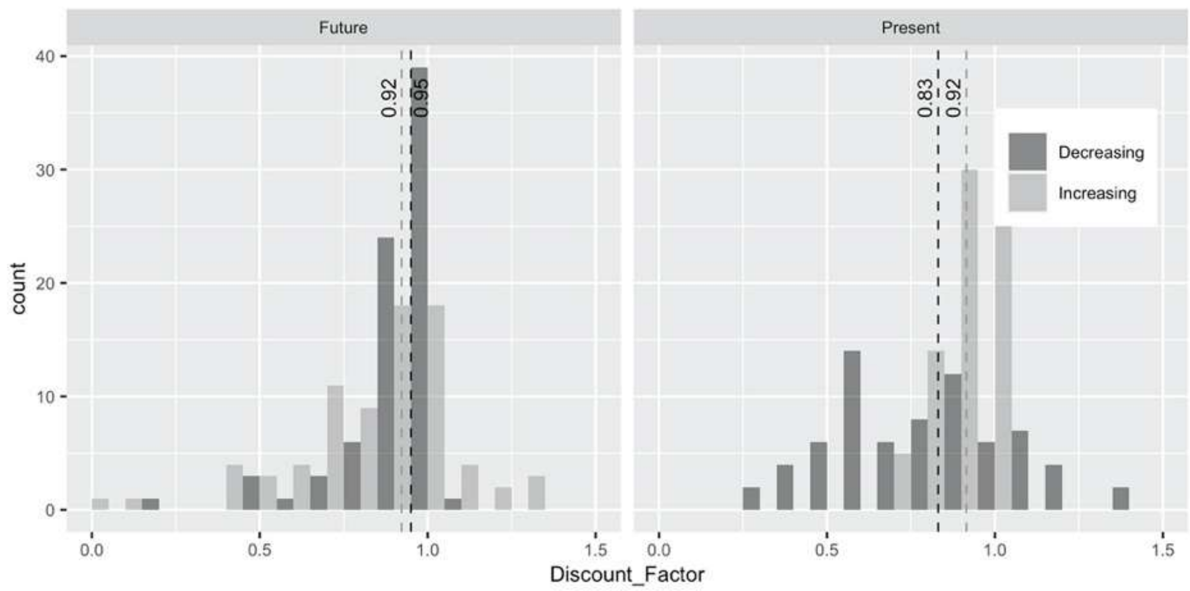


Figure 5. Individual Discount Factors Elicited from FI, FD, PI, and PD Choices



[8] While all tests are two-sided, our hypotheses are one-sided. In this regard, we interpret this result as having marginal significance, if we can take half of the two-sided p-value, hence as p = 0.06.

We also examine, separately for each subject, whether their estimated discount factors are jointly consistent with the predictions of ExRD and EnRD. We observe that 27% of subjects exhibit patterns consistent with both ExRD and EnRD, 42% exhibit patterns consistent with ExRD but not EnRD, 11% exhibit patterns consistent with EnRD but not ExRD, and the rest exhibit neither ExRD nor EnRD. The observed proportions of each type of subject are similar to those calculated for the discount factor assuming linear utility.

6.4. Structural estimation for combined reference effects

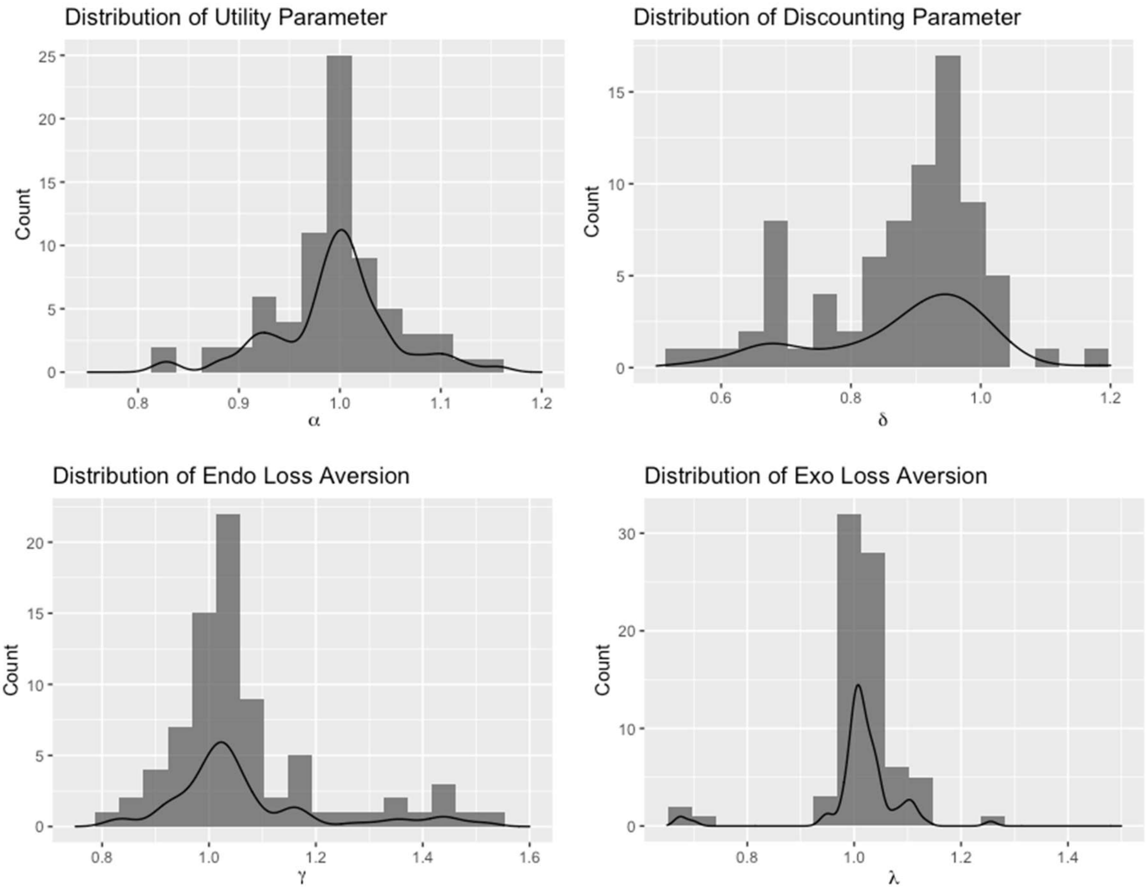
Our previous results support both exogenous and endogenous reference effects. In this section, to measure both effects quantitatively and delineate individual heterogeneity, we conduct structural estimations of the discounted utility and the combined model at both individual and aggregate levels. We summarize both individual and aggregate estimates in Table A2 of Appendix A. In the aggregate estimation, we find that loss aversions parameters are significantly larger than one for both ExRD and EnRD, and the combined model performs better than the standard discounted utility (Akaike Information Criterion, $p < 0.001$).

Figure 6 plots the individually estimated parameters for the combined model. The median estimate of the power utility parameter is one, which is close to observations in the literature, and the median discount factor is 0.92. For EnRD, the median weight of the gain-loss utility is 1.03, and 68% of the subjects have the weight exceeding one.[9] 22% of the subjects have the weight significantly larger than one and 7% have the weight significantly smaller than one for EnRD (one-sided $p < 0.05$). For ExRD, the median weight is 1.02, and 81% of subjects have the weight exceeding one. 38% of the subjects have the weight significantly larger than one and 5% have the weight significantly smaller than one for ExRD (one-sided $p < 0.05$).

To sum, we tested the loss aversion hypothesis in non-parametrical analysis and structural estimation. In the non-parametric analysis, we observed that the discounting factors are biased in the direction that is consistent with the theoretical predictions of both endogenous and exogeneous reference dependence. In the structural estimation, the loss aversion coefficients are statistically significant in support of the combined model with both reference points.

[9] In the individual estimation, fully converged estimated results are observed for 78 out of 80 subjects. The percentages here are computed based on these 78 subjects.

Figure 6. Individual Parameters of the Combined Model



7. Discussion

It has increasingly been recognized that choice lists may bias the elicitation of preference. For example, Bosch-Domènech and Silvestre (2013) show that the removal of some items from the lists yields a systematic decrease in risk aversion. He and Hong (2018) elicit the certainty equivalents of lotteries using choice lists and show that subjects become more risk averse if they respond to riskier lotteries in the first half of the lists. Freeman, Halevy, and Kneeland (2019) compare a choice list and simple binary choice, and show that the choice list could bias the elicitation of risk preference. Freeman and Mayraz (2019) find that subjects behave as if they are more willing to take a risk when a choice between a sure amount and a lottery is embedded in a choice list than when it is presented on its own. Beauchamp et al. (2020) vary the set of alternative outcomes by holding the lowest and highest outcomes fixed and changing intermediate outcomes on the choice list. They find that the manipulations robustly change the measured risk preferences. Also, choice list design can induce a reference dependent effect in the domain of risk (Sprenger, 2015). Similarly, in another popular elicitation of matching design in which subjects are asked to write down the amount of money they are willing to pay to get the object, Delquié (1993) conducts several experiments using adaptive matching questions to test framing effects and observes systematic biases in subjects' matching responses. We show that the choice list design induces reference-dependent behaviour, because subjects take the fixed option as a reference point, leading to biases in the elicited discount rate.

The observation that a choice list may bias the elicitation of time preference sheds light on some of the anomalies observed in recent studies. First, a notable feature of a choice list for time preference is that it generally yields high discount rates, which are well above the market interest rates and can be more than 100% (Frederick, Loewenstein, and O'donoghue, 2002; Cohen et al., 2020).[10] We argue that this may partly be a result of the biases caused by the choice list, because the majority of previous studies use a choice list to elicit an indifference present-oriented fixed option $(x_0, 0)$ and future-oriented varying options $(0, y_1)$. By applying the standard discounted utility, we have ${x_0}^\alpha = \delta' {y_1}^\alpha$, and the inferred discount factor would be $\delta' = \frac{{x_0}^\alpha}{{y_1}^\alpha}$. However, when the decision maker considers the fixed option $(x_0, 0)$ to be the reference point, the reference-dependent utility model would be a more suitable model. Accordingly, we would obtain ${x_0}^\alpha = \delta {y_1}^\alpha + (\lambda - 1)(-{x_0}^\alpha)$ and the elicited discount factor would be $\delta = \frac{\lambda {x_0}^\alpha}{{y_1}^\alpha} = \delta'\lambda$ under the reference-dependent model. Notice that λ is the exogenous loss-aversion parameter with $\lambda > 1$, so that $\delta = \delta'\lambda > \delta'$. Thus, if the decision maker has reference-dependent preferences, the estimated discount factor using the standard discounted utility will be downward-biased by a factor $1/\lambda$. In our setting, when we use the present-oriented fixed option, the estimated annual discount rate using the standard discounted utility is 29.4%. By contrast, when we use the reference-dependent utility to conduct the estimation, the estimated annual discount rate is only 22.6%.

Second, another puzzling observation in the literature on the elicitation of time preference is subadditivity (Read, 2001; Read and Roelofsma, 2003; Dohmen et al., 2017). For example, Dohmen et al. (2017) use choice lists to elicit the discount rate between now and 6 months, now and 12 months, and 6 months and 12 months. They observe that individuals tend to be more impatient for short- than long-term horizons (6-month duration vs 12-month duration),

[10] Interestingly, Andreoni and Sprenger (2012) use choice lists with future-oriented fixed option to elicit time preference and report that the median annual discount rate is 33% (reported in the third paragraph on p. 3352), which is similar to the 40% discount rate elicited by the CTB elicitation (reported in Table 3). Also, using a direct method, Attema et al. (2016) observe an annual discount rate of 35%.

but are similarly impatient regardless of when the short-term horizon starts (now and 6 months vs 6 months and 12 months). Given that the inferred discount factor between now and 6 months is $\delta'_{0,6}$ under the discounted utility model and the discount factor is $\delta_{0,6}$ under the reference-dependent model, as shown in the previous paragraph, we have $\delta'_{0,6} = (1/\lambda)\delta_{0,6}$. Similarly, $\delta'_{6,12} = (1/\lambda)\delta_{6,12}$ when the duration is between 6 months and 12 months, and $\delta'_{0,12} = (1/\lambda)\delta_{0,12}$ when the duration is between now and 12 months. Accordingly, the inferred annual discount factor would be $\delta'_{0,12} = {\delta'_{0,6}}^2 = (1/\lambda)^2(\delta_{0,6})^2 = (1/\lambda)^2\delta_{0,12}$ by considering a 6-month duration between now and 6 months, and $\delta'_{0,12} = {\delta'_{6,12}}^2 = (1/\lambda)^2\delta_{0,12}$ by employing the period between 6 and 12 months. Thus, the inferred discount factor would be downward-biased by $= (1/\lambda)$ using a 12-month duration between now and 12 months, while it would be downward-biased by $(1/\lambda)^2$ using a 6-month duration, regardless of whether it is between now and 6 months or between 6 months and 12 months. In addition, by comparing the inferred annual discount factor from the duration between now and 6 months with that from the duration between now and 12 months, one can also infer present bias behavior with beta as $(1/\lambda)^2$. In sum, we posit that the reference dependence on a choice list will bias the elicitation of time preference and can partially account for anomalies.[11]

8. Conclusion

This paper examines reference dependence in the elicitation of time preferences using a choice-list design. We manipulate the reference points by changing the fixed option and outcome sequences in the choice lists. We find that people appear to be more impatient when they take a present-oriented fixed option as a reference point and appear to be more patient when they take a future-oriented fixed option as a reference point. Consequently, the relation inferred from a choice list exhibits preference reversals. Our findings provide clear evidence that choice list with fixed option can bias the elicitation of time preference. In addition, early outcome is taken as a reference point for later outcome, which also biases the discount factor. These observations are further supported by the estimated discount rates using structural estimation.

[11] It is hard to precisely estimate the extent to which reference dependence on a choice list could account for these phenomena, since different studies also differ in terms of specific designs, instructions, subject pools, and culture (see Frederick, Loewenstein, and O'donoghue, 2002, for a review). It is also possible that some behavioral factors contribute to the occurrence of such observations, including transaction cost (e.g., Holcomb and Nelson, 1992; Benhabib, Bisin, and Schotter, 2010); inherent uncertainty (Halevy, 2008; Epper and Fehr-Duda, 2014); liquidity constraints (Epper, 2015); and memory capacity (Bao, Dai, and Yu, 2018).

These results demonstrate the importance of both the exogenous and the endogenous reference effect in intertemporal choices.

Our study provides a clean demonstration of reference dependence effects in the setting of choice-list elicitation, while avoiding potential confounds of previous studies that use explicit frames of gains and losses. We show that choice lists, despite numerous advantages, can cause systematic biases in the elicitation of time preference. We further provide a simple direct estimation of utility and discounting using outcome sequences in the choice lists, adding to some prior studies. Our observations can also help explain some anomalies in the elicitation of time preference.

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