MANAGEMENT SCIENCE
Vol. 59, No. 9, September 2013, pp. 2153–2169
ISSN 0025-1909 (print) | ISSN 1526-5501 (online)

informs

http://dx.doi.org/10.1287/mnsc.1120.1690

Is There One Unifying Concept of Utility? An Experimental Comparison of Utility Under Risk and Utility Over Time

Mohammed Abdellaoui
GREGHEC-CNRS and HEC Paris, 78351 Jouy en Josas, France,
abdellaoui@hec.fr

Han Bleichrodt
Erasmus School of Economics, Erasmus University, 3000 DR Rotterdam, The Netherlands,
bleichrodt@ese.eur.nl

Olivier l'Haridon
University of Rennes 1-CREM, 35065 Rennes Cedex, France; and GREGHEC, 78351 Jouy en Josas, France,
olivier.lharidon@univ-rennes1.fr

Corina Paraschiv
GREGHEC, 78351 Jouy en Josas, France; and University Paris Descartes, 75016 Paris, France,
paraschiv@hec.fr

The nature of utility is controversial. Whereas decision theory commonly assumes that utility is context specific, applied and empirical decision analysis typically assumes one unifying concept of utility applicable to all decision problems. This controversy has hardly been addressed empirically because of the absence of methods to measure utility outside the context of risk. We introduce a method to measure utility over time and compare utility under risk and utility over time. We distinguish between gains and losses and also measure loss aversion. In two experiments we found that utility under risk and utility over time differed and were uncorrelated. Utility under risk was more curved than utility over time. Subjects were loss averse both for risk and for time, but loss aversion was more pronounced for risk. Loss aversion over risk and time were uncorrelated. This suggests that loss aversion, although important in both decision contexts, is volatile and subject to framing.

Key words: decision under risk; intertemporal choice; nature of utility; prospect theory; discounting; loss aversion
History: Received July 10, 2012; accepted November 12, 2012, by Rakesh Sarin, decision analysis. Published online in *Articles in Advance* March 18, 2013.

1. Introduction

The concept of utility is widely used in decision analysis, but its nature is controversial. For the leading economists of the late 19th century, utility was a cardinal index of goodness that could be measured through introspection and that could be universally applied (Menger 1871, Walras 1874, Jevons 1879, Edgeworth 1881, Marshall 1890). This concept of one unifying cardinal utility was challenged by Pareto (1906), who showed that ordinal utility was sufficient to explain market data. The banishing of cardinal utility was furthered by the works of Johnson (1913), Slutsky (1915), and Hicks and Allen (1934a, b), who aimed to purge economics of introspection and to base it entirely on observable choice. This ordinal revolution coincided with the behaviorist revolution in psychology, which likewise aimed to rid psychology of introspection. It culminated in Samuelson's (1938) revealed preference paradigm that has dominated decision theory since. Detailed surveys of the history of utility are in Stigler (1950a, b), Edwards (1954), Lewin (1996), and Abdellaoui et al. (2007a).

Cardinal utility reemerged when von Neumann and Morgenstern (1944) derived it from a set of plausible axioms on risky choice. Meanwhile, it was found that cardinal utilities were also necessary for intertemporal (Samuelson 1937) and utilitarian welfare evaluations (Harsanyi 1955). The new consensus was that cardinal utility is relevant, but that it has no meaning outside its domain of application (Arrow 1951, Luce and Raiffa 1957, Fishburn 1989). Specifically, this implies that cardinal utility for risk can differ from cardinal intertemporal utility. In decision theory, several authors have explored the relationship between von Neumann Morgenstern risky utility and cardinal riskless utility (Dyer and Sarin 1982). Contrary to the ordinalists, these authors assumed that cardinal choiceless utility exists and, hence, that utility differences are meaningful.

Recently, the nature of utility has been reconsidered, fostered by developments in nonexpected utility theory, in particular the introduction of prospect theory. Under prospect theory, risk attitude is not only determined by utility, but also by probability weighting and loss aversion. This makes it possible that the utility function captures people's attitudes toward outcomes and is also applicable to decisions that do not involve risk (Wakker 1994, 2010). Simultaneously, behavioral economists and psychologists discovered inconsistencies in choices, which challenged reliance on revealed preferences. If choices can be inconsistent, then they may not reflect people's "true" preferences. These choice anomalies have led to the development of new concepts and interpretations of utility (Kahneman and Krueger 2006).

In applied decision analysis, transferability of utility is generally taken for granted, and utilities measured within one decision context are routinely applied in other contexts as well. For instance, in medical decision making, measurements of utility under risk are widely used to value intertemporal health profiles and in welfare evaluations. In empirical economics, transferability of utility is also commonly assumed. For example, Andersen et al. (2008) and Takeuchi (2011) used utility measured under risk to compute people's discount rates from intertemporal choices.

This paper explores empirically whether there exists one unifying concept of utility by testing whether cardinal utilities measured in different contexts are equal. Perhaps surprisingly, this question has hardly been addressed. The main reason is that no methods existed to measure utility outside the context of risk. A few studies compared utility under risk with choiceless utility measured through introspection (Abdellaoui et al. 2007a, Stalmeier and Bezembinder 1999), but these studies were, obviously, not based on revealed preference. In contrast, our study is entirely based on observed choice behavior.

The decision contexts we compare are risk and time. Several authors have emphasized the similarity between risk and time (Prelec and Loewenstein 1991, Quiggin and Horowitz 1995, Bommier 2006, Dasgupta and Maskin 2005). Halevy (2008), Epper et al. (2011), and Baucells and Heukamp (2012) have provided formal analyses of the relation between risk and time. In these models, utility over risk and utility over time are taken identical. Abdellaoui et al. (2011) found that the passage of time did not affect utility under risk. Hence, there are good reasons, both theoretical and empirical, to hypothesize that risk and time are decision contexts in which we could expect utility to be similar. An additional reason to study risk and time is that they are important areas of applied decision analysis, and it is useful to know whether utility measured under risk can be used in intertemporal evaluations and vice versa.[1]

We measured utility for gains, utility for losses, and loss aversion. We propose a new method to measure utility over time. The key insight underlying our method is that only one time weight needs to be known to measure utility over time. This insight substantially simplifies the measurement of utility.

By comparing loss aversion for risk and time, we could test whether there is a common psychological concept underlying loss aversion in different decision contexts. Gächter et al. (2007) compared loss aversion in a willingness-to-pay versus willingness-to-accept task with loss aversion in a risky decision task and observed that the two were correlated. They needed several simplifying assumptions to measure loss aversion, including linear utility. Our test complements Gächter et al. (2007) by looking at different decision contexts and by allowing for utility curvature.

In two experiments, we observed that utility under risk and utility over time differed and were uncorrelated. For gains, utility was concave for risk, but linear for time. For losses, utility was either convex or linear for risk, but concave for time. Most subjects were loss averse both for risk and time, but more so for risk. Loss aversion for risk and time were uncorrelated, suggesting that loss aversion, although important in both contexts, is volatile and subject to framing.

2. Theory

We assume that utility is reference dependent (Wakker 2010) both for decision under risk and for intertemporal choice. We further assume that preferences can be evaluated by an additive model in which utility is multiplied by a sign-dependent decision weight. This assumption amounts to separability over states of nature (for risk) and separability over time points (for time). For risk this assumption is less restrictive than for time. Separability of states of nature is more acceptable than separability of time points (Broome 1991), and, as we will see, the decision weights for decision under risk depend on the ranking of the outcomes, so we do not assume full separability of states of nature. We do assume full separability of time, however, and we discuss its restrictiveness and the implications of possible violations in §7.

[1] Andreoni and Sprenger (2012) and Coble and Lusk (2010) found that utility for risk and for time were different. They assumed, however, both expected utility and constant rate discounting, assumptions that are commonly violated and are known to cause biases. We avoid these assumptions.

Throughout, outcomes are monetary and more money is preferred to less. Outcomes are defined as gains and losses relative to a reference point. We assume that the reference point is 0. *Gains* are outcomes larger than 0, and *losses* are outcomes less than 0.

2.1. Decision Under Risk

We assume prospect theory and consider prospects involving two distinct outcomes at most. Let $(x, p; y)$ denote the prospect that gives money amount x with probability p and y with probability $1-p$. It is *mixed* if $x > 0 > y$, a *gain prospect* if $x \geq y \geq 0$, and a *loss prospect* if $0 \geq y \geq x$. There exists a preference relation $\succcurlyeq$ over prospects, with strict preference and indifference denoted by $\succ$ and $\sim$, respectively.

Under prospect theory, preferences over prospects are represented by a real-valued *utility function* U^r defined over money amounts and by two *probability weighting functions*, w^+ for gains and w^- for losses. The superscript r in U^r indicates that the utility function applies to risk and serves to distinguish it from the intertemporal utility function introduced later. The utility function is strictly increasing, satisfies $U^r(0) = 0$, and it is a ratio scale, meaning that we can freely choose the unit of utility. The probability weighting functions are strictly increasing and satisfy $w^i(0) = 0$ and $w^i(1) = 1$, $i = +, -$.

A prospect $(x, p; y)$ is evaluated as

$$\pi_1 U^r(x) + \pi_2 U^r(y), \tag{1}$$

where $\pi_1 = w^+(p)$ and $\pi_2 = w^-(1-p)$ for mixed prospects and $\pi_1 = w^i(p)$ and $\pi_2 = 1 - w^i(p)$, $i = +, -$, for gain and loss prospects.

Tversky and Kahneman (1992) assumed that U^r is S-shaped, concave for gains and convex for losses. Empirical evidence confirms concave utility for gains (Tversky and Kahneman 1992, Gonzalez and Wu 1999, Booij and van de Kuilen 2009), but for losses the evidence is mixed. Although most studies found slight convexity (Tversky and Kahneman 1992, Schunk and Betsch 2006), concave utility has also been observed (Bruhin et al. 2010). Utility was generally more linear for losses than for gains.

Prospect theory also assumes that people are loss averse. Different definitions of loss aversion coexist in the literature. We will use the definitions of Kahneman and Tversky (1979) and Köbberling and Wakker (2005) because these are best able to classify individual subjects (Abdellaoui et al. 2007b). According to Kahneman and Tversky (1979), loss aversion holds if for all gains x, $-U^r(-x) \geq U^r(x)$; that is, the absolute value of the utility of the loss exceeds the utility of the corresponding gain. Köbberling and Wakker (2005) define loss aversion as the kink at the reference point. The corresponding coefficient of loss aversion is $U_{\uparrow}^{r\prime}(0)/U_{\downarrow}^{r\prime}(0)$, where $U_{\uparrow}^{r\prime}(0)$ ($U_{\downarrow}^{r\prime}(0)$) stands for the left (right) derivative of utility at the reference point. Abdellaoui et al. (2007b) found median loss-aversion coefficients of 1.7 based on the definition of Kahneman and Tversky (1979) and 2.5 based on the definition of Köbberling and Wakker (2005). Booij and van de Kuilen (2009) also adopted the definition of Köbberling and Wakker (2005) and found loss-aversion coefficients between 1.6 and 2.0. They had to impose specific assumptions about probability weighting, however.

2.2. Decision Over Time

Let $(x, t; y)$ denote the *temporal prospect* that pays x at time point t and y now ($t = 0$). Preferences over temporal prospects are evaluated by the *sign-dependent discounted utility model*

$$U^t(y) + \tau^i(t)U^t(x), \quad i = +, -. \tag{2}$$

Loewenstein and Prelec (1992) proposed a model of intertemporal choice in which the intertemporal utility function U^t is sign dependent. As in prospect theory, they assumed that intertemporal utility is concave for gains, convex for losses, and reflects loss aversion. There is a dearth of evidence about the shape of intertemporal utility, primarily because of the lack of a measurement method. Previous studies that sought to correct discount rates for utility measured utility in a different domain and then used these measurements to compute utility discount rates (Andersen et al. 2008, Chapman 1996). Abdellaoui et al. (2010) measured utility within an intertemporal choice context and found that U^t was indeed concave for gains, but close to linear for losses. They obtained no evidence on loss aversion. To the best of our knowledge, the only study measuring loss aversion in intertemporal choice is the unpublished working paper by Tu (2004). He assumed linear utility and found a loss-aversion coefficient close to 2.

The sign-dependent discount functions τ^+ and τ^- are ratio scales with $\tau^i(0) = 1$, $i = +, -$. The specifications of τ^i are immaterial for our analyses, and we impose no restrictions on them. Hence, Equation (2) includes most of the discount functions that have been proposed in the literature as special cases. We allow the discount functions to differ for gains and losses following evidence from Abdellaoui et al. (2010) that τ^+ and τ^- differed even after correction for differences in utility curvature between gains and losses.

2.3. Preference for the Timing of Resolution of Uncertainty

Preferences under risk and preferences over time are closely related: delaying outcomes implies that these outcomes become uncertain, and attitudes toward uncertainty affect discounting. Halevy (2008), Epper et al. (2011), and Baucells and Heukamp (2012) modeled this relationship between risk and discounting. Their models are special cases of Equation (2), and, hence, all our conclusions about the equality of utility under risk and utility over time remain valid under their models.

If people view the delayed outcome as risky, then they have to wait until period t before the uncertainty of whether they will receive it is resolved. If they are not indifferent to the timing of resolution of uncertainty, Equation (2) may no longer represent their preferences. Kreps and Porteus (1978) were the first to model preferences for the timing of resolution of uncertainty. They assumed that people are expected utility maximizers. Their results were generalized to nonexpected utility preferences by Chew and Epstein (1989), Epstein and Zin (1989), and Grant et al. (1998). In §5 we test the robustness of our results to the introduction of a preference for the timing of resolution of uncertainty. Following Epstein and Zin (1989), we assume that the temporal prospect $(x, t; y)$ is evaluated as

$$U^t(y) + \beta U^t \circ (U^r)^{-1}(\pi U^r(x)), \qquad (3)$$

where β may reflect pure time preference, and π is a decision weight. Equation (3) is consistent with the main models of decision under uncertainty (Ghirardato and Marinacci 2001, Miyamoto 1988). Kreps and Porteus (1978) showed that under expected utility (the case where π is equal to the decision maker's subjective probability that the delayed outcome will be received), a preference for early (late) resolution of uncertainty is equivalent to $U^t \circ (U^r)^{-1}$ convex (concave). In Appendix E we show that this equivalence also holds under nonexpected utility preferences. Chew and Ho (1994) and Ahlbrecht and Weber (1997) tested Kreps and Porteus' (1978) model empirically, but found little support for it.

Wu (1999) modeled preference for early resolution through probability weights that measure cognitive attention and not through different utility functions for early and late resolution. Consequently, Wu's (1999) model is a special case of Equation (2).

3. Measurement Method

We assume that the sign-dependent utility function U^j, $j = r, t$, is composed of a loss-aversion coefficient λ^j and a basic utility function u^j:

$$U^j(x) = \begin{cases} u^j(x) & \text{if } x \geq 0, \\ \lambda^j u^j(x) & \text{if } x < 0, \end{cases} \qquad j = r, t. \qquad (4)$$

The basic utility function reflects the normative or economic component of utility. The loss-aversion parameter captures psychological factors, namely, the differential treatment of gains and losses. A similar separation between psychological and economic utility was made by Sugden (2003), Köbberling and Wakker (2005), and Köszegi and Rabin (2006).

Table 1 Measurement Method

	Assessed quantity	Indifference	Regression equation
Step 1: Utility gains	Risk: G^r	$G^r \sim (x, p_g; y)$	$G^r = u^{r^{-1}}(\pi^+(u^r(x) - u^r(y)) + u^r(y))$
	Time: G^t	$G^t \sim (x, t_g; y)$	$G^t = u^{t^{-1}}(\tau^+ u^t(x) + u^t(y))$
Step 2: Utility losses	L^r	$L^r \sim (x, p_l; y)$	$L^r = u^{r^{-1}}(\pi^-(u^r(x) - u^r(y)) + u^r(y))$
	L^t	$L^t \sim (x, t_l; y)$	$L^t = u^{t^{-1}}(\tau^- u^t(x) + u^t(y))$
Step 3:	L^r_*	$(G^r_*, p_g; L^r_*) \sim 0$	$\lambda^r = -\pi^+ u^r(G^r_*)/\pi^- u^r(L^r_*)$
Loss aversion	L^t_*	$(G^t_*, t_g; L^t_*) \sim 0$	$\lambda^t = -\tau^+ u^t(G^t_*)/u^t(L^t_*)$

The measurement of u and λ proceeded in three steps, summarized in Table 1. First, we measured utility for gains. For risk, we measured a subject's *certainty equivalent* G^r such that $G^r \sim (x, p_g; y)$. For time, we measured a subject's *present equivalent* G^t, the amount received now that is equivalent to $(x, t_g; y)$. The stimuli x and y varied across questions, but p_g and t_g were held constant. It might well be that subjects paid less attention to probability and time because they were held constant while outcomes varied, but this does not affect our measurements. We are interested in utility and not in the probability and time weights. The final column of Table 1 shows the equations that result from the observed indifferences under prospect theory and discounted utility (Equations (2) and (4)).

We estimated the equations by nonlinear least squares with the errors clustered by subject to account for individual heterogeneity and using exponential specifications for u^r and u^t:

$$u^j(x/|x_{\max}|) = \begin{cases} \dfrac{1 - e^{-\mu^j x/|x_{\max}|}}{\mu^j} & \text{if } x \geq 0, \\ \dfrac{e^{\nu^j x/|x_{\max}|} - 1}{\nu^j} & \text{if } x < 0, \end{cases} \qquad j = r, t. \qquad (5)$$

We scaled the outcomes by dividing them by $|x_{\max}|$, the outcome with the highest absolute value in a specific task.[2] The exponential utility function is concave (convex) for gains (losses) if $\mu > 0$ ($\nu > 0$), linear if $\mu = \nu = 0$, and convex (concave) if $\mu < 0$ ($\nu < 0$). Under Equation (5), both the right and the left derivative are 1 at 0, and thus Köbberling and

[2] In the first experiment, $x_{\max}$ was (−) €1,000 for gains (losses) for risk and (−) €500 for time. In the second experiment it was (−) €200 both for risk and for time.

Wakker's (2005) definition of loss aversion is defined. By contrast, the power utility function is in general not differentiable at 0 unless utility curvature is identical for gains and losses. We did not want to precommit to equal curvature, and therefore used the exponential specification. The exponential specification has the additional desirable feature that $\lambda > 1$ implies both loss aversion according to Köbberling and Wakker's (2005) definition and according to Kahneman and Tversky's (1979) definition. No restrictions are imposed on π^+ and τ^+ and probability weighting and discounting are unrestricted.

The second step, the measurement of utility for losses, was similar to the measurement for gains. We selected p_l and t_l and asked for the indifferences between $L^r \sim (x, p_l; y)$ and $L^t \sim (x, t_l; y)$.

The third and final step was to connect utility for gains and utility for losses and to quantify loss aversion. For risk, we selected a gain G^r_* and asked for the loss L^r_* that produced indifference between 0 for sure and the prospect $(G^r_*, p_g; L^r_*)$. For time, we asked for the loss that L^t_* that produced indifference between 0 for sure and the temporal prospect $(G^t_*, t_g; L^t_*)$. In these elicitations, we could also have selected a loss and have asked for the gain that produces indifference. In the first experiment, the selected gains were one of the certainty/present equivalents from the first part; in the second experiment, they were independently selected amounts.

The indifferences $(G^r_*, p_g; L^r_*) \sim 0$ and $(G^t_*, t_g; L^t_*) \sim 0$ uniquely determine the loss-aversion coefficients λ^r and λ^t for risk and time. Hence, one question suffices to determine the loss-aversion coefficient for risk[3] and one to determine the loss-aversion coefficient for time. In the actual experiments we asked more than one question to test the robustness of the measurements.

4. Experiments

We performed two experiments to measure utility for risk and utility for time, one in Rotterdam and one in Paris.

4.1. First Experiment: Rotterdam

Subjects. Subjects were 68 (29 female) students from Erasmus University with various academic backgrounds. They were paid a flat fee of €10 for their participation. The experimental questions were hypothetical. The mean duration of the entire experiment was 30 minutes. Before the actual experiment, the experimental design was tested and fine-tuned in several pilot sessions.

Procedure. The experiment was computer-run in small groups of two to four subjects. Subjects were seated in small cubicles and could not see each others' choices and were not allowed to communicate.

The computer determined randomly whether the risk or the time questions came first. The two parts were not interspersed. Each experimental part started with 6 training questions: two gain, two loss, and two mixed questions. So there were 12 training questions in total: 6 risk questions before the risk part started and 6 time questions before the time part started.

Preferences were elicited through a series of binary choices, which were part of an iterative process that zeroed in on subjects' indifference values. The stimuli in the first iteration were such that the risk (time) prospects had equal expected (undiscounted) value. We used six iterations in the mixed questions and five in the gain and loss questions. Each iteration process ended with a repetition of the first choice to reduce response errors. If the repeated choice in the iteration process differed from the initial choice, then the program indicated "you have changed your mind" and the entire iteration process was repeated for that question once. In such cases, we always stored the answer of the repeated iteration. Subjects had the possibility to go back to the first choice of the iteration process by clicking the back button.

We used choices because evidence suggests that they lead to fewer inconsistencies than matching where subjects are directly asked for their indifference values (Bostic et al. 1990). Figures A.1 and A.2 in Appendix A show the presentation of the risk and time questions.

Stimuli. Tables B.1 and B.2 in Appendix B show the risky and temporal prospects used. There were 32 questions in total to measure u^r and u^t, 8 for gains and risk, 8 for losses and risk, 8 for gains and time, and 8 for losses and time. We used substantial money amounts (up to €1,000) to detect curvature of utility. Utility is usually close to linear for small amounts (Wakker and Deneffe 1996). The probabilities p_g and p_l were set equal to 1/2, and the delays t_g and t_l to 1 year. The distributions of payments in the risk and time questions were close, because there is evidence suggesting that the distribution of the outcomes affects choices (Birnbaum 1992, Stewart et al. 2003). For each risky prospect there was a corresponding temporal prospect such that the expected value of the risky prospect was equal to the undiscounted value of the temporal prospect. Furthermore, the skewness of the outcomes was the same, and the standard deviations were close.

[3] To be precise, this is true if $p_l = 1 - p_g$ with p_g equal to the probability used in the first step, the measurement of utility for gains. This was the case in the first experiment. In the second experiment it did not hold and we needed two more indifferences to determine $w^+(p_g)$ and $w^-(1-p_g)$. For time we always set t_g and t_l equal to the delays used in the elicitation of utility, and no additional questions were needed.

The upper bound for a certainty equivalent was the highest amount in the prospect under evaluation. The upper bound for a present equivalent was the sum of the present amount and twice the delayed amount in the temporal prospect under evaluation. Hence, it was possible to observe negative discount rates. This is particularly important for losses. Negative discounting for unfavorable outcomes was, for instance, observed by Yates and Watts (1975), Loewenstein (1987), and Benzion et al. (1989) for money losses, and by van der Pol and Cairns (2000) for aversive health outcomes. No subject actually hit the upper bound.

We asked six questions to measure loss aversion, three for risk and three for time yielding three values of $\lambda^r(\lambda^t)$, which, according to prospect theory (discounted utility) and Equation (4), should be equal. Hence, these questions tested whether our subjects behaved according to prospect theory (discounted utility) and Equation (4).

Both the risk part and the time part started with the eight gain questions, followed by the eight loss questions, and finally the three mixed questions. The pilot sessions showed that interspersing the gain, loss, and mixed questions led to confusion and more response errors. Within the gain, loss, and mixed questions, the order of the questions was randomized.

To test for consistency, we repeated the third iteration of 14 randomly selected questions: 3 gain questions, 3 loss questions, and 1 mixed question, both for risk and for time. These questions were used only as consistency checks. We always used the original choices in the analyses.

4.2. Second Experiment: Paris

The main reason to perform the Paris experiment was to include an incentivized task (the elicitation of utility for gains). We also made several other changes to test the robustness of our findings. These changes are outlined below.

Subjects. Subjects in the Paris experiment were 52 undergraduate students in management at Paris Descartes University (35 female). Subjects were paid a flat fee of €10. Before the experiment, subjects were informed that, in addition to the flat payment, they had a 1 in 20 chance to be randomly selected to play one of the gain questions for real and that they could win up to €200. We kept the loss questions hypothetical. We used relatively large amounts (up to €200), and it is hard if not impossible to find subjects who are willing to participate in an experiment where they can lose up to €200. Upon arriving in the laboratory, subjects were informed that at the end of the experiment a random draw from an urn containing 20 balls (with one winning ball) would determine whether they could actually play one of the gain questions for real. Three subjects drew a winning ball. For them, an additional random draw determined the question to be played for real. If this was a risk question, it was played out immediately. If it was a time question, the payment due now was paid out immediately. For the delayed amount, we asked the subjects to leave a permanent address (typically their parents' address) and a sure email address. Subjects were told that they would be contacted 15 days before the future payment was due. The Paris experiment involved more questions than the Rotterdam experiment and lasted for 45 minutes on average.

Procedure. Data were collected in personal interview sessions and were entered in the computer by the interviewer to reduce the impact of errors. In the Rotterdam experiment, we observed no order effects and fewer inconsistencies for time, suggesting that subjects found the time questions easier to answer. We therefore started with the time questions in the Paris experiment. There were 18 training questions, 9 for time (3 gains, 3 losses, 3 mixed) at the start of the experiment and 9 for risk (3 gains, 3 losses, 3 mixed) before starting with the risk part.

The iteration process continued until successive stimulus values changed by less than €2. Hence, the number of iterations varied across questions, and across subjects. We did not replicate the first choice of the iteration process because few subjects reversed this choice in the Rotterdam experiment, and the Paris experiment was already longer. Figures A.3 and A.4 in Appendix A illustrate the way the risk and time questions were displayed in the Paris experiment. We changed the display compared with the Rotterdam experiment to make the presentation of the risk and time questions more similar.

Stimuli. Tables B.3 and B.4 in Appendix B show the risky and the temporal prospects used. There were 12 questions to measure u^r, 6 for gains and 6 for losses. The probabilities p_g and p_l were set equal to 1/4. We also measured $w^+(1/2)$, $w^+(3/4)$, and $w^-(1/2)$, because they were used in the elicitation of loss aversion. There were 14 questions in total to measure u^t, 7 for gains and 7 for losses. The delays t_g and t_l were both set equal to six months.

We used eight questions to measure loss aversion, four for risk and four for time. For risk, we used probability 3/4 in two questions and probability 1/2 in the other two questions. According to prospect theory and Equation (4), the four estimates of λ^r should be equal and should be independent of the probabilities used. For time, in two questions the loss was incurred immediately and the gain was delayed; in the other two questions the gain was received immediately and the loss was delayed.[4] Discounted utility (Equation (2)) and Equation (4) predicts that these

[4] Then the elicited indifference is $(L^t_*, t_g; G^t_*) \sim 0$ and $\lambda^t = -u^t(G^t_*)/\tau^- u^t(L^t_*)$.

changes should have no effect and that the four estimates of λ^t should be equal.

The order of the questions was first gains, then losses, and finally the mixed questions. Within the gain, loss, and mixed questions, the order of the questions was randomized. We included 16 consistency questions. We repeated both for risk and for time the third iteration of three randomly selected gain questions, of three randomly selected loss questions, and of two randomly selected mixed questions.

5. Main Results

5.1. Consistency

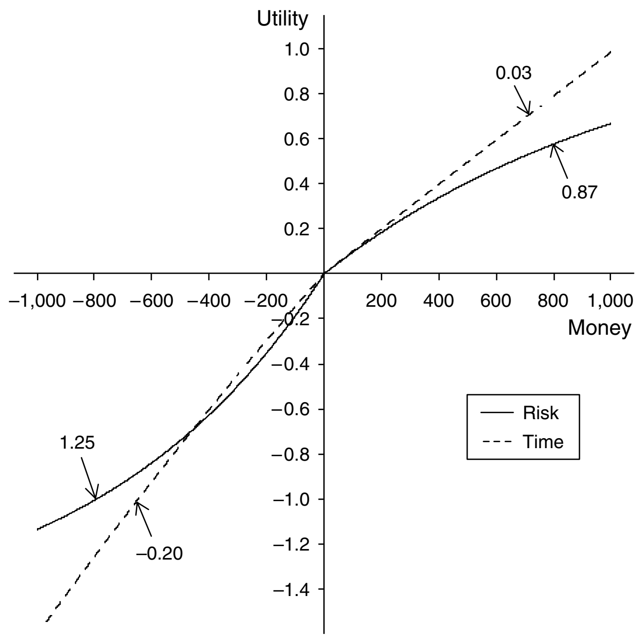
5.1.1. Rotterdam Experiment. We removed the data of three subjects. One subject did not understand the tasks, and the other two were outliers whose answers differed by more than three standard deviations from the mean. Including their responses would have had a disproportionate effect on the estimation results. This left 65 subjects in the final analyses.

The replication rates were 93.8% for the first choice and 88% for the third choice. The lower replication rate for the third choice was expected given that the stimuli were closer to the indifference values in these choices. The replication rates compare favorably with a median inconsistency rate of 23% observed in other experiments (Stott 2006). The replication rates were higher for time than for risk (96.5% versus 91% in the first choice and 91% versus 83% in the third choice; paired t-tests, $p < 0.01$ in both tests). The finding that there is more noise in decision under risk than in decision over time is consistent with the findings of Laury et al. (2012). Replication rates did not differ between gains and losses in the first choice, but they were higher for gains than for losses in the third choice (91% versus 84%, paired t-test, $p < 0.01$). This might be caused by the higher complexity of choices involving losses (de Lara Resende and Wu 2010).

5.1.2. Paris Experiment. The data of two subjects were removed from the final analyses. One did not understand the tasks, and the other was an outlier. This left 50 subjects in the final analyses.

The replication rate of the third choice was 97%. Replication rates did not differ between risk and time (96% versus 97.5%, paired t-test, $p = 0.23$), nor between gains and losses (96.5% versus 94.4%, paired t-test, $p = 0.28$). The latter finding is noteworthy because we used real incentives for gains but not for losses. Reliability was higher in the Paris experiment than in the Rotterdam experiment, for risk, for time, for gains, and for losses ($p < 0.01$ in all cases). A reason could be that we used personal interview sessions in the Paris experiment, but small group sessions in the Rotterdam experiment.

Figure 1 Utility Under Risk and Over Time Based on Pooled Data in the Rotterdam Experiment



5.2. Utility

5.2.1. Rotterdam Experiment. Figure 1 shows utility for risk and time based on the pooled data in the Rotterdam experiment. The figure also displays the estimated exponential coefficients; more detailed estimation results are in Appendix C. Utility for risk and time were clearly different, both for gains and for losses (paired t-test, $p < 0.01$ in both cases). As predicted by prospect theory, utility under risk was S-shaped, concave for gains and convex for losses (t-test, $p < 0.01$ in both cases). Utility over time was closer to linearity. For gains, we could not reject the hypothesis that utility was linear (t-test, $p = 0.71$) and for losses it was concave (t-test, $p < 0.01$).

Our subjects were loss averse both for risk and for time, but more so for risk. The mean values of the loss-aversion coefficients λ^r and λ^t were 1.99 and 1.45, respectively (paired t-test, $p = 0.02$). The value for risk was comparable to previous estimates. For time it was lower than the estimate obtained by Tu (2004).

We also estimated utility under risk and utility over time for each subject separately. The results were largely similar to those based on the pooled data. Utility under risk and utility over time were different both for gains and for losses (paired t-test, $p < 0.01$ in both tests) and they were uncorrelated. For gains, the Spearman rank correlation between the estimated exponential coefficients was 0.14 ($p = 0.27$), and for losses it was −0.12 ($p = 0.34$).

Utility under risk was S-shaped. For gains, 62% of the subjects had concave utility ($\mu^r > 0$), which was higher than the 38% with convex utility ($\mu^r < 0$) (binomial test, $p = 0.04$). For losses, 69% of the subjects had convex utility ($\nu^r > 0$), higher than the 31% with concave utility ($\nu^r < 0$) (binomial test, $p < 0.01$).

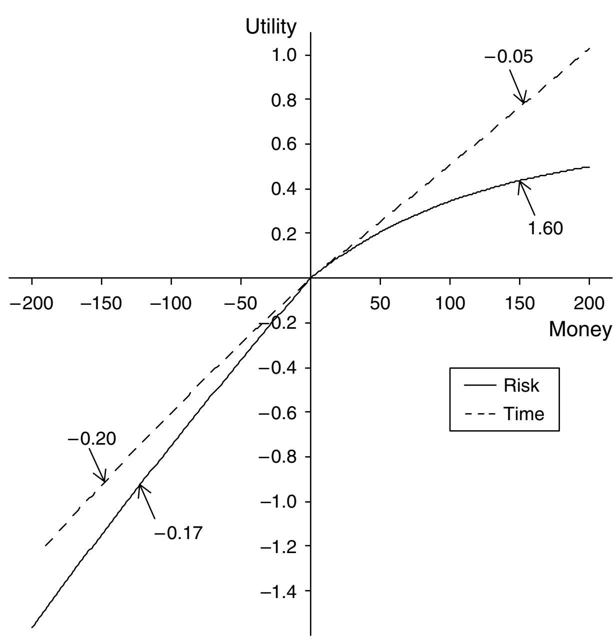
For time, utility was linear for gains and concave for losses. For gains, the proportions of subjects with concave and convex utility did not differ. For losses, more subjects (65%) had concave utility than convex utility (35%) (binomial test, $p = 0.01$).

There was significant loss aversion both for risk and for time. In contrast with the pooled data, we could not reject the hypothesis that loss aversion was the same for risk and time (paired t-test, $p = 0.32$). On the other hand, we found no correlation between loss aversion under risk and loss aversion over time (Spearman correlation, 0.16; $p = 0.22$). Loss aversion varied considerably across subjects. The interquartile ranges (IQRs) were [1.12, 1.84] for risk and [1.16, 1.56] for time.

Our tests of prospect theory and Equation (4) yielded mixed results. We could reject the hypothesis that the three values of λ^r were equal based on the pooled data (repeated measures ANOVA, $p = 0.04$), but not based on the individual subject data (repeated measures ANOVA, $p = 0.19$). For time, the data supported discounted utility and Equation (4). We could not reject the hypothesis that the three values of λ^t were equal, neither for the pooled data (repeated measures ANOVA, $p = 0.98$) nor for the individual subject data (repeated measures ANOVA, $p = 0.37$).

5.2.2. Paris Experiment. Figure 2 shows utility for risk and time based on the pooled data in the Paris experiment. In contrast with the Rotterdam

Figure 2 Utility Under Risk and Over Time Based on Pooled Data in the Paris Experiment



experiment, we did not observe prospect theory's S-shaped utility function for risk. Utility for gains was concave (t-test, $p < 0.01$), but for losses it was linear. For time, utility was similar to what we observed in the Rotterdam experiment: linear for gains and concave for losses (t-test, $p < 0.01$). For gains, utility differed between risk and time (paired t-test, $p < 0.01$), but for losses we could not reject the null hypothesis of equality (t-test, $p = 0.64$). The difference in the utility for losses between risk and time, reflected in Figure 2, was caused by a difference in loss aversion. Subjects were loss averse both for risk and for time (t-test, $p < 0.01$ in both cases), but, as in the Rotterdam experiment, more so for risk (mean loss-aversion coefficient, 1.44), than for time (mean loss-aversion coefficient, 1.15) (paired t-test, $p = 0.02$). Both for risk and for time, there was less loss aversion than in the Rotterdam experiment (t-test, $p < 0.01$ in both cases).

The individual data confirmed that utility was different for risk and time. Utility under risk and utility over time were not correlated. For gains, the Spearman rank correlation between the estimated exponential coefficients was −0.04 ($p = 0.79$), and for losses it was 0.05 ($p = 0.73$). Utility under risk was concave for gains and linear for losses. For gains, the proportion with concave utility (86%) was higher than the proportion with convex utility (binomial test, $p < 0.01$), but for losses the proportions did not differ (binomial test, $p = 0.32$). Utility over time was linear for gains and concave for losses based on the estimated exponential coefficients. However, for gains the proportion of subjects with convex utility (66%) was higher than the proportion (34%) with concave utility (binomial test, $p = 0.02$). For losses there was no difference (binomial test, $p = 0.23$).

Subjects were loss averse both for risk and for time, but more so for risk (paired t-test, $p < 0.01$). For risk, the median of the individual loss-aversion coefficients was 2.45, substantially larger than 1.44, the estimation based on the pooled data. The difference was due to individual heterogeneity in loss aversion (IQR of $\lambda^r = [1.67, 4.46]$). For time there was less heterogeneity (IQR of $\lambda^t = [0.98, 1.32]$), and loss aversion was similar to the pooled data. The correlation between loss aversion for risk and loss aversion over time was low and insignificant (Spearman correlation, 0.18; $p = 0.20$).

Loss aversion for risk was higher when the probability of a gain in the mixed questions was 3/4 than when it was 1/2. This held both for the pooled data and for the individual subject data (paired t-test, $p < 0.01$ in both cases) and it is inconsistent with prospect theory with utility as in Equation (4). For time, loss aversion depended on whether the loss or the gain was delayed, which is inconsistent with discounted utility and Equation (4). Loss aversion was higher when the gain was received immediately and the loss was delayed by six months than in the opposite case where the loss was incurred immediately and the gain was delayed (paired t-test, $p = 0.04$ for the pooled data, $p < 0.01$ for the individual subject data).

5.3. Preference for the Timing of Resolution of Uncertainty

Because we obtained mixed evidence about the validity of discounted utility, we also analyzed the results under Equation (3), which includes a preference for the timing of the resolution of uncertainty. We used U^r from the estimation of Equation (1) and then estimated U^t using Equation (3). The estimation did not lead to an improvement in fit (based on likelihood ratio tests), and the optimal parameter for π did not differ from 1 either in the Rotterdam or in the Paris experiment, suggesting that subjects did not perceive future outcomes as risky.

6. Auxiliary Analyses

6.1. Attitudes Toward Risk and Time

Previous evidence on the relationship between risk aversion and impatience is mixed. Anderhub et al. (2001) and Eckel et al. (2005) found a positive relation, that is, risk-averse people were less patient; Booij and van Praag (2009) found a negative relation; and Chabris et al. (2008) and Cohen et al. (2011) found no relation.

To measure risk aversion we computed for each subject and for all prospects i $(\mathrm{EV}_i - \mathrm{CE}_i)/\sigma_i$, where EV_i is the expected value of prospect i, CE_i is its certainty equivalent, and σ_i is its standard deviation. Larger values of this ratio correspond to more risk aversion. Consistent with prospect theory, most subjects were risk averse for gains and risk seeking for losses, and risk aversion was most pronounced for the mixed prospects (as predicted by loss aversion).

For temporal gain and loss prospects we computed the medians of $(|\mathrm{UV}_i| - |\mathrm{PV}_i|)/\sigma_i$, where UV_i is prospect i's undiscounted value, PV_i is its present value, and σ_i is its standard deviation. For mixed temporal prospects we used $(\mathrm{PV}_i - \mathrm{UV}_i)/\sigma_i$ when the loss was delayed and $(\mathrm{UV}_i - \mathrm{PV}_i)/\sigma_i$ when the gain was delayed. For all temporal prospects, the computed ratio increases with impatience. Impatience (positive discounting) was clearly the dominant pattern, but some subjects had negative discounting for losses, particularly in the Paris experiment.

In the Rotterdam experiment, there was a small negative correlation between risk aversion and impatience for gains (Pearson correlation, −0.23; $p = 0.06$) and for mixed prospects (Pearson correlation, −0.23; $p = 0.05$), but not for losses (Pearson correlation, −0.15; $p = 0.23$). In the Paris experiment, we observed no correlation between risk aversion and impatience.

6.2. Probability Weighting and Time Discounting

We also obtained some evidence on probability weighting and discounting (see Appendix D for the individual data, the pooled data were similar). In Rotterdam there was little probability weighting for $p = 1/2$ both for gains and for losses. The IQR was $[0.45, 0.60]$ for gains and $[0.36, 0.61]$ for losses, indicating that for gains most subjects did not weight $p = 1/2$ much, but there was more variation for losses. In Paris, the data were consistent with inverse S-shaped probability weighting (overweighting of small probabilities and underweighting of large probabilities) for gains and with underweighting of probabilities for losses. Probability weighting differed between gains and losses (paired t-test, $p < 0.01$).

Discounting did not differ between gains (11.8%) and losses (10.4%) in the Rotterdam experiment (paired t-test $p = 0.47$), but it was much higher for gains (54.4%) than for losses (19.4%) in the Paris experiment (paired t-test, $p < 0.01$). The higher discounting for gains than for losses is consistent with previous findings that assumed linear utility and no loss aversion (Benzion et al. 1989, Thaler 1981), but the difference is particularly large in the Paris experiment.

7. Discussion

Often decision theorists and empiricists are required to make assumptions about utility or they have to find ways to identify it from observed data. Our study can help them making such decisions. We found that utility under risk and utility over time were different. Our findings suggest that utility under risk and utility over time are context specific, and they caution against transferring utility across contexts, as is common in applied decision analysis. In decisions where both risk and time are relevant, as is often the case, it may be better to use two utility functions, one "risky function" to transform risky prospects into certainty equivalents and another "intertemporal function" to transform these certainty equivalents into present equivalents.

What do these risky and intertemporal functions look like? For risk the evidence was mixed. The Rotterdam experiment confirmed prospect theory's hypothesis of S-shaped utility, concave for gains and convex for losses, but in the Paris experiment utility was concave for gains and linear for losses. Less curvature for losses than for gains is commonly observed and our evidence is in line with this.

The intertemporal utility function was linear for gains and slightly concave for losses. Linear utility is often assumed in measurements of discounting. Our results suggest that this does not introduce much distortion. Abdellaoui et al. (2010) measured intertemporal utility for gains and losses without making a priori parametric assumptions, and they also observed that intertemporal utility was close to linear. Andersen et al. (2008) argued that assuming linear utility biases the measurement of discount rates. However, they measured utility in the context of risk and assumed expected utility. Our results challenge their implicit assumption that utility under risk can be used in intertemporal choice. The widely documented violations of expected utility cast further doubt on their findings.

We have grounds to believe that our findings regarding utility are robust and do not depend on the probability or time delay used in their elicitation. Abdellaoui et al. (2008) found that utility under risk did not depend on the probability used based on a method similar to ours. In the Paris experiment we collected some additional data on discounting for gains, and we checked for robustness using these additional data.[5] The results were similar. The Spearman correlation between the individual utility coefficients reported in this paper and the new coefficients was 0.56 ($p < 0.01$), and the pooled exponential coefficient was contained in the confidence interval based on the data used in this paper.

Loss aversion affected both decision under risk and decision over time, but it was stronger for risk. Loss aversion for risk and time were uncorrelated. This is puzzling and casts some doubt on the existence of a common psychological intuition underlying loss aversion. It contrasts with the findings of Gächter et al. (2007) and indicates that the nature of loss aversion is still unclear and requires further evidence. One explanation could be that loss aversion is fickle and volatile, and easily affected by changes in the framing of questions (Tversky and Kahneman 1981, Wakker 2010). This finding is related to previous findings. Ert and Erev (2008) found that loss aversion depends on framing, suggesting that it does not always occur. Likewise Novemsky and Kahneman (2005) showed that there are limits to loss aversion.

Several caveats are in order when interpreting our results. We assumed that prospect theory and discounted utility held with utility decomposed in a term reflecting attitudes toward outcomes and a term reflecting loss aversion (Equation (4)). Our evidence regarding the validity of these assumptions was mixed. In the Rotterdam experiment they were generally supported, but in the Paris experiment, which varied more experimental parameters, loss aversion depended on the probabilities and the sign of the outcome that was delayed. This is inconsistent with prospect theory and discounted utility. It is also inconsistent with other transitive theories of decision under risk because these agree with prospect theory for the binary prospects that we used. The inconsistencies we observed could be due to loss aversion not being constant, as we assumed in Equation (4). However, our findings are based on a limited number of tests, and, unlike us, Abdellaoui et al. (2008) found that loss aversion did not depend on the probabilities used.

We assumed throughout that our subjects' reference point was 0, an assumption that is widely used for the type of prospects in our study (e.g., Kahneman and Tversky 1979, Tversky and Kahneman 1992). We also analyzed our results under the assumption that the reference point was endogenously determined by the prospects under comparison and studied the three cases where the reference point was the lowest amount on offer, the highest amount on offer, and the certainty/present equivalent. Using these reference points generally led to a worse fit, but did not affect our main conclusions.

Discounted utility assumes separability of time points. This is a strong assumption that has been challenged empirically (Dolan and Kahneman 2008, Prelec and Loewenstein 1991, Wathieu 1997) and that could have affected the results. For instance, the lower loss aversion in intertemporal choice could be explained by violations of time separability. In decision under risk, losses cannot be compensated by gains: either a loss is incurred or a gain is received. On the other hand, in decision over time the loss and the gain are obtained jointly and the loss can at least partly be offset by the gain.

Violations of separability may contribute to the difference between utility over time and utility under risk. If subjects add the amounts in a temporal prospect and choose the prospect yielding the highest joint payments, then this would bias their utility toward linearity. However, we found no evidence for such a response strategy. If subjects added the amounts in the prospects, then their present equivalent should equal the sum of the amounts in the temporal prospect under evaluation. This held for four subjects for gains and for eight subjects for losses in the Paris experiment (it held for only one subject both for gains and for losses). In the Rotterdam experiment this strategy was harder to check because we used less iterations to derive indifference. There were 9 (8) subjects for whom the present equivalents were close to the sum of the amounts in the prospects for gains (losses) (for five subjects it was true both for gains and for losses). We reanalyzed the data from both experiments excluding these subjects. All conclusions remained valid, and the new parameter values were close to the original ones.

We had to ask some questions in which subjects received nonzero amounts at different points in time

[5] We estimated the exponential coefficient by nonlinear seemingly unrelated equations and the two-step estimation method developed by Gallant (1975).

because otherwise utility could not be identified. Discounted utility for single outcomes is a multiplicative representation, which is only unique up to a power (Krantz et al. 1971). There is some literature on sequence effects. For example, Loewenstein and Sicherman (1991) found that workers prefer increasing wage profiles. On the other hand, Frederick and Loewenstein (2008) and Manzini et al. (2010) found no evidence for a preference for increasing sequences. Chapman (2000) provided evidence that this can be explained by people's expectations: increasing wage profiles are the normal state of affairs. For health, decreasing sequences are normal, and Chapman (2000) indeed found that people prefer decreasing sequences of health. In our questions there were no a priori reasons why subjects should expect increasing or decreasing streams of outcomes. In summary, there is no clear evidence for specific behavior in the evaluation of sequences, and it is not obvious that it has introduced a bias in our study.

Money is a fungible reward. Consequently, most experimental studies, including ours, do not directly measure people's time preference for consumption (Cubitt and Read 2007). However, evidence suggests that money can be used as a proxy for consumption, because discount rates for money and consumption are correlated, and people do not reschedule money (Benhabib et al. 2010, Reuben et al. 2010).

Our main conclusions were similar across the two experiments. The only difference was the discounting of gains. The observed discount rate was higher in the Paris experiment, where we used real incentives for gains, than in the hypothetical Rotterdam experiment. This does not mean of course that the difference was due to the use of real incentives, because other factors varied as well between the experiments. However, given that we observed a much smaller difference in discounting for losses between the two experiments, it might be that subjects perceived future real payoffs as risky. Anderson and Stafford (2009) observed that the introduction of risk tends to increase discount rates, and Halevy (2008), Epper et al. (2011), and Baucells and Heukamp (2012) showed theoretically that uncertainty increases discount rates. On the other hand, we found no evidence that subjects considered future amounts risky in the analysis of a preference for the timing of resolution of uncertainty.

In a recent paper, Stewart et al. (2012) demonstrated that different distributions of outcomes give different choices, and therefore different revealed utility functions. This might be a source of some of the differences we observed between risk and time. However, it is difficult to determine exactly the distribution of outcomes that subjects took into consideration because this depends both on the outcomes subjects experienced in the bisection process and on the memory of real-world outcomes they brought into the experiment.

A potential problem in nonlinear estimation is that parameters cannot always be easily identified. For instance, more risk aversion can be explained by more concave utility, but also by more convex probability weighting. To check for this potential problem, we re-analyzed the data from the Paris experiment using an alternative measurement method, which is not vulnerable to this nonuniqueness problem.[6] The results were similar both for the pooled and for the individual data, and all of our conclusions remained valid. Utility under risk and utility over time differed both for gains and for losses, and they were uncorrelated.

8. Conclusion

Utility under risk and utility over time were different and uncorrelated with utility curvature more pronounced for risk than for time. Utility under risk was concave for gains and convex to linear for losses. Utility for losses was closer to linear than utility for gains. Intertemporal utility was close to linear. Our subjects were loss averse both in decision under risk and in decision over time, but it was stronger for risk. Loss aversion for risk and time were uncorrelated, suggesting that even though loss aversion is important in both domains, it is volatile and affected by framing.

Acknowledgments

Aurélien Baillon, Paola Manzini, Peter P. Wakker, an associate editor, and three reviewers provided helpful comments. Han Bleichrodt's research was made possible through a grant from the Netherlands Organization for Scientific Research.

[6] Consider the measurement of risky utility for gains. The new method requires specifying a base prospect $(x^*, p_g; 0)$, where x^* is the highest gain proposed to the subjects in the risky prospects. Thus, the base prospect spans the range of possible gains. Under prospect theory, the observed indifference $G^r_* \sim (x^*, p_g; 0)$ implies $u^r(G^r_*) = w^+(p_g)u^r(x^*)$. The other indifferences $G^r \sim (x, p_g; y)$ that we asked imply $u^r(G^r) = w^+(p_g)[u^r(x) - u^r(y)] + u^r(y)$. Consequently, $G^r = u^{r^{-1}}((u^r(G^r_*)/u^r(x^*))(u^r(x) - u^r(y)) + u^r(y))$. The latter equation is independent of the decision weight $w^+(p_g)$ and allows uniquely estimating the utility parameter. This feature is shared with Wakker and Deneffe's (1996) trade-off method and makes utility elicitation robust against probability weighting. For losses the method is similar. For choice over time, the method requires a base prospect $(x^*, t_g; 0)$, and by a similar derivation it gives the regression equation $G^t = u^{t^{-1}}((u^t(G^t_*)/u^t(x^*))u^t(x) + u^t(y))$, which is independent of the time weight. We used this new method to reanalyze the data from the Paris experiment with base prospects (200, 1/4; 0) and (200, 6 mos.; 0) for gains and (−200, 1/4; 0) and (−200, 6 mos.; 0) for losses. We could not apply the new method to the Rotterdam data because the Rotterdam experiment did not contain prospects spanning the range of outcomes.

Appendix A. Presentations of Choices

Figure A.1 Presentation of the Risky Choices in the Rotterdam Experiment

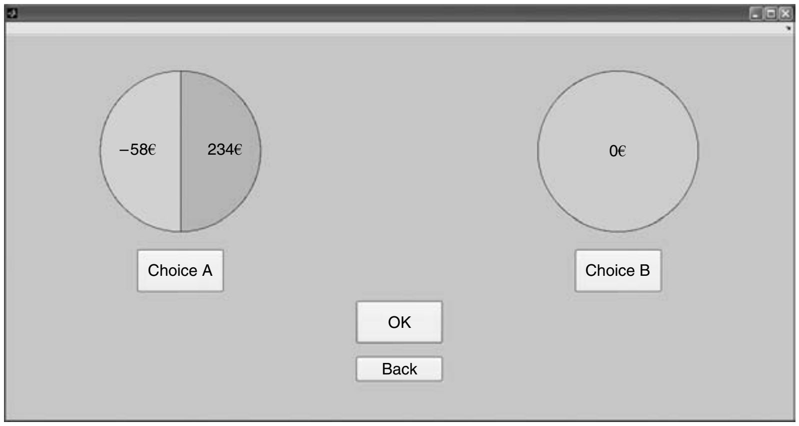


Figure A.2 Presentation of the Intertemporal Choices in the Rotterdam Experiment

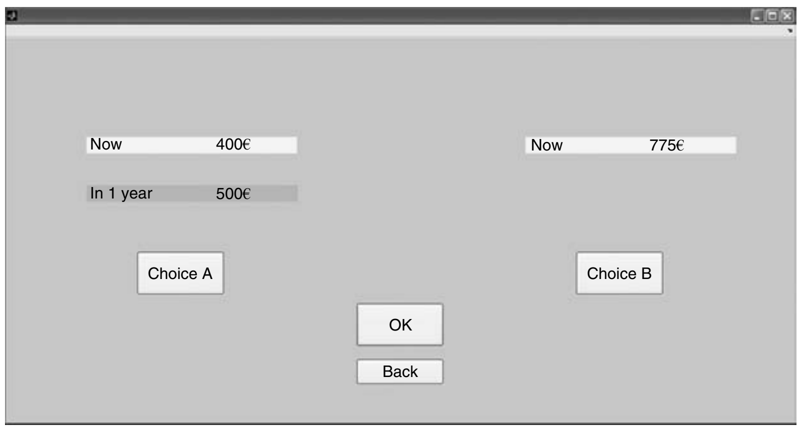


Figure A.3 Presentation of the Risky Choices in the Paris Experiment

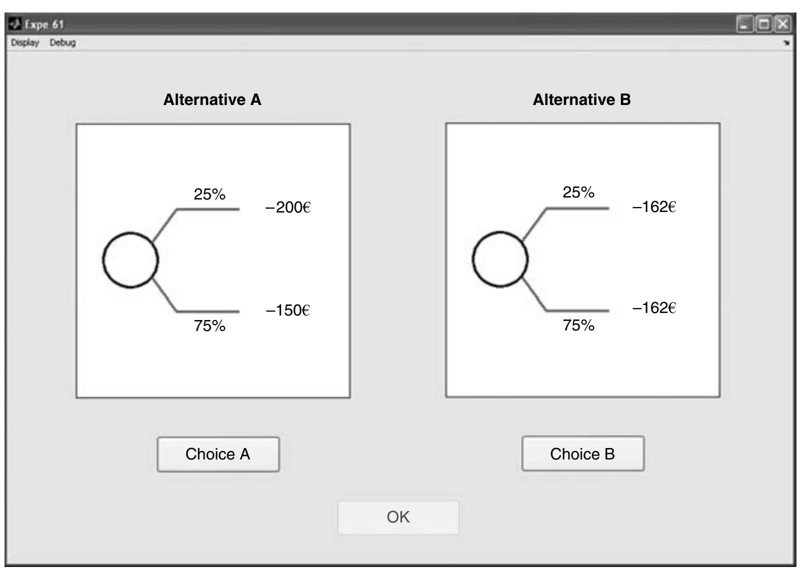


Figure A.4 Presentation of the Intertemporal Choices in the Paris Experiment

Appendix B. Experimental Data

Table B.1 Results of the Rotterdam Experiment: Risk

	Prospect	Median	IQR	Mean
Gain prospects	(400, 1/2; 0)	193.50	[143.50, 193.50]	169.27
	(600, 1/2; 0)	290.50	[196.50, 309.00]	264.06
	(600, 1/2; 200)	393.50	[356.00, 406.00]	374.85
	(800, 1/2; 200)	471.50	[391.75, 509.00]	449.63
	(800, 1/2; 400)	593.50	[568.50, 606.00]	586.00
	(1,000, 1/2; 400)	690.50	[610.75, 709.00]	652.50
	(1,000, 1/2; 600)	793.50	[743.50, 806.00]	778.50
	(1,000, 1/2; 800)	903.00	[896.50, 909.00]	898.15
Loss prospects	(−400, 1/2; 0)	−193.50	[−206.00, −165.38]	−184.08
	(−600, 1/2; 0)	−290.50	[−313.63, −271.50]	−283.68
	(−400, 1/2; −200)	−393.50	[−406.00, −343.50]	−371.96
	(−800, 1/2; −200)	−393.50	[−434.00, −331.00]	−388.20
	(−800, 1/2; −400)	−593.50	[−606.00, −531.00]	−567.15
	(−1,000, 1/2; −400)	−690.50	[−709.00, −615.50]	−659.15
	(−1,000, 1/2; −600)	−793.50	[−806.00, −756.00]	−779.65
	(−1,000, 1/2; −800)	−896.50	[−903.00, −882.50]	−889.62
Mixed prospects	$(G^r_{*1}, 1/2; -L^r_{*1})$	−99.00	[−179.25, −60.25]	−124.05
	$(G^r_{*2}, 1/2; -L^r_{*2})$	−178.50	[−285.00, −97.13]	−214.91
	$(G^r_{*3}, 1/2; -L^r_{*3})$	−272.50	[−361.63, −106.25]	−257.32

Note. In the mixed prospects, G^r_{*1} was the certainty equivalent of the prospect (400, 1/2; 0), G^r_{*2} was the certainty equivalent of the prospect (600, 1/2; 0), and G^r_{*3} was the certainty equivalent of the prospect (600, 1/2; 200).

Table B.2 Results of the Rotterdam Experiment: Time

	Prospect	Median	IQR	Mean
Gain prospects	(200, 1 yr.; 0)	181.00	[156.00, 193.50]	166.38
	(300, 1 yr.; 0)	271.50	[215.50, 290.50]	251.08
	(300, 1 yr.; 100)	371.50	[329.38, 390.50]	354.84
	(400, 1 yr.; 100)	462.50	[437.50, 487.50]	448.27
	(400, 1 yr.; 200)	562.50	[512.50, 587.50]	547.50
	(500, 1 yr.; 200)	652.50	[621.50, 684.00]	639.29
	(500, 1 yr.; 300)	721.50	[690.50, 784.00]	725.35
	(500, 1 yr.; 400)	852.50	[790.50, 884.00]	832.58

Table B.2 (Continued)

	Prospect	Median	IQR	Mean
Loss prospects	(−200, 1 yr.; 0)	−181.00	[−193.50, −156.00]	−179.08
	(−300, 1 yr.; 0)	−271.50	[−290.50, −234.00]	−262.89
	(−300, 1 yr.; −100)	−371.50	[−390.50, −329.38]	−354.82
	(−400, 1 yr.; −100)	−462.50	[−487.50, −431.25]	−444.42
	(−400, 1 yr.; −200)	−537.50	[−587.50, −512.50]	−524.81
	(−500, 1 yr.; −200)	−652.50	[−684.00, −590.50]	−628.22
	(−500, 1 yr.; −300)	−721.50	[−784.00, −690.50]	−725.85
	(−500, 1 yr.; −400)	−821.50	[−884.00, −790.50]	−802.77
Mixed prospects	$(-L^t_{*1}, 1\text{ yr.}; G^t_{*1})$	−149.50	[−172.00, −116.88]	−141.11
	$(-L^t_{*2}, 1\text{ yr.}; G^t_{*2})$	−224.00	[−266.50, −175.38]	−214.91
	$(-L^t_{*3}, 1\text{ yr.}; G^t_{*3})$	−324.50	[−365.00, −271.88]	−306.77

Note. In the mixed prospects, G^t_{*1} was the present equivalent of the prospect (200, 1 yr.; 0), G^t_{*2} was the present equivalent of the prospect (300, 1 yr.; 0), and G^t_{*3} was the present equivalent of the prospect (300, 1 yr.; 100).

Table B.3 Results of the Paris Experiment: Risk

	Prospect	Median	IQR	Mean
Gain prospects	(100, 1/4; 0)	25.00	[20.00, 38.00]	27.98
	(200, 1/4; 50)	81.00	[75.00, 96.00]	84.22
	(200, 1/4; 100)	129.00	[125.00, 136.00]	128.98
	(50, 1/4; 0)	17.00	[12.00, 20.00]	16.82
	(150, 1/4; 100)	118.00	[114.00, 121.00]	118.86
	(200, 1/4; 150)	167.00	[164.00, 170.00]	166.88
	(200, 1/4; 0)	39.00	[32.00, 50.00]	46.44
	(200, 1/2; 0)	67.00	[50.00, 83.00]	67.40
	(200, 3/4; 0)	106.00	[79.00, 129.00]	106.08
Loss prospects	(−100, 1/4; 0)	−20.00	[−29.00, −17.00]	−22.66
	(−200, 1/4; −50)	−78.00	[−88.00, −68.00]	−78.72
	(−200, 1/4; −100)	−121.00	[−128.00, −116.00]	−122.30
	(−50, 1/4; 0)	−10.00	[−12.00, −10.00]	−11.02
	(−150, 1/4; −100)	−112.00	[−116.00, −110.00]	−113.12
	(−200, 1/4; −150)	−162.00	[−166.00, −160.00]	−163.08
	(−200, 1/4; 0)	−47.50	[−61.00, −32.00]	−48.28
	(−200, 1/2; 0)	−77.00	[−92.00, −62.00]	−78.24
Mixed prospects	$(200, 1/2; -L^r_{*1})$	−77.00	[−107.00, −51.00]	−87.84
	$(50, 1/2; -L^r_{*2})$	−26.00	[−36.00, −20.00]	−29.46
	$(200, 3/4; -L^r_{*3})$	−126.00	[−180.00, −83.00]	−137.62
	$(50, 3/4; -L^r_{*4})$	−33.50	[−58.00, −26.00]	−42.04

Table B.4 Results of the Paris Experiment: Time

	Prospect	Median	IQR	Mean
Gain prospects	(100, 6 mos.; 0)	78.00	[74.00, 85.00]	77.24
	(75, 6 mos.; 25)	82.00	[76.00, 87.00]	81.52
	(150, 6 mos.; 0)	120.00	[109.00, 135.00]	119.66
	(50, 6 mos.; 0)	38.00	[34.00, 42.00]	37.12
	(100, 6 mos.; 50)	130.00	[120.00, 140.00]	129.14
	(150, 6 mos.; 50)	172.00	[159.00, 181.00]	168.80
	(200, 6 mos.; 0)	163.00	[149.00, 177.00]	159.42
Loss prospects	(−100, 6 mos.; 0)	−93.50	[−101.00, −87.00]	−93.10
	(−75, 6 mos.; −25)	−91.00	[−101.00, −87.00]	−92.58
	(−150, 6 mos.; 0)	−143.00	[−151.00, −130.00]	−138.70
	(−50, 6 mos.; 0)	−49.00	[−51.00, −44.00]	−48.46
	(−100, 6 mos.; −50)	−142.00	[−151.00, −135.00]	−141.42
	(−150, 6 mos.; −50)	−185.00	[−201.00, −170.00]	−183.50
	(−200, 6 mos.; 0)	−179.00	[−201.00, −170.00]	−182.60
Mixed prospects	$(-L^t_{*1}, 6\text{ mos.}; 200)$	−191.00	[−200.00, −180.00]	−184.82
	$(-L^t_{*2}, 6\text{ mos.}; 50)$	−45.00	[−50.00, −41.00]	−43.46
	$(200, 6\text{ mos.}; -L^t_{*3})$	−166.00	[−180.00, −145.00]	−158.64
	$(50, 6\text{ mos.}; -L^t_{*4})$	−39.00	[−45.00, −30.00]	−37.28

Appendix C. Parametric Estimations

	Utility gains	Utility losses	Loss-aversion coefficient
Rotterdam			
Risk	0.87 (0.29)	1.25 (0.36)	1.99 (0.23)
Time	0.03 (0.08)	−0.20 (0.06)	1.45 (0.08)
Paris			
Risk	1.60 (0.25)	−0.17 (0.18)	1.44 (0.12)
Time	−0.06 (0.08)	−0.20 (0.06)	1.15 (0.04)

Note. Standard errors in parentheses.

Appendix D. Median Probability Weighting and Discounting Based on the Individual Data

	Rotterdam		Paris	
	Gain	Loss	Gain	Loss
Probability weight	$w^+(1/2) = 0.51$ [0.45, 0.60]	$w^-(1/2) = 0.55$ [0.36, 0.61]	$w^+(1/4) = 0.38$ [0.30, 0.61] $w^+(1/2) = 0.48$ [0.41, 0.64] $w^+(3/4) = 0.64$ [0.47, 0.86]	$w^-(1/4) = 0.21$ [0.17, 0.30] $w^-(1/2) = 0.37$ [0.28, 0.52]
Discount factor	0.89 [0.81, 0.97]	0.91 [0.81, 0.97]	0.80 [0.71, 0.86]	0.92 [0.84, 1.00]
Discount rate	11.8% [3.3, 23.7]	10.4% [3.3, 22.8]	54.4% [35.6, 95.0]	19.4% [1.4, 42.2]

Note. IQR in brackets.

Appendix E. Proof That a Preference for Early Resolution of Uncertainty Is Equivalent to Convexity of $U^t \circ (U^r)^{-1}$

Let p be the subject's subjective probability that the delayed outcome will be received. A preference for early resolution of uncertainty means that $((x, p; z), t; y)$ is less preferred than $((x, t; y), p; (z, t; y))$. Ghirardato and Marinacci (2001) showed that all the main nonexpected utility models imply that prospects $(x, p; z)$ can be evaluated as $\pi U^r(x) + (1-\pi)U^r(y)$ with π a decision weight. Hence, the utility of $((x, p; z), t; y)$ is equal to $U^t(y) + \beta U^t(U^r)^{-1}(\pi U^r(x) + (1-\pi)U^r(z))$, which is less or equal than $U^t(y) + \beta\pi U^t(x) + \beta(1-\pi)U^t(z)$ if $U^t(U^r)^{-1}$ is convex. But $U^t(y) + \beta\pi U^t(x) + \beta(1-\pi)U^t(z)$ is equal to the utility of $((x, t; y), p; (z, t; y))$.

References

Abdellaoui M, Attema AE, Bleichrodt H (2010) Intertemporal tradeoffs for gains and losses: An experimental measurement of discounted utility. *Econom. J.* 120:845–866.

Abdellaoui M, Barrios C, Wakker PP (2007a) Reconciling introspective utility with revealed preference: Experimental arguments based on prospect theory. *J. Econometrics* 138:356–378.

Abdellaoui M, Bleichrodt H, l'Haridon O (2008) A tractable method to measure utility and loss aversion under prospect theory. *J. Risk Uncertainty* 36:245–266.

Abdellaoui M, Bleichrodt H, Paraschiv C (2007b) Loss aversion under prospect theory: A parameter-free approach. *Management Sci.* 53:1659–1674.

Abdellaoui M, Diecidue E, Öncüler A (2011) Risk preferences at different time points: An experimental investigation. *Management Sci.* 57:975–987.

Ahlbrecht M, Weber M (1997) Preference for gradual resolution of uncertainty. *Theory Decision* 43:167–185.

Anderhub V, Gneezy U, Güth W, Sonsino D (2001) On the interaction of risk and time preferences: An experimental study. *German Econom. Rev.* 2:239–253.

Andersen S, Harrison GW, Lau MI, Rutström EE (2008) Eliciting risk and time preferences. *Econometrica* 76:583–618.

Anderson LR, Stafford SL (2009) Individual decision-making experiments with risk and intertemporal choice. *J. Risk Uncertainty* 38:51–72.

Andreoni J, Sprenger C (2012) Risk preferences are not time preferences. *Amer. Econom. Rev.* 102:3357–3376.

Arrow KJ (1951) Alternative approaches to the theory of choice in risk-taking situations. *Econometrica* 19:404–437.

Baucells M, Heukamp F (2012) Probability and time tradeoff. *Management Sci.* 58:831–842.

Benhabib J, Bisin A, Schotter A (2010) Present-bias, quasi-hyperbolic discounting, and fixed costs. *Games Econom. Behav.* 69:205–223.

Benzion U, Rapoport A, Yagil J (1989) Discount rates inferred from decisions: An experimental study. *Management Sci.* 35:270–284.

Birnbaum MH (1992) Violations of monotonicity and contextual effects in choice-based certainty equivalents. *Psych. Sci.* 3:310–314.

Bommier A (2006) Uncertain lifetime and intertemporal choice. *Internat. Econom. Rev.* 47:1223–1246.

Booij AS, van de Kuilen G (2009) A parameter-free analysis of the utility of money for the general population under prospect theory. *J. Econom. Psych.* 30:651–666.

Booij AS, van Praag BMS (2009) A simultaneous approach to the estimation of risk aversion and the subjective discount rate. *J. Econom. Behav. Organ.* 70:374–388.

Bostic R, Herrnstein RJ, Luce RD (1990) The effect on the preference reversal of using choice indifferences. *J. Econom. Behav. Organ.* 13:193–212.

Broome J (1991) *Weighing Goods* (Basil Blackwell, Oxford, UK).

Bruhin A, Fehr-Duda H, Epper T (2010) Risk and rationality: Uncovering heterogeneity in probability distortion. *Econometrica* 78:1372–1412.

Chabris CF, Laibson D, Morris CL, Schuldt JP, Taubinsky D (2008) Individual laboratory-measured discount rates predict field behavior. *J. Risk Uncertainty* 37:237–269.

Chapman GB (1996) Temporal discounting and utility for health and money. *J. Experiment. Psych.: Learn. Memory Cognition* 22:771–791.

Chapman GB (2000) Preferences for improving and declining sequences of health outcomes. *J. Behavioral Decision Making* 13:203–218.

Chew SH, Epstein LG (1989) The structure of preferences and attitudes towards the timing of the resolution of uncertainty. *Internat. Econom. Rev.* 30:103–117.

Chew SH, Ho JL (1994) Hope: An empirical study of attitude toward the timing of uncertainty resolution. *J. Risk Uncertainty* 8:267–288.

Coble KH, Lusk JL (2010) At the nexus of risk and time preferences: An experimental investigation. *J. Risk Uncertainty* 41:67–79.

Cohen M, Tallon JM, Vergnaud JC (2011) An experimental investigation of imprecision attitude and its relation with risk attitude and impatience. *Theory Decision* 71:81–109.

Cubitt RP, Read D (2007) Can intertemporal choice experiments elicit time preferences for consumption? *Experiment. Econom.* 10:369–389.

Dasgupta P, Maskin E (2005) Uncertainty and hyperbolic discounting. *Amer. Econom. Rev.* 95:1290–1299.

de Lara Resende JG, Wu G (2010) Competence effects for choices involving gains and losses. *J. Risk Uncertainty* 40:109–132.

Dolan P, Kahneman D (2008) Interpretations of utility and their implications for the valuation of health. *Econom. J.* 118:215–234.

Dyer JS, Sarin RK (1982) Relative risk aversion. *Management Sci.* 28:875–886.

Eckel CC, Johnson CA, Montmarquette C (2005) Saving decisions of the working poor: Short- and long-term horizons. Carpenter J, Harrison GW, List JA, eds. *Field Experiments in Economics: Research in Experimental Economics*, Vol. 10 (JAI Press, Greenwich, CT), 219–260.

Edgeworth FY (1881) *Mathematical Physics, an Essay on the Application of Mathematics to the Moral Sciences* (Paul, London).

Edwards W (1954) The theory of decision making. *Psych. Bull.* 51:380–417.

Epper T, Fehr-Duda H, Bruhin A (2011) Viewing the future through a warped lens: Why uncertainty generates hyperbolic discounting. *J. Risk Uncertainty* 43:169–203.

Epstein LG, Zin SE (1989) Substitution, risk aversion, and the temporal behavior of consumption and asset returns. *Econometrica* 57:937–969.

Ert E, Erev I (2008) The rejection of attractive gambles, loss aversion, and the lemon avoidance heuristic. *J. Econom. Psych.* 29:715–723.

Fishburn PC (1989) Retrospective on the utility theory of von Neumann and Morgenstern. *J. Risk Uncertainty* 2:127–158.

Frederick S, Loewenstein G (2008) Conflicting motives in evaluations of sequences. *J. Risk Uncertainty* 37:221–235.

Gächter S, Johnson EJ, Herrmann A (2007) Individual-level loss aversion in riskless and risky choice. IZA Discussion Paper 2961, Institute for the Study of Labor, Bonn, Germany.

Gallant AR (1975) Seemingly unrelated nonlinear regressions. *J. Econometrics* 3:35–50.

Ghirardato P, Marinacci M (2001) Risk, ambiguity, and the separation of utility and beliefs. *Math. Oper. Res.* 26:864–890.

Gonzalez R, Wu G (1999) On the form of the probability weighting function. *Cognitive Psych.* 38:129–166.

Grant S, Kajii A, Polak B (1998) Intrinsic preference for information. *J. Econom. Theory* 83:233–259.

Halevy Y (2008) Strotz meets Allais: Diminishing impatience and the certainty effect. *Amer. Econom. Rev.* 98:1145–1162.

Harsanyi JC (1955) Cardinal welfare, individualistic ethics, and interpersonal comparisons of utility. *J. Political Econom.* 63:309–321.

Hicks JR, Allen RGD (1934a) A reconsideration of the theory of value—Part I. *Economica* 14:52–76.

Hicks JR, Allen RGD (1934b) A reconsideration of the theory of value—Part II. *Economica* 14:196–219.

Jevons WS (1879) *The Theory of Political Economy* (Macmillan, London).

Johnson WE (1913) The pure theory of utility curves. *Econom. J.* 23:483–513.

Kahneman D, Krueger AB (2006) Developments in the measurement of subjective well-being. *J. Econom. Perspect.* 20:3–24.

Kahneman D, Tversky A (1979) Prospect theory: An analysis of decision under risk. *Econometrica* 47:263–291.

Köbberling V, Wakker PP (2005) An index of loss aversion. *J. Econom. Theory* 122:119–131.

Köszegi B, Rabin M (2006) A model of reference-dependent preferences. *Quart. J. Econom.* 121:1133–1166.

Krantz DH, Luce RD, Suppes P, Tversky A (1971) *Foundations of Measurement*, Vol. 1 (Academic Press, New York).

Kreps DM, Porteus EL (1978) Temporal resolution of uncertainty and dynamic choice theory. *Econometrica* 46:185–200.

Laury SK, McInnes MM, Swarthout JT (2012) Avoiding the curves: Direct elicitation of time preferences. *J. Risk Uncertainty* 44:181–217.

Lewin SB (1996) Economics and psychology: Lessons for our own day from the early twentieth century. *J. Econom. Literature* 34:1293–1323.

Loewenstein GF (1987) Anticipation and the valuation of delayed consumption. *Econom. J.* 97:666–684.

Loewenstein GF, Prelec D (1992) Anomalies in intertemporal choice: Evidence and an interpretation. *Quart. J. Econom.* 107:573–597.

Loewenstein GF, Sicherman N (1991) Do workers prefer increasing wage profiles? *J. Labor Econom.* 9:67–84.

Luce RD, Raiffa H (1957) *Games and Decisions* (Wiley, New York).

Manzini P, Mariotti M, Mittone L (2010) Choosing monetary sequences: Theory and experimental evidence. *Theory Decision* 69:327–354.

Marshall A (1890) *Principles of Economics* (Macmillan, London).

Menger K (1871) *Grundätze Der Volkswirtschaftslehre* (Braumüller, Vienna).

Miyamoto JM (1988) Generic utility theory: Measurement foundations and applications in multiattribute utility theory. *J. Math. Psych.* 32:357–404.

Novemsky N, Kahneman D (2005) The boundaries of loss aversion. *J. Marketing Res.* 42:119–128.

Pareto V (1906) *Manuele Di Economia Politica* (Piccolo Biblioteca Scientifica, Milan).

Prelec D, Loewenstein GF (1991) Decision making over time and under uncertainty: A common approach. *Management Sci.* 37:770–786.

Quiggin J, Horowitz J (1995) Time and risk. *J. Risk Uncertainty* 10:37–55.

Reuben E, Sapienza P, Zingales L (2010) Time discounting for primary and monetary rewards. *Econom. Lett.* 106:125–127.

Samuelson PA (1937) A note on the measurement of utility. *Rev. Econom. Stud.* 4:155–161.

Samuelson PA (1938) A note on the pure theory of consumer's behaviour. *Economica* 5:61–71.

Schunk D, Betsch C (2006) Explaining heterogeneity in utility functions by individual differences in decision modes. *J. Econom. Psych.* 27:386–401.

Slutsky EE (1915) Sulla teoria del bilancio del consumatore. *Giornale degli Economisti* 51:1–26.

Stalmeier PFM, Bezembinder TGG (1999) The discrepancy between risky and riskless utilities: A matter of framing? *Medical Decision Making* 19:435–447.

Stewart N, Reimers S, Harris AJL (2012) On the origin of utility, weighting, and discounting functions: How they get their shapes and how to change their shapes. Working paper, University of Warwick, Conventry, UK.

Stewart N, Chater N, Stott HP, Reimers S (2003) Prospect relativity: How choice options influence decision under risk. *J. Experiment. Psych.: General* 132:23–46.

Stigler GJ (1950a) The development of utility theory. I. *J. Political Econom.* 58:307–327.

Stigler GJ (1950b) The development of utility theory. II. *J. Political Econom.* 58:373–396.

Stott HP (2006) Cumulative prospect theory's functional menagerie. *J. Risk Uncertainty* 32:101–130.

Sugden R (2003) Reference-dependent subjective expected utility. *J. Econom. Theory* 111:172–191.

Takeuchi K (2011) Non-parametric test of time consistency: Present bias and future bias. *Games Econom. Behav.* 71:456–478.

Thaler RH (1981) Some empirical evidence on dynamic inconsistency. *Econom. Lett.* 8:201–207.

Tu Q (2004) Reference points and loss aversion in intertemporal choice. Working paper, Tilburg University, Tilburg, The Netherlands.

Tversky A, Kahneman D (1981) The framing of decisions and the psychology of choice. *Science* 211:453–458.

Tversky A, Kahneman D (1992) Advances in prospect theory: Cumulative representation of uncertainty. *J. Risk Uncertainty* 5:297–323.

van der Pol MM, Cairns JA (2000) Negative and zero time preference for health. *Health Econom.* 9:171–175.

von Neumann J, Morgenstern O (1944) *The Theory of Games and Econom. Behavior* (Princeton University Press, Princeton, NJ).

Wakker PP (1994) Separating marginal utility and probabilistic risk aversion. *Theory Decision* 36:1–44.

Wakker PP (2010) *Prospect Theory: For Risk and Ambiguity* (Cambridge University Press, Cambridge, UK).

Wakker PP, Deneffe D (1996) Eliciting von Neumann-Morgenstern utilities when probabilities are distorted or unknown. *Management Sci.* 42:1131–1150.

Walras L (1874) *Eléments d'Économie Politique Pure* (Pichon and Durand-Auzias, Paris).

Wathieu L (1997) Habits and the anomalies in intertemporal choice. *Management Sci.* 43:1552–1563.

Wu G (1999) Anxiety and decision making with delayed resolution of uncertainty. *Theory Decision* 46:159–198.

Yates JF, Watts RA (1975) Preferences for deferred losses. *Organ. Behav. Human Performance* 13:294–306.