A Parameter-Free Analysis of the Utility of Money for the General Population under Prospect Theory*

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ABSTRACT. Extensive data have convincingly shown that expected utility, the reigning economic theory of rational decision making, fails descriptively. The descriptive inadequacy of expected utility questions the validity of classical utility measurements. This paper presents the results of an experiment that completely measures the utility function for different positive and negative monetary outcomes, using a representative sample of N = 1932 from the general public, in a completely parameter-free way. Hence, the present paper provides a parameter-free measurement of the rational component of risk attitudes from the general population. This information is crucial for policy decisions on important economic problems such as equitable taxation and the cost benefit analysis of education, health care, and retirement. In addition, we obtain individual parameter-free measurements of loss aversion. The results give empirical support to a recent conjecture by Rabin, being that utility curvature is less pronounced then suggested by classical utility measurements, using a large representative sample. Also, females are more risk averse than males, which confirms frequent findings, but our results give more background and show that this finding is primarily driven by utility for gains and loss aversion, and not by utility of losses.

JEL-Classification: D81, C91, C93

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1. Introduction

Expected utility is the reigning economic theory of rational decision making under risk. In the classical expected utility framework, outcomes are transformed by a strictly increasing utility function and prospects are evaluated by the probability-weighted average utility. Therefore, risk attitudes are solely explained by utility curvature under expected utility. For example, *risk aversion* (preferring the expected value of a prospect to the prospect itself) holds if and only if the utility function is concave, implying diminishing marginal utility. However, a decade of extensive experimentation has convincingly shown that "risk aversion is more than the psychophysics of money" (Lopes 1987): numerous studies have systematically falsified expected utility as a descriptive theory of decision making (Allais 1953; Kahneman & Tversky 1979). This descriptive inadequacy has been the main inspiration for the development of many new descriptive theories of individual decision making under risk (for a survey, see Starmer 2000). The most prominent of these nonexpected utility models is prospect theory (Kahneman & Tversky 1979; Tversky & Kahneman 1992).

Prospect theory entails that besides the transformation of outcomes, probabilities are transformed by a subjective probability weighting function, reflecting sensitivity towards probabilities. In addition, prospect theory entails that outcomes are evaluated relative to a reference point, reflecting sensitivity towards whether outcomes are better or worse than the status quo. Consequently, in the prospect theory framework, the one-to-one relationship between utility curvature and risk attitudes no longer holds: risk attitudes are determined by a combination of utility curvature, subjective probability weighting, and the steepness of the utility function for negative outcomes (*losses*) relative to the steepness of the utility function for positive outcomes (*gains*), i.e. *loss aversion*. Therefore, the validity of classical measurements of risk attitudes can be questioned, which explains why these measurements have often led to preference inconsistencies (Hershey & Schoemaker 1985) or theoretical implausibilities (Rabin 2000a).

From a policy perspective, it is important to decompose risk attitudes into a utility curvature part, a subjective probability weighting part, and a loss aversion part at the individual level. Choice behavior based on diminishing marginal utility is considered to be rational by most economists in the sense that these choices satisfy the fundamental axioms of expected utility. Choice behavior based on subjective probability weighting for example does not agree with these normatively compelling axioms.

This paper presents the results of an experiment that completely measures the utility function for different positive and negative monetary outcomes, using a representative sample of N = 1932 respondents from the Dutch population, in a completely parameter-free way. The measurement technique we use is the (gamble-) tradeoff method introduced by Wakker and Deneffe (1996), which is robust against subjective probability distortion and is parameter-free in the sense that a priori assumptions about the true underlying functional form of the utility function are not necessary. Hence, the present paper provides the first parameter-free measurement of the rational component of risk attitudes of the general population, which is important for policy decisions on economic problems such as equitable taxation and the cost benefit analysis of education, health care, and retirement. In addition, we have obtained individual parameter-free measurements of loss aversion under expected utility. The obtained dataset also allows us to test whether utility curvature is more or less pronounced for losses than for gains, whether scaling up monetary outcomes leads to a higher or a lower degree of utility curvature or loss aversion, and to relate the obtained measurements of utility curvature and loss aversion to socio-demographic characteristics.

First of all, our results support Rabin's (2000b, p. 202) claim that diminishing marginal utility is an "implausible explanation for appreciable risk aversion, except when the stakes are very large": we confirm that utility curvature is less pronounced then suggested by classical utility measurements. Second, the results show that utility is concave for gains and convex for losses, reflecting *diminishing sensitivity* as predicted by prospect theory but contrary to the classical prediction of universal concavity. In addition, the results confirm the common finding that females are more risk averse then males. Contrary to classical studies that ascribed this gender difference solely to differences in the degree of utility curvature, our results show that this finding is primarily driven by utility for gains and loss aversion, and not by utility of losses. Fourth and finally, we did not find significant evidence for the hypothesis that both the degree of utility curvature and the degree of loss aversion increases with the size of the outcomes involved.

The remainder of this paper is organized as follows. Section 2 briefly provides background information about the ongoing debate in the literature about the proper shape of the utility function. Section 3 discusses prospect theory, and Section 4 provides an explanation of the measurement techniques we used to obtain parameter-free measurements of utility curvature and loss aversion at the individual level. Section 5 presents the experimental method, followed by the presentation of the results of the experiment in Section 6. Section 7 contains a discussion of the experimental method and the experimental results and Section 8 concludes. Finally, Appendix A presents details of the experimental instructions.

2. Background

As mentioned in the introduction, measuring risk attitudes and decomposing risk attitudes into a rational and irrational component is crucial from a policy perspective. Consider for example the *equal sacrifice principle* first put forth by Mill (1848). According to this principle, tax rates should be set in such a way that all people paying tax lose the same amount of utility. Hence, information about the utility that people derive from money obtained in isolation, that is, obtained in an environment where confounding effects such as probability weighting did not play a role, is necessary. Young (1990) used historical tax data from the US to derive the utility function of taxpayers under the assumption that the equal sacrifice principle holds. Because the resulting estimates of the utility function are consistent with estimates from the finance literature, Young (1990) justified US tax policy. However, Young (1990) assumed expected utility and, hence, his results may have been distorted by probability weighting.

Parametric studies that provide measurements and decompositions of risk attitudes into a rational and irrational part are numerous and, consequently, there is an ongoing debate about the shape of the utility function. For gains, most studies have corroborated that the utility function is concave-shaped reflecting the natural intuition that each new euro brings less utility than the euro before and implying diminishing marginal utility (Wakker & Deneffe 1996). However, the debate regarding the shape of the utility function for losses has not been settled.

First of all, there is no consensus at present about the fundamental question whether the utility function for losses is convex or concave. Some studies found concave utility for losses (Davidson, Suppes & Siegel 1957; Laury & Holt 2000 (for real incentives only)), while other studies found convex utility for losses (Currim & Sarin 1989; Tversky & Kahneman 1992; Abdellaoui 2000; Etchart-Vincent 2004). Second, some studies did not only find convex utility for losses but also found more pronounced convexity for losses than concavity for gains (Fishburn & Kochenberger 1979; Abdellaoui, Bleichrodt & Paraschiv 2004), and this constitutes another point of debate since other studies found that convexity for losses is less pronounced than concavity for gains (Fennema & van Assen 1999; Köbberling, Schwieren & Wakker 2004; Abdellaoui, Vosmann & Weber, 2005). Finally, there is no consensus on whether utility curvature is more (or less) pronounced for larger outcomes. Increasing relative risk aversion has been found, for example, by Kachelmeier & Shehata (1992), Holt & Laury (2002, 2005), and Harrison, Johnson, McInnes & Rustrom (2003), whereas the opposite result, i.e. a decreasing relative risk aversion coefficient, has been found, for example, by Friend & Blume (1979), and Blake (1996).

There are four possible confounding factors in the aforementioned studies that are not present in the current study, and that may explain the seemingly contradictory findings. First, some studies assume expected utility and, thus, ignore the important role of probability weighting in risk attitudes. Second, the functional form of the utility (and probability weighting-) function are sometimes assumed beforehand and, therefore, the estimations depend critically on the appropriateness of the assumed functional form: conclusions drawn on the basis of the parameter estimates need no longer be valid if the true functional form differs from the assumed functional form. Third, most of these studies use aggregate data to estimate the different assumed functional forms, ruling out heterogeneity of individual preferences. Fourth and finally, student populations are commonly used as subjects, making the external validity of the results questionable.

3. Prospect Theory

Let $\mathbb{R}$ be the set of possible monetary outcomes. We consider decision under risk. A *prospect* is a finite probability distribution over the outcomes. Thus, a prospect yielding outcome x_i with probability p_i ($i = 1,\ldots, n$) is denoted as $(p_1{:}x_1,\ldots, p_n{:}x_n)$. A two-outcome prospect $(p{:}x, 1-p{:}y)$ is denoted by $(p{:}x, y)$ and the unit of payment for outcomes is one euro. In this paper, *prospect theory* refers to the modern (cumulative) version of prospect theory that corrected a theoretical mistake in the original '79 version, introduced by Tversky & Kahneman (1992). Prospect theory entails that the value of a prospect with outcomes $x_1 \leq \ldots \leq x_k \leq 0 \leq x_{k+1} \leq \ldots \leq x_n$ is given by:

$$\sum_{i=1}^{k} \pi_i^{-} \mathrm{U}(x_i) + \sum_{j=k+1}^{n} \pi_j^{+} \mathrm{U}(x_j) \qquad (3.1)$$

Here $\mathrm{U}: \mathbb{R} \rightarrow \mathbb{R}$ is a continuous and strictly increasing *utility function* satisfying $\mathrm{U}(0) = 0$, and π^{+} and π^{-} are the *decision weights*, for gains and losses respectively, defined by:

$$\pi_i^{-} = w^{-}(p_1 + \ldots + p_i) - w^{-}(p_1 + \ldots + p_{i-1}) \quad \text{for } i \leq k, \text{ and}$$

$$\pi_j^{+} = w^{+}(p_j + \ldots + p_n) - w^{+}(p_{j+1} + \ldots + p_n) \quad \text{for } j > k \qquad (3.2)$$

Here w^{+} is the *probability weighting function for gains* and w^{-} is the *probability weighting function for losses*, satisfying $w^{+}(0) = w^{-}(0) = 0$ and $w^{+}(1) = w^{-}(1) = 1$, and both strictly increasing and continuous. Thus, the decision weight of a positive outcome x_i is the marginal w^{+} contribution of p_i to the probability of receiving better outcomes and the decision weight of a negative outcome x_i is the marginal w^{-} contribution of p_i to the probability of receiving worse outcomes. Finally note that the decision weights do not necessary sum to 1 and that prospect theory coincides with expected utility if people do not distort probabilities, i.e. prospect theory coincides with expected utility if w^{+} and w^{-} are the identity.

4. Measuring The Utility Function

This section provides an explanation of the measurement techniques we used to obtain parameter-free measurements of utility curvature and loss aversion at the individual level.

4.1 Measuring Utility Curvature: The Tradeoff Method

The (gamble-) tradeoff method, first introduced by Wakker and Deneffe (1996), draws inferences from a series of indifferences between two-outcome prospects in order to obtain a so-called *standard sequence of outcomes*, i.e. a series of outcomes that is equally spaced in utility units. Contrary to other elicitation techniques often used to measure individual utility functions such as the certainty equivalent method, the probability equivalent method, and the lottery equivalent method (McCord & de Neufville 1986), utilities obtained through the tradeoff method are robust to subjective probability distortion. Hence, besides being valid under expected utility, the tradeoff method retains validity under prospect theory, rank-dependent utility and cumulative prospect theory (Wakker & Deneffe 1996).

Consider an individual who is indifferent between the prospects $(p{:}x_1, g)$ and $(p{:}x_0, G)$ with $0 \leq g \leq G \leq x_0 \leq x_1$. In most existing laboratory experiments employing the tradeoff method (as well as in our field experiment) individual indifference is obtained by eliciting the value of outcome x_1 that makes a person indifferent between these two prospects while fixing outcomes x_0, G, g, and probability p. Under prospect theory, indifference between these prospects implies that:

$$w^{+}(p)\big(\mathrm{U}(x_1)-\mathrm{U}(x_0)\big)=\big(1-w^{+}(p)\big)\big(\mathrm{U}(G)-\mathrm{U}(g)\big) \qquad (4.1)$$

Thus, under prospect theory, the weighted improvement in utility by obtaining outcome G instead of outcome g is equivalent to the weighted improvement in utility by obtaining outcome x_1 instead of outcome x_0. Now suppose that the same person is also indifferent between the prospects $(p{:}x_2, g)$ and $(p{:}x_1, G)$. If we apply the prospect theory formula to this indifference we find that:

$$w^{+}(p)\big(\mathrm{U}(x_2)-\mathrm{U}(x_1)\big)=\big(1-w^{+}(p)\big)\big(\mathrm{U}(G)-\mathrm{U}(g)\big) \qquad (4.2)$$

Combining equations 4.1 and 4.2 yields:

$$U(x_2) - U(x_1) = U(x_1) - U(x_0) \quad (4.3)$$

Thus, the tradeoff in utilities between receiving outcome x_2 instead of outcome x_1 is equivalent to the tradeoff in utilities between receiving outcome x_1 instead of outcome x_0 under prospect theory. Or, put differently, x_1 is the utility-midpoint between outcome x_0 and outcome x_2 and the sequence of outcomes x_0, x_1, x_2 is equally spaced in terms of utility units. We can continue eliciting individual indifference between prospects (p:x_i, g) and (p:x_{i-1}, G) in order to obtain an increasing sequence $x_0,\ldots, x_n$ of gains that are equally spaced in utility units. A similar process can be used to construct a decreasing sequence of equally spaced losses. More specifically, individual indifference between the prospects (p:y_i, l) and (p:y_{i-1}, L) with $0 \geq l \geq L \geq y_0 \geq y_1 \geq \ldots \geq y_n$ implies that the resulting decreasing sequence of losses $y_0,\ldots, y_n$ is equally spaced in utility units under prospect theory. In what follows, we will use the term *utility increment* to denounce the (equal) utility difference between the elements of the particular standard sequence considered.

4.2 Measuring Loss Aversion

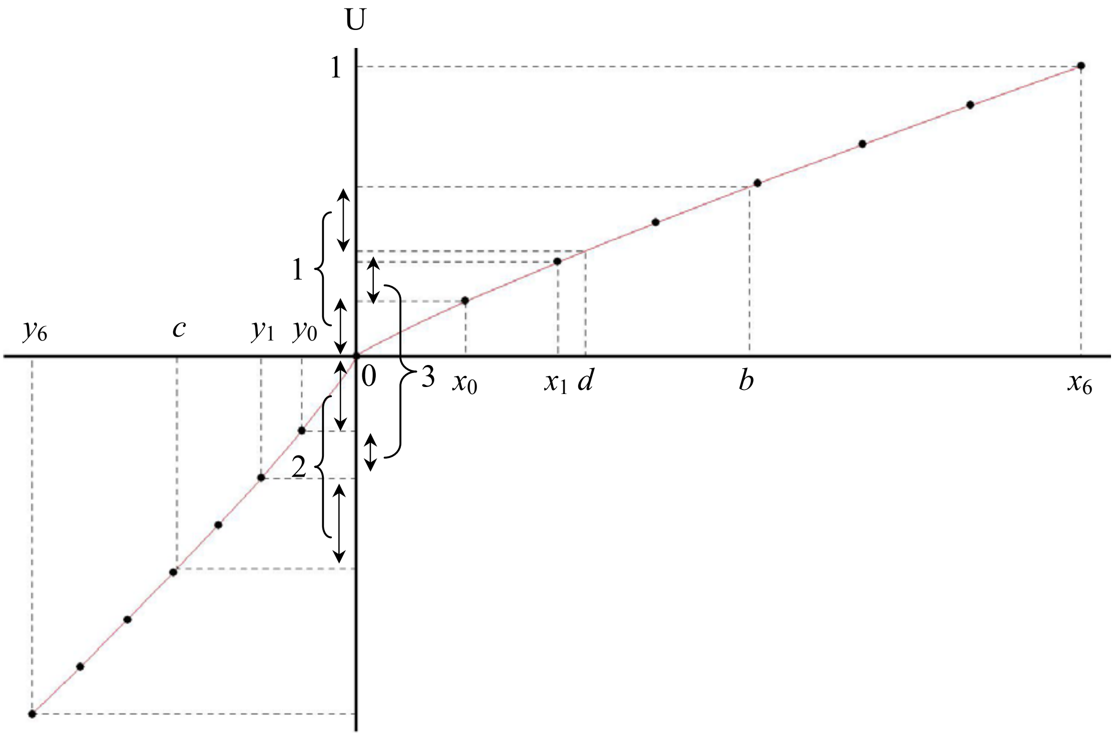
The tradeoff method allows measuring utilities for either gains or losses. Without any further information these measurements cannot be combined, because they are not on the same scale. This requires the elicitation of additional indifferences that also involve mixed prospects, i.e. prospects that yield both gains and losses. This will then amount to measuring loss aversion and, with the proper use of the obtained standard sequences, this can be done in a parameter-free way.

To measure loss aversion, we first determine the utility-distance of $x_0,\ldots, x_n$ to outcome 0. Indeed, although we know that the sequence is equally spaced in utility units, we do not know how far their utility is above U(0) = 0. This we determine by obtaining the value of outcome b that makes a person indifferent between the prospects (r:b, 0) and (r:x_1, x_0), where r is some fixed probability. Under prospect theory, indifference between these prospects implies:

$$U(x_0) - U(0) = \frac{w^+(r)}{1 - w^+(r)}\left(U(b) - U(x_1)\right) \quad (4.4)$$

If the quantities on the right hand side of this equation are known then, for the purpose of utility measurement, this equation can be seen as eliciting the location of the utilities of the standard sequence for gains with respect to the utility 0 that is attached to outcome 0. Put differently, Equation 4.4 identifies the utility distance between outcome 0 and the outcomes of the standard sequence for gains. This is illustrated by brace 1 in Figure 4.1 below.

FIGURE 4.1 – Linking the Utilities for Gains and Losses



Assuming that $w^+(r)$ is known, the right-hand side of Equation 4.4 can be quantified directly in terms of the number of utility increments of the standard sequence if $b \in \{x_0,\ldots, x_n\}$. The indifference outcome b usually is not an element of the obtained standard sequence of gains. If the obtained indifference outcome b falls within the range of the standard sequence, i.e. $b \in [x_1, x_n]$, then an estimate of U(b) can be obtained by using linear interpolation. For example, if $b \in [x_{j-1}, x_j]$, then U(b) can be approximated by

$$\frac{b-x_{j-1}}{x_j - x_{j-1}}\left(\mathrm{U}(x_j)-\mathrm{U}(x_{j-1})\right)+\mathrm{U}(x_{j-1}) \qquad (4.5)$$

This approximation can be justified on the grounds that utility is often found to be linear over small monetary intervals (Wakker & Deneffe 1996).

As a second step in our measurement of loss aversion, we measure the utility distance between outcome zero and the standard sequence $y_0,\ldots, y_n$ of losses. This can be done by obtaining the outcome c that makes an agent indifferent between the prospects $(r{:}0, c)$ and $(r{:}y_0, y_1)$. Under prospect theory, indifference between these prospects implies:

$$\mathrm{U}(y_0)-\mathrm{U}(0)=\frac{w^-(1-r)}{1-w^-(1-r)}\big(\mathrm{U}(c)-\mathrm{U}(y_1)\big) \tag{4.6}$$

This second step is illustrated by brace 2 in Figure 4.1. Assuming that $w^-(1-r)$ is known, again only U(c) has to be determined in order to quantify the right-hand side of Equation 4.6 in terms of the number of utility increments of the standard sequence of losses. Because indifference outcome c need not be an element of the obtained standard sequence of losses, the utility of outcome c has to be interpolated from this sequence again.

The first two indifferences measure the utility distances between outcome 0 and the standard sequences of gains and losses respectively. In the third and final step, the utility function for gains is linked to the utility function for losses by eliciting the outcome $d > x_0$ that makes the agent indifferent between the mixed prospects $(r{:}d, y_1)$ and $(r{:}x_0, y_0)$. This is illustrated by brace 3 in Figure 4.1. Under prospect theory, indifference between these prospects implies

$$\mathrm{U}(y_0)-\mathrm{U}(y_1)=\frac{w^+(r)}{w^-(1-r)}\big(\mathrm{U}(d)-\mathrm{U}(x_0)\big) \tag{4.7}$$

From a measurement perspective this equation amounts to relating the utility increment of the standard sequence of losses to that of the standard sequence of gains. The utility of outcome d has to be interpolated from the standard sequence of gains again.

Equations 4.5 – 4.7, the fact that standard sequences are equally spaced in utility units, and linear interpolation of the utility of indifference outcomes b, c, d, fully determine the utilities of the outcomes $\{y_n,\ldots, y_0, 0, x_0,\ldots, x_n\}$.

In the above steps, the probability weights corresponding to the probabilities used in the elicitation procedure were assumed to be known, while in fact they are unknown a priori. Several parameter-free techniques to obtain these probability weights have been proposed in the literature (Abdellaoui 2000, Bleichrodt & Pinto

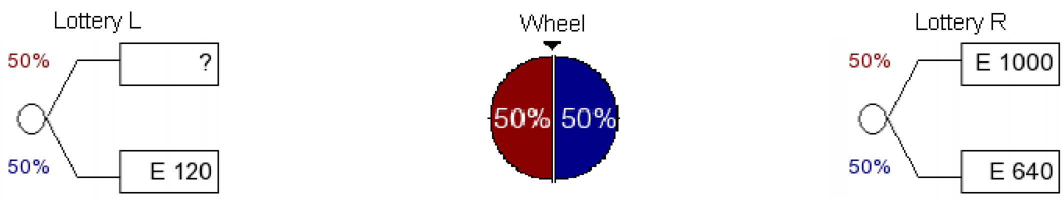
2000). Hence, if combined with these measurement methods, the three indifferences stated above can in principle be used to measure the utilities of the standard sequences of gains and losses on the same scale. In the present study, we did not pose additional questions to obtain the probability weights, and assume either linear probability weighting as in classical economic analyses or use the empirical estimates of the probability weights found by Kahneman & Tversky (1992) in the analysis. A different parameter-free method to measure loss aversion is in Abdellaoui, Bleichrodt & Paraschiv (2005).

5. The Experiment: Method

Participants. N = 1932 Dutch participated in the experiment which was held in February 2006. We used the DNB Household survey which is a household panel that completes a questionnaire every week on the Internet or, if Internet is not available in the household, by a special box connected to the television. The household panel is a representative sample of the Dutch population.

Procedure. Respondents first read experimental instructions (see Appendix A) and were then asked to answer a practice question to familiarize them with the experimental setting. In the instructions it was emphasized that there were no right or wrong answers. In order to obtain indifference between prospects we used direct matching, that is, respondents were asked to report an outcome of a prospect for which they would be indifferent between two particular prospects, which were framed as depicted in Figure 5.1 below.

FIGURE 5.1 – The Framing of the Prospect Pairs



Respondents were thus simply asked to report the upper prize of the left prospect that would make them indifferent between both prospects. The wheel in the middle served to explain probabilities to respondents. Both the probabilities reported in the wheel and the colors of the wheel corresponded to the probabilities of the prospects. The prizes of the prospects used were hypothetical (for a discussion see Section 7).

Stimuli. For each respondent we obtained a total of 16 indifferences; see Table 5.1.

TABLE 5.1 – The Obtained Indifferences

Matching Question	Prospect L		Prospect R
1	(0.5: $\underline{a}$, 10)	~	(0.5: 50, 20)
2	(0.5: $\underline{x_1}$, g)	~	(0.5: x_0, G)
.	.		.
.	.		.
7	(0.5: $\underline{x_6}$, g)	~	(0.5: x_5, G)
8	(0.5: $\underline{y_1}$, l)	~	(0.5: y_0, L)
.	.		.
.	.		.
13	(0.5: $\underline{y_6}$, l)	~	(0.5: y_5, L)
14*	(0.5: $\underline{b}$, 0)	~	(0.5: x_1, x_0)
15*	(0.5: 0, $\underline{c}$)	~	(0.5: y_0, y_1)
16*	(0.5: $\underline{d}$, y_1)	~	(0.5: x_0, y_0)

Notes: underlined outcomes are the matching outcomes and questions marked with an asterisk were presented in randomized order.

Following the first practice question, matching questions 2 to 7 served to obtain an increasing sequence of gains $x_0,\ldots, x_6$ that are equally spaced in utility units, followed by six matching questions to obtain a decreasing sequence of losses $y_0,\ldots, y_6$ that are equally spaced in terms of utility (see Section 4.1). Matching questions 14-16 served to obtain a parameter-free measurement of the degree of loss aversion at the individual level, under expected utility (see Section 4.2). As can be seen in Table 5.1, the parameter values of p and r used throughout Section 4 were set at 1/2, as in Bleichrodt & Pinto's (2000) experiment.

Treatments. In order to be able to test whether utility curvature is more pronounced for larger monetary outcomes, respondents were randomly assigned to two different treatments. These treatments only differed in the parameters values used for G, g, x_0, L, l, and y_0. In the low-stimuli treatment, these parameters values were set at $G = 64$, $g = 12$, $x_0 = 100$, $L = -32$, $l = -6$, and $y_0 = -50$. In the high-stimuli treatment, all parameter values were scaled up by a factor 10, i.e. the parameters values were set at $G = 640$, $g = 120$, $x_0 = 1000$, $L = -320$, $l = -60$, and $y_0 = -500$.

6. The Experiment: Results

In the following analyses, the number of observations used varies considerably. The precise number of observations used in each analysis will be reported separately. The (sometimes high) rate of dropped observations is mainly determined by an imposed monotonicity condition (the obtained standard sequence of gains (losses) had to be strictly increasing (decreasing)), and an imposed completeness condition (each respondent had to complete all matching questions). Violation of such conditions suggests that respondents did not understand the questions or were not well motivated. We also dropped some extreme observations that similarly suggested lack of understanding.

Although dropping observations is unfavorable, it has some advantages especially when using a large representative sample. Then the performed analysis is based on data of respondents who had a good understanding of the questions, making them of better quality. In the same way, some other studies of large representative samples dropped even more subjects: for determining the relative risk aversion coefficient (see Section 6.1.2), Guiso & Paiella (2003) and Dohmen, Falk, Huffman, Sunde, Schupp & Wagner (2005) were even forced to drop 57% and 61% of their observations, respectively.

6.1.1 Utility Curvature: Non-Parametric Analysis

Table 6.1 summarizes the results regarding the obtained utility function for monetary gains and losses under the different treatments. As can be seen in the table, the difference between the successive elements of the average standard sequences is mostly increasing over all treatments for both gains and losses. This implies concave utility for gains and convex utility for losses, reflecting *diminishing sensitivity*: people are more sensitive to changes near the status quo than to changes remote from the status quo, as predicted by prospect theory but contrary to the classical prediction of universal concavity. Also, at face value utility curvature seems to be more pronounced for larger monetary outcomes.

TABLE 6.1 – Mean Results Utility Curvature

	GAINS				LOSSES			
	High (N = 383)		Low (N = 431)		High (N = 330)		Low (N = 360)	
i	x_i	$x_i - x_{i-1}$	x_i	$x_i - x_{i-1}$	y_i	$y_i - y_{i-1}$	y_i	$y_i - y_{i-1}$
1	1993 (602)	993	205 (94)	105	−851 (231)	350	−86 (36)	36
2	3000 (1131)	1007	319 (184)	114*	−1243 (431)	392*	−126 (59)	40*
3	4060 (1692)	1060*	441 (313)	122*	−1664 (634)	421*	−168 (83)	42*
4	5161 (2311)	1101**	576 (561)	135***	−2075 (856)	411	−211 (106)	43**
5	6283 (2980)	1122**	727 (865)	151*	−2494 (1069)	419	−254 (130)	43
6	7447 (3713)	1164**	893 (1244)	166	−2920 (1297)	426***	−298 (156)	44

Notes: standard deviations in parenthesis. * significantly higher than its predecessor at the 1% level. ** significantly higher than its predecessor at the 5% level. *** significantly higher than its predecessor at the 10% level.

We performed Wilcoxon signed-rank tests to test whether the differences between the successive elements of the standard sequence for gains and losses are indeed significantly increasing. As can be seen in Table 6.1, a total of 4 differences between the obtained successive elements of the standard sequence were significantly increasing for gains. In the loss domain, 3 differences between the obtained elements of the standard sequences were significantly increasing in both the low and the high-stimulus treatment. Only one difference was significantly decreasing. Overall, our results thus suggest the presence of significant diminishing sensitivity, which is consistent with the findings of other parameter-free studies employing the tradeoff method to obtain utilities for gains (Wakker & Deneffe 1996; Abdellaoui 2000; Abdellaoui, Barrios & Wakker 2005) and losses (Fennema & van Assen 1999; Etchard-Vincent 2004) as well as with results from studies using parametric fittings (Currim & Sarin 1989; Tversky & Kahneman 1992; Heath, Huddart & Lang 1999; Davies & Satchell 2003)

TABLE 6.2 – Classification of Respondents

		LOSSES				
		Concave	Linear	Convex	Missing	Total
GAINS	Convex	50	31	77	58	216
	Linear	25	108	43	59	235
	Concave	49	44	143	121	363
	Missing	35	30	49	–	114
	Total	159	213	318	238	928

Finally, for each respondent we calculated the area under the normalized utility function for both gains and losses and we classified a respondent's utility function as concave (convex; linear) when this area was larger than (smaller than; equal to) 1/2 for gains. For losses, a utility function was classified as concave (convex; linear) when the area was smaller than (larger than; equal to) 1/2. As Table 6.2 shows, a vast majority of utility functions exhibited a concave shape for gains combined with a convex shape for losses, again implying diminishing sensitivity as predicted by prospect theory.

6.1.2 Utility Curvature: Parametric Analysis

Although we obtained utilities in a parameter-free way using the trade-off method, we also used parametric methods to analyze the data. For each respondent, we estimated the *power utility function* with parameter ρ for both treatments. Thus, for each respondent and for each separate domain (gains and losses) we estimated:

$$U(x) = x^{\rho} \quad \text{for } \rho > 0 \quad (6.1)$$

$$U(x) = \ln(x) \quad \text{for } \rho = 0 \quad (6.2)$$

$$U(x) = -x^{\rho} \quad \text{for } \rho < 0 \quad (6.3)$$

by minimizing the sum of squared residuals. The power utility function with parameter ρ is currently the most popular parametric family for fitting utility (Wakker 2006) and is also known as the family of constant relative risk aversion (CRRA) because the ratio $-xU''(x)/U'(x)$, i.e. the *index of relative risk aversion*, is constant and equal to $1 - \rho$. We also estimated the *exponential utility function* for both gains and losses which is defined by:

$$U(x) = e^{-\gamma z} - 1 \quad \text{for } \gamma > 0 \quad (6.4)$$

$$U(x) = z \quad \text{for } \gamma = 0 \quad (6.5)$$

$$U(x) = 1 - e^{-\gamma z} \quad \text{for } \gamma < 0 \quad (6.6)$$

where $z = (x - x_0)/(x_6 - x_0)$. This family is also known as the family of constant absolute risk aversion (CARA) because the ratio $-U''(x)/U'(x)$, i.e. the *Pratt-Arrow measure of risk aversion*, is constant and equal to γ.

Finally, we estimated the *expo-power utility function*, introduced by Abdellaoui, Barrios & Wakker (2005), which is a variation of the two-parameter family proposed by Saha (1993) and which is defined by:

$$U(x) = -\exp(-z^{\delta}/\delta) \quad \text{for } \delta \neq 0 \quad (6.7)$$

$$U(x) = -1/z \quad \text{for } \delta = 0 \quad (6.8)$$

where $z = x / x_6$. This particular specification allows for both concave and convex utility functions and a subset of this specification allows for the combination of concave utility, a decreasing Pratt-Arrow measure of risk aversion ($(1 - \delta)/x + x^{\delta-1}$) and an increasing index of relative risk aversion ($1 - \delta + x^{\delta}$), which is a desirable feature because these phenomena are often found empirically (Abdellaoui, Barrios & Wakker 2005). As mentioned in the introduction, the one-to-one relationship between utility curvature and risk attitudes is not valid under nonexpected utility models such as prospect theory and, thus, we avoid the terms index of relative risk aversion and Pratt-Arrow measure of risk aversion in what follows.

Table 6.3 below summarizes the average optimal parameter estimates for the different parametric specifications for each specific treatment, found by minimizing the sum of squared residuals. As can be seen in the table, the average individual parametric estimate of the power coefficient ρ for gains is 0.94 in both the high- and the low-stimulus treatment. This result seems to be consistent with a mean estimate for gains based on parameter-free data of 0.91 found by Abdellaoui, Barrios & Wakker (2005). A two-sided Mann-Whitney test does not reject the null hypothesis that the ranks of the estimated ρ-parameters for gains are equal across the high- and the low-stimulus treatment (z = 0.253, p-value = 0.8005).

TABLE 6.3 – Estimation Results

Treatment	ρ	γ	δ
Gains, high	0.94	0.14	1.36
N = 378	(0.40)	(0.64)	(0.36)
Gains, low	0.94	0.19	1.36
N = 428	(0.41)	(0.86)	(0.38)
Losses, high	0.90	0.17	1.36
N = 326	(0.55)	(0.66)	(0.49)
Losses, low	0.93	0.19	1.39
N = 356	(0.55)	(0.76)	(0.51)

Note: standard deviations in parenthesis.

Analysis of the individual ρ-parameters on the basis of one-sided Wilcoxon signed rank sum tests does indicate that the ρ-coefficients for gains are significantly lower than 1 in both the high- and the low-stimulus treatment (low: z = –5.009, p-value = 0.000; high: z = –4.944, p-value = 0.000), which implies a significant overall degree of diminishing marginal utility for gains.

For losses, the obtained parameter estimates were 0.90 for the high-stimulus treatment and 0.93 for the low stimulus treatment respectively, which is in line with a trimmed mean estimate of 0.901 based on parameter-free data found by Fennema & Van Assen (1999). Again, a two-sided Mann-Whitney test does not reject the null hypothesis that the ranks of the estimated ρ-parameters for losses are equal across the treatments (z = 0.141, p-value = 0.888). In addition, the obtained ρ-coefficients for losses proved to be significantly lower than 1 in both the high and the low-stimulus treatment based on one-sided Wilcoxon signed rank sum tests (low: z = –5.662, p-value = 0.000; high: $z = -5.466$, p-value = 0.000) which suggests diminishing sensitivity, as predicted by prospect theory.

Interestingly, an overall two-sided Wilcoxon rank sum test rejects the null-hypothesis that the ranks of the obtained ρ-coefficients are equal between the gain and the loss domain in favor of the hypothesis that the ρ-coefficients are higher in the gain domain compared to the loss domain ($z = 2.159$, p-value = 0.0308). Thus, we have obtained evidence suggesting that utility is concave for gains but is even more convex for losses. This finding supports the results obtained by Abdellaoui, Bleichrodt & Paraschiv (2004) and Fishburn & Kochenberger (1979, p. 511). The parameter estimates of the other functional forms are all highly correlated and, hence, statistical tests based on the other functional families gives very similar results and will not be reported here.

The large representative dataset allows us to relate the degree of utility curvature with socio-demographic variables. Therefore, we performed a simple regression analysis with the individual estimators as dependent variables and a treatment dummy and several socio-demographic variables as independent variables. The results of this simple regression are reported in the first three columns of Table 6.4. As can be seen in Table 6.4, the estimated coefficient for gains (ρ^+) is significantly lower for females than for males, but a significant negative relation between gender and the estimated coefficient for losses (ρ^-) is not found. This finding is indirectly consistent with the common finding that females are generally more risk averse for gains than males (Barsky 1997; Hartog, Ferrer-i-Carbonell & Jonker 2002; Donkers, Melenberg & van Soest 2000), but contradicts the results of a recent study by Fehr-Duda, de Gennaro & Schubert (2006), who did not find gender differences in the utility functions for both gains and losses based on parametric fittings and using students as subjects.

TABLE 6.4 – Results Regression

Variable	ρ^+	ρ^-	λ
TrLow	-0.002 (0.029)	0.022 0.043	-0.121 (0.158)
Female	-0.065* (0.030)	0.030 (0.042)	0.340* (0.170)
Income /1000	-0.002 (0.013)	-0.004 0.018	-0.02 (0.07)
Age	0.001 (0.001)	0.002 (0.002)	0.002 (0.005)
Education	-0.0004 (0.006)	0.010 (0.008)	-0.062* (0.031)
N	803	678	437

Notes: standard errors in parentheses. * significant at the 5% level.

Because our method to obtain utilities is robust to subjective probability weighting, our results suggest that part of the difference in risk attitudes between males and females is rational: the utility that females obtain from positive monetary outcomes diminishes quicker compared to males, leading to more risk-averse behavior. Interestingly, our results suggest that this the difference in the degree of utility curvature between genders pertains to gains only. Other socio-demographic variables such as income, age, and education all proved to have no significant effect on the degree of utility curvature for both gains and losses.

6.2 Loss Aversion

Unfortunately, a commonly accepted definition of loss aversion does not exist in the literature (Abdellaoui, Bleichrodt & Paraschiv 2005). We define the loss aversion parameter λ as follows:

$$\lambda = \frac{\mathrm{U}(y_0)}{\mathrm{U}(x_0)} \frac{x_0}{y_0} \tag{6.9}$$

This definition best approximates the definitions proposed by Tversky & Kahneman (1992), Wakker & Tversky (1993) and Köbberling & Wakker (2004).[1] Table 6.5 below presents the summary statistics for the different indifference values of outcomes *b*, *c*, and *d*, and the resulting loss aversion parameter under expected utility, i.e. $w(½) = ½$, and prospect theory using the probabilities corresponding to the subjective probability weighting function found by Kahneman & Tversky (1992), being $w^{-}(½) = 0.4540$ and $w^{+}(½) = 0.4206$. The mean value of λ under expected utility, denoted by λ_{EU}, is 1.69 for the high-stimuli treatment and 1.64 for the low stimuli treatment. Under prospect theory with the parameter estimates found by Tversky & Kahneman (1992), the mean value of λ, denoted by λ_{PT}, is equal to 1.79 for the high-stimuli treatment and 1.74 for the low stimuli treatment.

TABLE 6.5 – Mean Results Loss Aversion

	High N = 210	Low N = 229
b	4016 (1604)	386 (150)
c	−1569 (612)	−157 (59.0)
d	1842 (833)	180 (87.6)
λ_{EU}	1.69 (1.10)	1.64 (1.43)
λ_{PT}	1.79 (1.17)	1.74 (1.51)

Note: standard deviations in parenthesis.

This overall decrease in the degree of loss aversion with the size of outcomes is consistent with the findings of Abdellaoui, Bleichrodt & Paraschiv (2004, p. 27) and

[1] Tversky & Kahneman (1992) implicitly used $\lambda = U(-\$1)/U(\$1)$ as an index of loss aversion. Wakker & Tversky (1993) defined loss aversion as $U'(-x) \geq U'(x)$ for all relevant $x > 0$, which could be translated to a loss aversion coefficient of $\lambda = U'(-x)/U'(x)$ for some proper *x* (Abdellaoui, Bleichrodt & Parashiv 2005). Finally, Köbberling & Wakker (2004) proposed defining loss aversion as the ratio between the left and the right derivative of the utility function at the reference point, i.e. $\lambda = U'_{\uparrow}(0)/U'_{\downarrow}(0)$.

Bleichrodt & Pinto (2002), who found a decreasing degree of loss aversion with the size of the outcomes in the health domain. This difference in estimates between the high-stimulus and the low-stimulus treatment is however not statistically significant based on a two-sided Mann-Whitney test ($z = -0.054$, p-value = 0.9569). Thus, generally, our result suggests that on average people weight a particular loss about 1.7 times as heavy as a corresponding gain when making decisions. The obtained λ is lower than the parametric estimate of $\lambda = 2.25$ obtained by Tversky & Kahneman (1992), and the non-parametric estimate of $\lambda = 2.15$, based on the definition of loss aversion proposed by Kahneman & Tversky (1979) and found by Abdellaoui, Bleichrodt & Paraschiv (2005). Our mean estimate of λ is however more consistent with a recent study by Johnson, Gaechter & Herrman (2006) who found an average overall mean λ of 1.85 using a large sample of car buyers.

Interestingly, if we regress the obtained measurement of loss aversion with socio-demographic characteristics, we find that females are significantly more loss averse than males as the final column of Table 6.4 shows. Thus, on average, females weight losses about .34 more heavily than males.[2] In addition, education has a significant negative effect on the degree of loss aversion. These results are consistent with the results obtained by Johnson, Gaechter & Herrman (2006).

7. Discussion

7.1 Discussion of Method

We used direct matching to obtain indifferences between prospects. There is evidence that using direct choice between prospects by using a bisection method (Abdellaoui 2000) or by using a multiple price list (Tversky & Kahneman 1992; Holt & Laury 2002) to obtain indifference between prospects yields more consistent results (Bostic,

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[2] It could be argued that this holds because females and males weight probabilities differently as a recent study by Fehr-Duda, de Gennaro and Schubert (2006) suggests. However, if we use the median obtained parameter estimates from the aforementioned study, being $w^+(½) = 0.468$ and $w^-(½) = 0.5$ for males and $w^+(½) = 0.425$ and $w^-(½) = 0.524$ for females, the average obtained λ becomes 1.60 for males and 2.21 for females. Hence, the gender difference in loss aversion becomes even stronger if we correct for gender differences in subjective probability weighting.

Herrnstein & Luce 1990; Luce 2000). However, using such methods to obtain indifferences is fairly time consuming which was not tractable in this large-scale experiment with the general public.

We used hypothetical incentives in our experiment. There is an extensive debate in experimental methodology about whether real or hypothetical incentives yield better or more reliable data. Camerer & Hogarth (1999) and Hertwig & Ortmann (2001) provide excellent summaries of the ongoing debate. In general, real incentives do seem to reduce data variability (Camerer & Hogarth 1999) and increase risk aversion in choice (Holt & Laury 2002, 2005) and direct matching tasks (Kachelmeier & Shehata 1992). We did not use the incentive compatible Becker-DeGroot-Marschak (BDM) rewarding scheme to implement real incentives for the following reasons. First of all, a large part of the experiment concerned substantial losses and, hence, real incentives could not be used for ethical reasons. Second, the BDM scheme is fairly complex (Braga & Starmer 2005) and the BDM scheme is prone to irrational auction strategies (Plott & Zeiler 2005, p. 537). For example, respondents might report a higher matching outcome thinking it is a clever bargaining strategy or respondents might fail to understand that it is a dominant strategy to report their true matching outcome. Because it is important to minimize the burden on respondents in a large-scale experiment, this was another reason for not implementing real incentives. Third, there is evidence that real incentives do not affect results in relatively simple tasks (Camerer & Hogarth 1999). Fourth and finally, due to practical limitations it is virtually impossible to implement real incentives in a large-scale experiment (Donkers, Melenberg & van Soest 2001; Guiso & Paiella 2003; Dohmen et al 2005), although Harrison, Johnson, McInnes & Rutström (2006) did use real incentives in their impressive study.

7.2 Discussion of the Results

If we compare our findings with other measurements of risk attitudes using large representative datasets, we find that our estimated relative risk coefficient for gains of 0.06 (= 1 – 0.94) is relatively small. For example, Harrison et al (2006) found a mean risk aversion coefficient of 0.67, and Barksy, Juster, Kimball & Shapiro (1997) found a mean risk tolerance (the reciprocal of the constant relative risk coefficient) of 0.24

which translates into a mean relative risk coefficient of 4.16. The smallest degree of relative risk aversion coefficient found by Hartog et al (2002) was 20. Clearly, the difference between these studies and the present study is that all these studies assumed expected utility and hence ignored the important role of probability weighting in the analysis. Hence, our results give empirical support to the conjecture of Rabin (2000b, p.202) being that diminishing marginal utility is an “implausible explanation for appreciable risk aversion, except when the stakes are very large”: utility curvature is less pronounced then suggested by classical utility measurements. Hence, this suggests that the phenomenon probability weighting is valid outside the laboratory, that is, the results support the external validity of subjective probability weighting.

In addition, the results confirm the common finding that females are more risk averse then males. Contrary to classical studies that ascribed this gender difference solely to differences in the degree of utility curvature, we are able to test whether this finding is caused by gender differences in the degree of utility curvature, loss aversion, or subjective probability weighting. The results show that females are more risk averse than males because the utility that females obtain from monetary gains diminishes quicker compared to males, but, more importantly, because females are more loss averse than males.

8. Conclusion

We have obtained parameter-free measurements of the rational (utility) component of risk attitudes using a representative sample from the Dutch population. Such measurements are of crucial importance for policy decisions on important economic problems such equitable taxation and the cost benefit analysis of education, health care, and retirement. The results suggest that utility is concave for gains and convex for losses, implying diminishing sensitivity, as predicted by prospect theory. In addition, our results suggest that classical utility measurements are overly concave, which is possibly caused by the ignoring of probability weighting in these studies. We have also found evidence that utility for gains diminishes quicker for females than for males, which explains the common finding in the literature that females are generally more risk averse than males. Further, we found that the degree of utility curvature is not altered by scaling up monetary outcomes. Finally, we have obtained measurements of loss aversion. The results show that on average the general public weights losses 1.7 times as much as a commensurable gain and that males and higher educated persons are less loss averse.

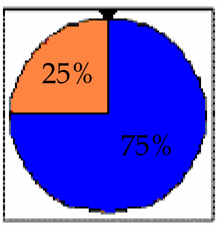
Appendix A. Experimental Instructions

[Instructions are translated from Dutch]

Welcome at this experiment on individual decision making. The experiment is about your risk attitude. Some people like to take risks while other people like to avoid risks. The goal of this experiment is gain additional insight into the risk attitude of people living in the Netherlands. This is very important for both scientists and policymakers. If we get a better understanding of how people react to situations involving risk, policy can be adjusted to take this into account (for example with information provision on insurance and pensions, and advice for saving and investment decisions). Your cooperation at this experiment is thus very important and is highly appreciated.

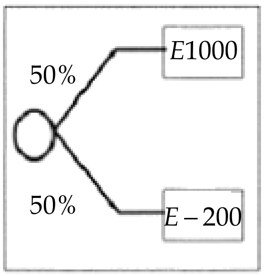
The questions that will be posed to you during this experiment will not be easy. We therefore ask you to read the following explanation attentively. In this experiment, there are no right or wrong answers. It is exclusively about your own preferences. In those we are interested.

Probabilities (expressed in percentages) play an important role in this experiment. Probabilities indicate the likelihood of certain events. For example, you probably have once heard Erwin Krol say that the probability that it will rain tomorrow is equal to 20 percent (20%). He then means, that rain will fall on 20 out of 100 similar days. During this experiment, probabilities will be illustrated using a wheel, as depicted below.



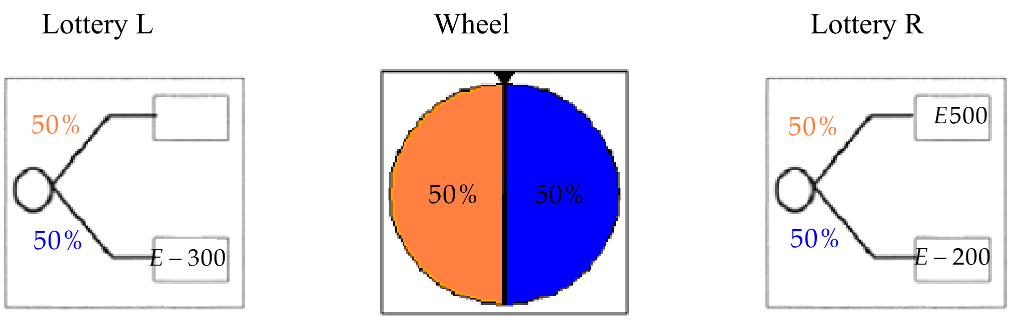
Suppose that the wheel depicted in the picture above is a wheel consisting of 100 equal parts. Possibly you have seen such a wheel before in television shows such as The Wheel of Fortune. Now imagine that 25 out of 100 parts of the wheel are orange and that 75 out of 100 parts are blue. The probability that the black indicator on the top of the wheel points at an orange part after spinning the wheel is equal to 25% in that case. Similarly, the probability that the black indicator points at an blue part after spinning the wheel is equal to 75%, because 75 out of 100 parts of the wheel are blue. The size of the area of a color on the wheel thus determines the probability that the black indicator will end on a part with that color.

Besides probabilities, lotteries play an important role in this experiment. Perhaps you have participated in a lottery such as the National Postal Code Lottery yourself before. In this experiment, lotteries yield monetary prizes with certain probabilities, similar to the National Postal Code Lottery. However, the prizes of the lotteries in this experiment can also be negative. If a lottery yields a negative prize, you should imagine yourself that you will have to pay the about amount of money. In the following explanation we will call a negative prize a loss and a positive prize a profit. During this experiment, lotteries will be presented like the example presented below:



In this case, the lottery yields a profit of 1000 Euro with probability 50%. However, with probability 50%, this lottery yields a loss of 200 Euro. You should image that if you participated in this lottery, you would get 1000 Euro with probability 50%, and with probability 50% you would have to pay 200 Euro.

During this experiment you will see two lotteries, named Lottery L (Left) and Lottery R (right), on the top of each page. Between these lotteries you will see a wheel that serves as an aid to illustrate the probabilities used. You will see an example of the layout of the screen on the next page.



In this example, Lottery R yields a profit of 500 Euro with probability 50% and with probability 50% it yields a loss of 200 Euro. You should imagine that, if we would spin the wheel once and the black indicator would point at the orange part of the wheel, Lottery R would yield a profit of 500 Euro. However, if the black marker would point at the blue part of the wheel, Lottery R would yield a loss of 200 Euro.

Similarly, Lottery L yields a loss of 300 Euro with probability 50%. However, as you can see, the upper prize of Lottery L is missing. During this experiment, we will repeatedly ask you for the upper prize of Lottery L (in Euro) that makes Lottery L and Lottery R equally good or bad for you. Thus, we will ask you for the upper prize of Lottery L for which you value both lotteries equally.

You could imagine that most people prefer Lottery L if the upper prize of Lottery L is very high, say 3000 Euro. However, if this prize is not so high, say 500 Euro, most people would prefer Lottery R. Somewhere between these two prizes there is a “turnover point” for which you value both lotteries equally. For high prizes you will prefer Lottery L and for low prizes you will prefer Lottery R. The turnover point is different for everybody and is determined by your own feeling. To help you a little bit in the choice process, we will report the range of prizes in which the answer of most people lies approximately at each question.

How this works precisely will become clear in the practice question that will start if you click on the CONTINUE button below. If something it not clear to you, you can read the explanation of this experiment again by pressing the BACK button below.

[Practice question]

The practice question is now over. The questions you will encounter during this experiment are very familiar to the practice question. If you click on the BEGIN button below, the experiment will start. If you want to go through the explanation of this experiment again, click on the EXPLANATION button. Good luck.

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