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Are violations of the stationarity principle mistakes?

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ABSTRACT

We report an experiment that tests whether violations of the stationarity principle of the exponentially discounted utility model are mistakes. In normative decision theory, a mistake is defined as a choice that a decision-maker does not wish to maintain following an analysis of their decision. If observed violations of the stationarity principle are mistakes of that type, its normative credentials remain intact. The intertemporal decisions of 448 subjects were observed and categorized according to whether they were stationary or not. Subjects were then provided with a normative argument in support of a counterfactual behavior, alongside the opportunity to revise their decisions. The majority of subjects made stationary choices and did not revise them, despite the normative reason to do so. Those choices cannot be attributed to mistakes. However, final choices also exhibit systematic present-biased violations of the stationarity principle that cannot be attributed to errors. Hence, whilst the stationarity principle cannot be excluded as a requirement of rationality for the majority of our subjects, nor can it claim to be universal.

1. Introduction

Samuelson's (1937) exponentially discounted utility model (henceforth *EDU model*) is the incumbent standard of rational action in intertemporal choice. It is simple, tractable and derives normative appeal from Strotz's (1955) demonstration that only an exponential discount function will guarantee the dynamically consistent choices that avoid vulnerability to a Dutch book (Callender, 2021; Frederick et al., 2002; Loewe, 2006).[1] The crucial ingredient in Strotz's (1955) proof is the *stationarity principle*, which holds that the ranking of two temporally-located outcomes (e.g. x today, y tomorrow; $x < y$) depends only on the outcomes and the delay between receiving them. Stationarity means that if an additional common delay is applied to the outcomes (e.g. x in n days and y in $n + 1$ days; $n > 0$), preferences are unaffected.

Notwithstanding the attractions of the EDU model, influential contributors to the literature have called for it to be abandoned as the standard of normative behavior (e.g. Callender, 2021; Frederick et al., 2002; Manzini and Mariotti, 2009). These calls are usually based on philosophical argument (e.g. Callender, 2021; Greene, 2021; Steele, 2021) and the introspective appeal of behavior which is inconsistent with stationarity. For example, Fisher (1930) describes how present-biased, non-stationary preferences can be rational for those with uncertain futures.[2]

The case against the normativity of stationarity is rarely argued on the basis of evidence. A likely reason is that almost all evidence of the failure of the EDU model is from studies designed to evaluate its *descriptive* performance (see Frederick et al., 2002; Kirby, 1997; Read, 2004 and Andersen et al., 2014 for reviews). Whilst that evidence shows that observed choices are often inconsistent with the stationarity principle, it does not necessarily undermine the claim to normativity; because it does not establish whether non-stationary behavior represents an intentional rejection of the principle's prescribed choices, or rather an erroneous departure from an otherwise sound requirement of

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[1] See Mulligan (1996) and Steele (2021) for arguments supporting the normativity of the EDU model. We use 'normative' to refer to choices that can be defended as rational (e.g. prescribed by a rational choice theory), and not to 'how things should be' according to moral or legal considerations, as is sometimes meant in other literatures.

[2] Azfar (1999) presents a formal rationale for hyperbolic discounting based upon favoring present consumption.

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rational of choice. In other words, if observed violations of the stationarity principle are result of mistakes that decision-makers would be willing and able to correct if they were to engage in error-free reasoning, its status as an achievable requirement of rationality remains intact.[3]

Nielsen and Rehbeck (2022) describe an analogous state of affairs in experimental evidence pertaining to the axioms of risky choice theory. In that literature, the response has been to build upon a small number of studies from the late 1960s and early 1970s to revisit the question of whether violations of canonical risky choice axioms are mistakes (MacCrimmon, 1968; Slovic and Tversky, 1974; Moskowitz, 1974; Benjamin et al., 2021; Nielsen and Rehbeck, 2022; Herweg et al., 2024; Humphrey and Kruse, 2024, 2025). In this paper, we report the results of an experiment that extends that literature to the study of intertemporal decision-making.

The experiment is based upon Slovic & Tversky's (1974) classic test of whether violations of Savage's (1954) sure-thing principle are mistakes.[4] We observed choices in "smaller-outcome-sooner versus larger-outcome-later" tasks, which were categorized according to whether they violated or respected the stationarity principle. Subjects were then provided with what Gilboa (2010) calls an analysis of those decisions. This entailed challenging subjects' commitment to their choices, by presenting them with a normative argument favoring a counterfactual behavior with a claim to represent rational action. Subjects who made stationary choices were given an argument based upon Fisher's (1930) rationalization of non-stationary choices that favor present consumption. Subjects who violated stationarity received an argument supporting it. Choices were then repeated. Mistaken choices are those the decision-maker does not wish to maintain following the analysis of their decisions. We explain the origins of this definition of choice error the next section. We observe that modal behavior in final choices respects stationarity. However, 21% of final choices violate stationarity, are systematically patterned in the direction of a present-bias, and cannot be attributed to mistakes.

2. Background

2.1. Errors in normative decision-making

We follow the definition of a choice error that is commonly used in normative decision theory and behavioral economics. Its origins and applications are described by Dietrich et al. (2021), which we shall summarize here to clarify the meaning of a *choice error* in the sense that we use it, and how our experiment tests for them. Discussion of the role of choice errors in behavioral economics can be traced to a symposium on the 'Foundations and applications of the theory of risk bearing' that took place in Paris in 1952. At that meeting, Maurice Allais (1953) presented Leonard Savage with hypothetical lottery choice tasks, in which Savage's choices violated the sure-thing principle of his own subjective expected utility theory (Savage, 1954). Savage's response was to revise one of his choices such that a violation was no longer committed. In doing so, he concluded that he had corrected a choice that was, upon reflection, a mistake (Savage, 1954, p.103). Savage's interpretation of an error is therefore the violation of an axiom that the decision-maker is willing and able to correct, once they become aware of it.

That view has endured in a significant body of influential work in behavioral economics. For example, in motivating prospect theory, Kahneman & Tversky, 1979, p.277) describe violations of expected utility theory's axioms as something that decision-makers would correct upon realizing the implications of their choices. The job of prospect theory is to describe behavior in the "many situations" (p.277) where decision-makers do not have the opportunity to learn that choices have violated principles they would rather respect.

Savage's perspective can also be recognized in behavioral welfare economics; defined by Infante et al. (2016) as the branch of normative economics where, "violations of rationality requirements result from interactions between error-inducing psychological processes and coherent latent preferences" (Dietrich et al., 2021, p.146). For example, Thaler and Sunstein (2008) characterize latent preferences as those revealed by the effortful operation of slow and deliberate "System 2″ reasoning (Wason and Evans, 1974), which can police and correct the systematic biases that stem from fast and automatic "System 1" judgements. The implication is that latent preferences are those that are free of errors, and would be revealed as the outcome of a deliberate and consciously controlled process of reasoning, possibly as a result of the correction of initially biased judgements. By defining latent preferences in that way, behavioral welfare economists are able to maintain the satisfaction of preferences as a normative criterion, despite evidence showing that revealed preferences are often inconsistent and context-dependent in ways that seem irrelevant to welfare (Dietrich et al., 2021, p.147).

It follows that an objective of experimental behavioral welfare economists is to identify methods that recover error-free latent preferences that respect standard principles of rational consistency. Dietrich et al. (2021) describe Slovic and Tversky's (1974) experiment design as an example of how behavioral welfare economics might go about that. Hence, in Slovic and Tversky's (1974) design, and our application of it, the normative arguments can be interpreted as catalyzing a deliberate and conscious, Savage-like reflection on initial choices, in order to filter-out those that the decision-maker considers to have been mistakes.

A related interpretation of the role of counterfactual normative arguments in filtering-out choice mistakes is described by Gilboa (2010). In the face of observed violations of classical choice theory, Gilboa (2010) proposes the preaching of that theory to help individuals make better choices. On this view, if conformity with classical theory can be successfully preached to violators, then violations of that theory can be treated as errors that decision-makers are willing to correct, and the normative status of the classical theory survives. Dietrich et al. (2021, p.161) suggest that Savage's response to his violation of the sure-thing principle at the Paris symposium can be interpreted as him preaching that axiom to himself. In our experiment, the normative argument supporting stationarity that was presented to subjects who violated it in initial decisions, is an example of what Gilboa (2010) has in mind regarding the preaching of classical theory. Gilboa et al. (2010) classify the choices made after preaching as being either subjectively or objectively rational. Choices that are maintained following an argument supporting counterfactual behavior are subjectively rational, because the decision-maker was not persuaded that those choices were wrong. Behavior that emerges as a result of initial choices being revised is objectively rational, because the argument in favor of that revision was persuasive. In the latter case, the initial choices can be considered mistakes.

[3] Frederick et al. (2002) claim otherwise: "…the DU anomalies do not necessarily violate any standard or principle that people believe they should uphold" (p.352) and "even when the [*violating*] choice pattern is pointed out to people, they do not regard themselves as having made a mistake." (p.365). The claim is substantiated with two studies. Firstly, Frederick and Read (2002) observe that differences in discount rates for larger and smaller outcomes are more pronounced when the evaluations are made in close succession rather than separately. Frederick et al. (2002) argue that the failure of subjects to co-ordinate the more adjacent evaluations to conform with the EDU model, means they did not consider doing so normatively appropriate. That interpretation, however, is untested conjecture. Secondly, Loewenstein and Sicherman (1991) observe that the EDU model was violated by subjects preferring an increasing wage profile over a decreasing one, even though it was explained that by saving and investment the latter would generate greater consumption opportunity. Whilst this study links choices to normative judgements, it lacks incentive compatible decision tasks.

[4] Halevy (2008); Saito (2011) and Andreoni and Sprenger, 2012 discuss the relationship between violations of the sure-thing principle and violations of stationarity.

It is evident from the above literature that the concern with errors in normative decision-making has been largely focused on whether violations of classical theory are mistakes. That focus persists in recent research (e.g. Nielsen and Rehbeck, 2022). Slovic and Tversky's (1974) approach is more general, because it does not preclude the possibility that choices which respect an axiom might also be mistakes. As Humphrey and Kruse (2025) put it, Slovic and Tversky's (1974) design does not exhibit a precommitment to candidate errors being only those choices that violate standard rationality requirements. This more general perspective is especially pertinent in contexts where behavior that violates an axiom is defensible as normative. For example, Loomes and Sudgen's (1983) rationale for violations of the transitivity axiom of expected utility theory, based on regret-aversion; and Fisher's (1930) description of present-biased choices as rational for those with uncertain futures, which is of particular interest here. We therefore adopt a similarly agnostic approach. In our experiment, all subjects are provided with the opportunity to revise initial choices in light of a normative argument that supports doing so, irrespective of whether those choices violated or respected the stationarity principle.

2.2. Discounted utility, stationarity and preference reversal

In this section, we explain how the EDU model and its most popular alternative, the quasi-hyperbolic discounting model (Phelps and Pollak, 1968; Laibson, 1997), apply to the decision tasks used in the experiment. To contextualize the question of whether violations of stationarity are mistakes, we shall pay particular attention to the role of that principle. If we observe that stationarity is violated in final decisions, then those choices cannot be attributed to errors of the type described in the previous section. In which case, the status of the stationarity principle as a rationality requirement is undermined, and the EDU model is insufficient to describe behavior. Descriptive duties must be performed by another model, such as the quasi-hyperbolic discounting model that we explain below. For subjects who respect the stationarity principle in final choices, its normative and descriptive credentials remain intact.

The experiment employed decision tasks based on Thaler (1981). In a 'proximate' payment task, decision-makers chose between receiving outcome x at time s, or receiving outcome y at time s+t, where $x \leq y$, $t > 0$. Then, in a 'remote' payment task, they faced the same choice, except that an additional common delay of $\Delta > 0$ was applied to the receipt of each outcome. Discounted utility models entail a discount function $D_s(\tau)$ applied at time s for outcomes received at s+τ, where $\tau \geq 0$. The discount function describes the weights attached to outcomes that are received through time. In the EDU model, discounting is assumed to be constant through time, and is described by $D(\tau) = \delta^{\tau} = [1/(1+\rho)]^{\tau}$, where δ^{τ} is the discount factor, ρ is the discount rate, and τ represents the time intervals under consideration.

Assume that in the proximate task, a smaller payment x received at time s is indifferent to a larger delayed payment y received at s+t. Under the EDU model, where the utility function describes the instantaneous utility of receiving those outcomes, expression (1) must be true:

$$D(s)u(x_s) = D(s+t)u(y_{s+t}) \tag{1}$$

Now consider the stationarity principle, which is defined by Halevy (2015) as follows. For outcomes x and y, dates t, $t' \geq 0$, and payment delays Δ_1, $\Delta_2 \geq 0$, preferences are stationary if:

$$(x, t+\Delta_1) \succsim_t (y, t+\Delta_2) \Leftrightarrow (x, t'+\Delta_1) \succsim_t (y, t'+\Delta_2) \tag{2}$$

Where $\succsim_t$ denotes weak preference in period t and (x, t+Δ_1), for example, denotes outcome x received at time t+Δ_1. Expression (2) means that the ranking of two temporally-located outcomes depends only on the outcomes and the delay (Δ_2-Δ_1) between receiving them. Therefore, if expression (1) is true, stationarity requires:

$$D(s+\Delta)u(x_{s+\Delta}) = D(s+t+\Delta)u(y_{s+t+\Delta}) \tag{3}$$

That is, the common delay of $\Delta > 0$ applied to the receipt of outcomes x and y in the remote task will leave preferences unaffected. Solving (1) and (3) shows that stationarity means D(s)/D(s+t) = D(s+Δ)/D(s+t+Δ), for payment delays t, $\Delta > 0$. In other words, discounting between periods s and s+t is the same as discounting between periods s+Δ and s+t+Δ.

In the absence of stationary preferences, decision-makers might commit a preference reversal. A *present-biased preference reversal* (Thaler, 1981) is manifest in a smaller payment x received at time s, being chosen over a larger delayed payment y received at s+t, but that preference being reversed when the additional common payment delay $\Delta > 0$ is applied to both outcomes. These preferences require expressions (4) and (5), respectively, which solve to yield (6):

$$D(s)u(x_s) > D(s+t)u(y_{s+t}) \tag{4}$$

$$D(s+t+\Delta)u(y_{s+t+\Delta}) > D(s+\Delta)u(x_{s+\Delta}) \tag{5}$$

$$D(s)/(D(s+t) > D(s+\Delta)/D(s+t+\Delta) \tag{6}$$

Hence, preferences are present-biased if expression (6) is true for all t, $\Delta > 0$. Since expression (6) is inconsistent with (3), it cannot be true if preferences are stationary.

The quasi-hyperbolic discounting model involves the discount function $D(\tau) = 1$ if τ=0, and $D(\tau)$=$\beta\delta^{\tau}$ for β, $\delta \in (0, 1)$, if $\tau > 0$, and where δ^{τ} is the discount factor described above. If s = 0, so that the receipt of x in the proximate payment task is immediate, expression (6) is straightforwardly true under that model and present-biased preference reversals are explained. For example, assuming t, $\Delta = 1$, expression (6) is $1/\beta\delta > \beta\delta/\beta\delta^2 = 1/\delta$ (or, more generally, $1/\beta\delta^{\tau} > 1/\delta^{\tau}$). The intuition is a taste for present consumption, which results in greater discounting between periods s and s+t than between periods s+Δ and s+t+Δ.

The contribution of stationarity to the normative status of the EDU model is illustrated by Fig. 1 (Callender, 2021). Each choice is of the type described above, between a smaller-but-sooner outcome x and a larger-but-later outcome y. The receipt of outcomes is shown along a time-line relative to when a choice is taken (denoted 'choice'). Stationarity requires that either x or y is chosen in both decisions 1 and 2. A *present-biased* preference reversal is a preference for x in decision 1, but y in decision 2. A *future-biased* reversal is the opposite. Since preference reversals imply a vulnerability to arbitrage, stationarity has been central to the normative claims of the EDU model. More recently, Halevy (2015) explains that invulnerability to exploitation requires choices to be consistent through time, but stationary preferences are insufficient to ensure that. *Time-consistency* requires a preference for either x or y in both decisions 2 and 3. For stationary preferences to imply time-consistency they must also be *time-invariant*, which requires a corresponding stable preference for x or y in both decisions 1 and 3. Halevy's (2015) clarification means that whilst stationarity is an important ingredient of time-consistent behavior, the normative status of time-invariance should also be studied. The discussion in Callender (2021) is a start. Our focus is on the stationarity principle, because of its role in the EDU model's claim to normativity in work both since and prior to Halevy (2015).

3. Experiment design

Following the recommendation of Andersen et al. (2014), we presented the choice tasks as multiple price lists described in Table 1. The left-hand panel of Table 1 shows a list of 16 relatively proximate trade-offs. Subjects proceeded down the list and chose between receiving €30 today (option A) and amounts to be paid 7 days later, which begin at €30 and are incremented by €1 up to €45 (option B). The right-hand panel shows 16 similar choices, but with a payment delay of 30 days added to each option. Option A in the proximate menu does not include a front-end payment delay. According to Andersen et al. (2014, p.18), this should facilitate the observation of any non-stationary

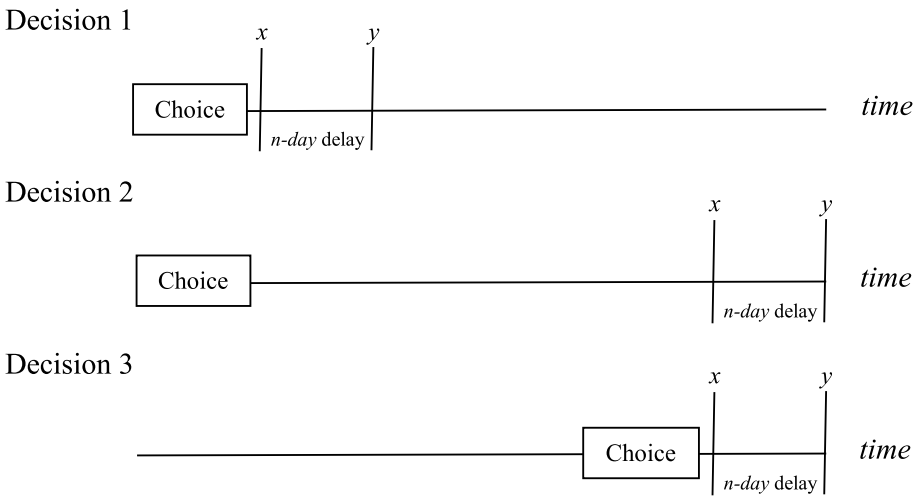

Fig. 1. Stationarity, time-invariance and time-consistency.

Table 1
Choice tasks.

Proximate Menu			Remote Menu		
Task	*Option A*	*Option B*	*Task*	*Option A*	*Option B*
1	€30 today	€30 in 7 days	17	€30 in 30 days	€30 in 37 days
2	€30 today	€31 in 7 days	18	€30 in 30 days	€31 in 37 days
.	.	.	.	.	.
16	€30 today	€45 in 7 days	32	€30 in 30 days	€45 in 37 days

preferences held by subjects, by contributing to a "passion for the present".

The design is within-subjects and the order of the proximate and remote menus was varied to control for reference point effects of the type discussed by Frederick et al. (2002, p.386). The stationarity principle requires switching from A to B at the same point in each menu. Present-biased (future-biased) reversals involve switching from A to B earlier (later) in the remote menu than in the proximate menu. Earlier switching points indicate greater patience, because less compensation is required for a 7-day payment delay. Having made their decisions, all subjects received the message:

Now that you have made your choices, you have the opportunity to reflect on them and consider how some economists who investigate these types of situations would interpret your behavior. You are not obliged to behave as these economists suggest. Your choices are solely a matter of your preference. You will then be asked to make your choices again. Since real money is at stake, please consider your choices carefully and decide in the way that you prefer.

> *Each question asks whether an amount of money x is sufficient compensation to delay payment by 7 days.*
>
> *Your choices in situations 1 to 16 reveal that you require ⟨€x⟩ compensation to delay receiving €30 for 7 days.*
>
> *Your choices in situations 17 to 32 reveal that you require ⟨€y⟩ compensation to delay receiving €30 for 7 days in 30 days' time.*
>
> *Some economists who investigate these situations would interpret your choices as follows:*

Subjects who violated stationarity then received the message:

> *Your choices are illogical as they require different amounts of compensation for an identical delay (7 days) of an identical payment (€30). Situations 1 to 16 are the same as situations 17 to 32. You are always asked the same question: How much compensation do you require to delay a payment of €30 by 7 days? It is therefore reasonable to require the same amount of compensation to delay the payment by 7 days.*

Subjects who respected stationarity then received a message supporting a present-bias:

> *Your choices are illogical as they require an identical amount of compensation to delay payment by 7 days in both situations 1 to 16 and situations 17 to 32, even though situations 1 to 16 differ from situations 17 to 32. In situations 17 to 32, payment is in 30 days' time at the earliest. You therefore have to wait for the payment irrespectively of how you choose. In situations 1 to 16, this is not the case. Here delaying payment by 7 days means you will be giving-up immediate payment. As immediate payment is normally valued, it would be reasonable to ask for more compensation for delaying payment in situations 1 to 16 than in situations 17 to 32.*

As explained above, the purpose of the normative arguments is to filter-out choices that the decision-maker considers to have been mistaken. That purpose is served by prompting a deliberate and conscious reflection on initial choices, by describing an alternative that can be seen as reasonable, or attractive, even though it may ultimately be rejected. This is how Savage (1954) described his reaction to the Allais (1953) paradox choices that violated the sure-thing principle. Although he concluded that the violation was a mistake, the "intuitive attraction" he continued to feel towards those choices was an integral part of the careful refection that led to that conclusion (Savage, 1954, p.103). If the preaching of alternative choices was trivially dismissible, by lacking reason or attraction, it would not fulfil that purpose. Consequently, the arguments were phrased in a manner comparable to those used to challenge choices in tests of whether violations of the sure-thing principle are mistakes (MacCrimmon, 1968; Moskovitz, 1974; Slovic and Tversky, 1974; Humphrey & Kruse, 2024, 2025). The former message is analogous to Savage's (1954) defense of the sure-thing principle

as a rule of logic, which was the basis of "Dr. S's" view in Slovic and Tversky (1974). The latter message derives normativity from the certainty of immediate payment (Fisher, 1930; Thaler, 1981; Callender, 2021). It is analogous to Allais' (1953) certainty-based rationale for violating the sure-thing principle, which was argued by "Dr. A" in Slovic and Tversky (1974). Following the normative arguments, subjects repeated the decisions.[5]

Although close variants of Slovic and Tversky's (1974) design have recently been usefully deployed in the experimental risky choice literature (e.g. Humphrey and Kruse, 2024, 2025), there are alternative designs that address the question of whether axiom violations are mistakes; notable amongst which is Nielsen and Rehbeck (2022). We refer readers to the extensive discussion in that paper and Humphrey and Kruse (2025) of the advantages and disadvantages of each approach. Below, we summarize the reasons why we based our experiment on an application of Slovic and Tversky's (1974) design.

Firstly, the normative arguments explain the respective rationales for stationary and present-biased choices in the context of the decision tasks subjects had completed. By contrast, Nielsen and Rehbeck (2022) elicit general attitudes towards axioms by representing them as abstract rules that apply to all choices. In their design, subjects subsequently completed a series of lottery choice tasks before those who had normatively approved of an axiom, but violated it in choices, were given a reconciliation opportunity in which approval could be withdrawn or choices revised (the latter being taken as evidence of choice mistakes). The context-specificity of our approach benefits from being simple and transparent, and is thereby less susceptible to misunderstanding. The relatively moderate cognitive demands of a single type of choice task also minimizes choice fatigue, which may otherwise limit the allocation of cognitive resources to understanding and engaging with the arguments during the choice revision opportunity. Given the preliminary nature of our study, we chose to prioritize that over generality.

Secondly, experiments involving an intervention by an 'authority' (e.g. the normative arguments), are potentially susceptible to experimenter demand effects. Humphrey and Kruse (2024) define a demand effect as the revision of choices to conform with the argument seen, for reasons other than the satisfaction of preferences (e.g. not wanting to appear resistant to advice). Measures that control for demand effects include incentivizing the satisfaction of preferences, and ensuring the dominance of payoffs over the subjective costs of participation in the experiment (Smith, 1982); which was supported in our experiment by expected earnings at least double the typical shadow wage of student subjects. Alongside this, a desirable property of Slovic and Tversky's (1974) design is that it generates data that can be used to test for demand effects. If subjects are susceptible to demand effects of this type, their choice revision decision would be independent of the argument seen. We report the results of that test below.[6]

Thirdly, as explained above, our design is agnostic over the types of choices that could be mistakes. All initial choices are challenged with a normative argument that supports a revision, and accompanied by the opportunity to do so. This contrasts with Nielsen and Rehbeck's (2022) approach, where the revision opportunity is given only to those subjects whose choices violated axioms. In situations where both choices that violate an axiom and those that respect it can lay claim to rationality, truncating data collection in that way would forego observations required for a balanced and complete assessment of what counts as rational action.[7]

We used ORSEE (Greiner, 2015) to recruit 448 (248 female) subjects from a register of volunteers to participate in one of 26 pre-arranged sessions. Our analysis excludes 18 subjects who had multiple switching points in the price lists (details of which can be found in the supplementary material, Appendix B). The age of subjects ranged from 18 to 45 years, with a mean of 24. Subjects were paid according to their choice in a task that was randomly selected after all tasks had been completed. The experiment also involved multiple price list tasks to measure risk attitude (Holt and Laury, 2002) and loss-aversion (Gächter et al., 2022), which are described in the supplementary material (Appendix C). These tasks were included in the random lottery incentive system and subjects knew this. To control for transactions costs, all payments were made by bank transfer. For subjects who received "€30 today", the transfer was immediate. To control for influences on behavior associated with payments being made by bank transfer (such as a lack of trust, or heightened risk aversion), payment credibility was ensured by transferring payments from an account at well-known German retail bank, which contained funds underwritten by the University. Payments were scheduled in the bank's online system at the end of each session, and all subjects knew this. Sessions lasted for less than one hour and average payment was €32. The experiment was programmed using SoPHIE (Hendriks, 2012).[8]

4. Results

Table 2 describes the number of subjects exhibiting each combination of initial (pre-argument) and final (post-argument) choice patterns.[9] In initial choices, 73% of subjects respected stationarity. Violations are approximately evenly distributed between present-biased (12.1%) and future-biased (14.9%) preference reversals (note that 'preference reversal' refers only to non-stationary choices within each set of decisions, and not to the revision of choices following the normative argument). A two-sided binomial test accepts the null-hypothesis that each type of violation is equally likely ($p = 0.3071$).

The proportion of preference reversals observed in initial decisions is substantially lower than the 80%-plus reported elsewhere (e.g. Takeuchi, 2011; Kirby and Herrnstein, 1995); a potential factor in which is our use of cognitively transparent multiple price lists. Another possibility is associated with all payments being made by bank transfer (in order to control the payment procedure across laboratory and online sessions). This meant that accessing immediate payment would require a visit to the ATM. This could have weakened present-biased preference reversals by operating as a front-end payment delay, and thereby undermining the "passion for the present" described by Andersen et al. (2014).[10] However, these findings are not without precedent in the

[5] Messages were slightly modified for a small number of subjects who either required no compensation for delayed payment, or did not accept a delay at all. Details can be found in the supplementary material (Appendix B).

[6] The potential for demand effects supports simple context-specific designs that promote understanding. More complex designs may have greater need of pre-task comprehension tests. Those tests often require subjects to deliver correct answers to questions about the design to demonstrate comprehension. If the 'understanding' part of comprehension tests transfers to decision tasks (which is desirable), it is conceivable that the expectation of correct and incorrect responses transfers as well. In designs susceptible to demand effects, that is not desirable.

[7] If Allais (1953) and Savage (1954) has resolved to settle their debate over the rationality of the sure-thing principle by experimentation involving Allais' lottery choice tasks, it is unimaginable that Allais would have accepted a design that entertained only the choices he favored as potential mistakes.

[8] 14 sessions were laboratory based and 12 were online, with identical procedures. The data are pooled because choices are independent of how the experiment was implemented (based upon a chi-square test of independence, a two-sample rank-sum test of stochastic equivalence, and a comparison of sample proportions for each category of behavior at the aggregate level, and each category of pre- and post-arguments behavior at the individual level). The tasks that measured risk attitude and loss-aversion were used to check for differences between laboratory and online sessions. There were none.

[9] Data are available at the Open Science Framework repository: https://doi.org/10.17605/OSF.IO/VDC7M

[10] At the time of the experiment, there were three Sparkasse ATMs within 400m of the laboratory.

Table 2
Choice patterns before and after normative arguments.

		Final choices (post-argument)			
		Stationary	Present-biased	Future-biased	*Totals*
Initial choices (pre-argument)	Stationary	267 (62.1%)	35 (8.1%)	12 (2.8%)	*314 (73.0%)*
	Present-biased	27 (6.3%)	19 (4.4%)	6 (1.4%)	*52 (12.1%)*
	Future-biased	46 (10.7%)	2 (0.5%)	16 (3.7%)	*64 (14.9%)*
	Totals	*340 (79.1%)*	*56 (13.0%)*	*34 (7.9%)*	*430 (100%)*

extant literature; both Sopher and Sheth (2006) and Halevy (2015) observe that modal behavior respects stationarity, and neither can rule-out that deviations are random noise.

Post-argument choices reveal an increase in overall respect for stationarity from 73% to 79.1% of choices. The rate of present-biased reversals is reasonably stable, increasing slightly from 12.1% to 13%. However, the rate of future-biased reversals falls from 14.9% of initial choices to 7.9% of final choices. A two-sided binomial test of the null hypothesis that each type of reversal is equally likely yields $p = 0.0263$. The null hypothesis is rejected at the 5% significance level; stationarity violations in final choices systematically favor a present-bias. This finding should be qualified by noting that future-biased choices were not supported by a normative argument. We discuss the implications of that qualification below.

The aggregate-level data exhibit three salient properties. Firstly, a clear majority of subjects respected the stationarity principle. That observation holds in the final decisions that followed the presentation of normative arguments, which included the challenge to stationarity posed by the argument favoring a present-bias. For subjects whose final choices respected stationarity, its normative credentials remain intact. Secondly, assuming that subjects understood the normative arguments, the systematic present-biased violations of stationarity observed in final choices are not choice mistakes. All of those choices had passed through the filter of the normative arguments, and were the result of either the maintenance of initial present-biased choices, or the revision of initial non-present-biased choices. Hence, they are either subjectively or objectively rational according to the Gilboa et al. (2010) criteria.[11] Thirdly, the aggregate data suggest that future-biased reversals – which imply *less* compensation for giving-up immediate payment – may be largely attributable to mistakes. That indication is subject to confirmation by the individual-level analysis, which we now turn to discuss.

The individual-level choice data echo the properties of the aggregate data. The leading diagonal of Table 2 represents subjects who maintained their initial choices, despite the challenge of a normative argument supporting counterfactual behavior. This reveals that 62.1% of subjects maintained choices that respected stationarity, whilst 8.1% of subjects maintained choices that violated it. These choices are not mistakes that those subjects wanted to correct. Table 2 also reveals that out of 314 subjects who respected stationarity in initial choices, 267 (85%) continued to do so in final choices. Out of the 116 subjects that initially violated stationarity, 35 (30%) continued to do so in final choices. A two-sided test of difference in sample proportions, of the null hypothesis of no difference, yields $p = 0.0000$ (unadjusted). Subjects who initially violated stationarity were significantly more likely to regard those choices as mistakes than subjects who initially respected it.

Table 3
Post hoc analysis of choice revisions.

Revision between patterns	p-values	
	unadjusted	adjusted*
Stationary ↔ present-biased reversals	0.374	0.374
Stationary ↔ future-biased reversals	0.000	0.000
Present-biased ↔ future-biased reversals	0.289	0.374

* Adjusted using the Benjamini and Hochberg (1995) method.

The off-leading diagonals represent subjects who revised their initial decisions. A two-sided Stuart-Maxwell test of marginal homogeneity, of the null hypothesis that initial choices are the same as final choices, yields $p = 0.0011$. The null hypothesis can be rejected at the 1% significance level. Final choices are significantly different to initial choices and characterized by greater alignment with stationarity. Post-hoc analysis provides a detailed diagnosis of that finding. Table 2 shows that 6.3% of subjects initially committed present-biased reversals, but revised choices to respect stationarity following the normative argument in support of doing so. For these subjects, stationary choices were successfully preached, and their initial violation can be attributed to an error. By contrast, 8.1% of subjects made stationary choices, but revised them to commit a present-biased reversal. For that group, stationary choices can be attributed to errors. Since the outflow of stationary choices to present-biased reversals offsets revisions in the opposite direction, we observe no systematic tendency for revisions to favor one of these choice patterns over the other. Table 3 reports the results of a pairwise symmetry test of the null hypothesis that the revision rates are the same, based upon a two-tailed binomial exact test adjusted for multiple testing using the Benjamini and Hochberg (1995) procedure, which yields $p = 0.374$. Since final decisions are characterized neither by fewer stationary choices, nor by more subjects switching-out of stationary choices than those who switched-in, it cannot be concluded that the stationarity principle is of devoid of normative content.

Tables 2 and 3 also reveal that more subjects revised initially future-biased preference reversals to align with stationarity than revised choices in the opposite direction ($p = 0.000$); thereby attributing those violations to mistakes they wanted to correct. Alongside the stable proportion of present-biased reversals, this pattern of choice revisions delivers the systematic violation of stationarity observed in final aggregate-level choices, which is characterized by significantly more present-biased than future-biased reversals.[12]

As mentioned above, it is untested whether the distribution of final choices would be affected by an argument supporting future-biased reversals. Since any such argument would need to explain why less

[11] Understanding the arguments was motivated by the inclusion of the post-argument tasks in the incentive system, and instructions that made that clear. It was in subjects' interests to reveal their genuine preferences in the post-argument tasks and to engage with information pertinent to the identification of those preferences. This includes the normative arguments, as well as details of the tasks themselves. There were also opportunities for clarification throughout the experiment (via an anonymous chatbox in the online sessions, that remained live throughout the experiment). There were no such questions. A test for experimenter demand effects, that we report below, also reveals that choice revisions in the post-argument tasks depended on the argument seen. This suggests that the meanings of the argument mattered to that decision. If the meanings of the arguments mattered, it is plausible that those meanings were understood.

[12] A post-hoc test of pairwise symmetry does not allow rejection of the null hypothesis of an equal number of revisions from present- to future-biased choices and vice versa (adjusted p=0.374).

compensation *should* be accepted for giving-up immediate payment, it would risk being trivially dismissible as lacking reason; and thereby fail to challenge initial choices as required by Slovic and Tversky (1974) type designs. However, if such an argument could be found and was persuasive to some subjects, it might support that pattern of choices in the data. That possibility should be borne in mind when interpreting our findings. That said, the present experiment design has generated data which cannot have been affected by the absence of an argument supporting future-biased reversals, and which support the conclusion that future-biased reversals are more likely to be mistakes than present-biassed reversals. Consider subjects who initially violated stationarity and therefore saw only the argument supporting that principle. Of those subjects who revised choices to align with it, future-biased reversers were significantly more inclined to do so than present-biased reversers (respectively, 46/64=72% and 27/52=52%; two-tailed test of difference in sample proportions $p = 0.0269$).[13]

We now turn to consider experimenter demand effects. Recall that we define a demand effect as the revision of choices to conform with the argument seen, for reasons other than the satisfaction of preferences. Hence, if choice revisions are explained by demand effects, they will be independent of the argument seen. Of the 314 subjects who respected stationarity in initial decisions and saw the argument supporting a present-biased reversal, 35 revised their choices to align with it. Of the 116 subjects who violated stationarity in initial decisions and saw the argument supporting it, 73 revised their choices to align with that argument. A two-sided test of difference in sample proportions rejects the null hypothesis that these rates of choice revisions are the same, with significance greater than 1% ($p < 0.00001$). Subjects did not simply revise their choices to align with whichever argument they had seen.

Alongside experimenter demand effects, Slovic and Tversky's (1974) design is potentially susceptible to other influences on choices that might complicate the interpretation of observed behavior. For example, repeated choice tasks may engender a status quo bias relative to initial choices, stimulate a preference for consistency, or engage other motives for which repetition might serve as a catalyst. Nielsen and Rehbeck (2022) also point to cognitive inertia in the choice revision opportunity, induced by the cognitive demands of the series of prior tasks. Many of these issues are addressed directly by Humphrey and Kruse (2025). They report direct tests of whether Slovic and Tversky's (1974) design is susceptible to demand effects, a status quo bias, or other decision motives entailing repeated tasks. They find that it is not. In the present design, we controlled for the influence of cognitive inertia in the choice revision decision by using cognitively transparent multiple price list tasks prior to that opportunity, and incentivizing choices that satisfied preferences. Note that cognitive inertia is inconsistent with the observation that final choices are significantly different from initial choices.

Finally, we conducted a multinomial logit regression analysis of whether choices are explained by risk attitude, loss-aversion, the order of the proximate and remote choice menus, gender, age, area of study, or performance on a 3-item cognitive reflection test.[14] The reference categories were economics students, and stationary choices made prior to the normative arguments. Detailed results can be found in the supplementary material (Appendix A). The regression analysis reveals that behavior is not explained by any of the above variables, except for the study area of subjects, where we observe the behavior of law students to significantly differ from that of the reference category of economics students. Specifically, there is a complete absence of present-biased preference reversals in the initial choices of law students, but some exhibited in final choices. No other group of subjects behaved in that way, which caused the quasi-complete separation of law students in the regression analysis. This is reflected in two results. Firstly, we observe a significant negative coefficient for present-biased reversals for law students (-14.592, $p < 0.001$). Secondly, when we allow for the normative arguments to differentially affect the behavior of participants from different study areas (with an interaction variable between study area and an indicator for decisions taken before or after the arguments), we observe a significant effect only for law students; the coefficient for '*Law* x *After Message*' for present-biased reversals is 13.769 ($p < 0.001$). We have no hypothesis to explain why law students behaved differently to others, but cannot rule-out that the effects are statistical outliers stemming from the untypical behavior of a small number (7%) of subjects. When law students are removed from the sample, there is no significant effect of the study area on choices.[15]

5. Conclusion

We have studied whether observed violations of the stationarity principle of the EDU model are mistakes, manifest in choices that decision-makers themselves do not wish to maintain following an analysis of their behavior. In a within-subject experiment, 448 subjects made intertemporal choices in multiple price lists which could either respect or violate stationarity. Subjects were then given an argument designed to challenge those choices, by supporting a counterfactual behavior with a claim to represent rational action. Choices were then repeated.

Our main conclusions are threefold. Firstly, the overall weight of evidence against the normativity of stationarity in our data is small. Modal behavior respects stationarity by some margin: 79.1% of subjects either continued to respect it after being given a normative reason not to, or switched to do so having had its logic explained. Those choices do not represent mistakes. Final choices also exhibit fewer violations of stationarity than initial choices. Secondly, however, we also observe violations of stationarity that are not mistakes: 19.1% of subjects either violated it in both sets of choices, or revised initial choices to do so. When choices have passed through the filter of the normative arguments to purge them of mistakes, a present-bias persists. Thirdly, our findings highlight the hazards of inferring the normative content of choice models from descriptive data. Since final choices exhibit significantly more present-biased than future-biased preference reversals, the violation of stationarity is systematic. By describing that pattern of choices, hyperbolic discounting models succeed where the EDU model fails. However, it would be incorrect to surmise that the EDU model is devoid of normative content. The distribution of final choices is partly explained by subjects revising initial choices away from future-biased reversals to respect stationarity, after seeing the argument in favor of doing so. Paradoxically, preaching the normative force of stationarity contributed to the EDU model's descriptive failure.[16]

[13] A trivially dismissible argument supporting future-biased reversals would be an example of what Nielsen Rehbeck, (2022), p.2241) call an "intentionally unappealing" intervention. In their study, intentionally unappealing "control axioms", which have the opposite implications to counterpart risky choice axioms, are used to illuminate demand effects. For example, "control transitivity" holds that if x≻y and y≻z, then z≻x. Subjects might subscribe to a control axiom if they commit a demand effect, but would not if they have understood the experiment. Such a device is unnecessary in Slovic and Tversky's (1974) design, because the inclusion of arguments that speak both for and against an axiom, delivers the 'built-in' test of demand effects that we report below.

[14] The number of subjects in each study area was 177 (41%) economics, 67 (16%) humanities, 88 (20%) STEM, 30 (7%) law, 14 (3%) social science, 40 (9%) other and 14 (3%) other (non-student). Frederick (2005) discusses the relationship between time preference and performance on a CRT.

[15] For the whole sample, a Wald test rejects the null hypothesis that choices are unaffected by study area, or its interaction with the before or after arguments indicator ($p<0.0001$). When the model is re-estimated excluding law students, the same test is no longer statistically significant ($p=0.2942$).

[16] This conclusion should be interpreted in the context our previous discussion of the absence of an argument supporting future-biased reversals. That discussion includes the unaffected finding that future-biased reversals are more likely to be errors than present-biased reversals.

In summary, whilst the normative credentials of the EDU model remain intact for the majority of our subjects, that model is not a standard of rational action to which all subscribe. As Fisher (1930) explained, present-biased reversals may be a requirement of rationality for some decision-makers. Since we observe systematic present-biased reversals that are not mistakes, we cannot reject that argument. In that respect, our data would not support the case for policy-maker intervention to address present-biased behavior. As Dietrich et al. (2021, p.146) explain, the public policy prescribed by normative behavioral economists has the job of addressing the tendency of decision-makers to make bad choices. For Thaler and Sunstein (2008), this amounts to making decision-makers better off *as judged by themselves*, by correcting what they themselves would consider to be mistakes. The present-biased reversals we observe in final choices are not mistakes of that type. Alongside which, a vulnerability to arbitrage grounded in preference reversals requires decision-makers to not only hold those preferences, but to be willing to trade on that basis. Our experiment was designed to speak only to the first of those requirements; hence our data do not establish a vulnerability to arbitrage. Addressing that issue might be a worthwhile avenue for future research.

Finally, although Slovic and Tversky's (1974) design has the desirable properties we have described, we acknowledge that our conclusions are based on a single set of parameters and the particular approach we have employed. Hence, we make no claims regarding the generality of our findings; we encourage both further experimental studies and robustness checks. There are natural design extensions that might be considered. An anonymous reviewer suggested a design which controlled for the possibility of choice revisions in repeated tasks in the absence of normative arguments. Humphrey and Kruse (2025) discuss the benefits of supplementing the standard Slovic and Tversky (1974) design with a treatment that presents subjects with both normative arguments, rather than only that which supports counterfactual choices. In anticipation of continued growth in empirical studies of normative decision-making, we hope that our novel application of an influential experiment design to intertemporal decision-making, serves as an informative benchmark for further investigation.

CRediT authorship contribution statement

Steven J. Humphrey: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Felix C. Meickmann:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no conflict of interest. The research complies with ethical requirements for decision-making experiments involving human subjects at the Laboratory for Economics Research (LaER) at The University of Osnabrück. All subject participated having given informed consent.

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Supplementary materials

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Data availability

https://doi.org/10.17605/OSF.IO/VDC7M (Data are available at the Open Science Framework repository:)

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