# Essays on behavioral finance

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Ayşe Terzi
Tilburg, March 2017

# Contents

Chapter 1

# Introduction and Summary

This thesis consists of 4 self-contained chapters. The chapters are based on the following research papers:

- *Chapter 2*: A. Terzi, K. Koedijk, C. Noussair and R. Pownall, Reference Point Heterogeneity, *Frontiers in Psychology, 7:1347, September 2016*
- *Chapter 3*: A. Terzi, K. Koedijk, C. Noussair and R. Pownall (2017), Reference Point Formation and Demographics, *Working paper*
- *Chapter 4*: A. Terzi (2017), Ambiguity and Information Aggregation in Asset Markets, *Working paper*
- *Chapter 5*: A. Terzi (2017), Time Discounting under Ambiguity, *Working paper*

In Chapter 2, we report an experiment, in which we investigate which of four potential reference points: (1) a population average payoff level, (2) the announced expected payoff of peers in a similar decision situation, (3) a historical average level of earnings that others have received in the same task, and (4) an announced anticipated individual payoff level, best describes decisions in a decontextualized risky decision making task. It is well-established that, when confronted with a decision to be taken under risk, individuals use reference payoff levels as important inputs. The purpose of the paper is to study which reference points characterize decisions in a setting in which there are several plausible reference levels of payoff. We find heterogeneity among individuals in the reference points they employ. The population average payoff level is the modal reference point, followed by experimenter's stated expectation of a participant's individual earnings, followed in turn by the average earnings of other participants in previous sessions of the same experiment. A sizeable share of individuals show multiple reference points simultaneously. Reference points are not affected by a shock to income.

In Chapter 3, using a large demographically representative sample, we investigate the role of demographics and personality traits on the inclination of using different earnings levels as a reference point in a risky decision making task. Two competing reference points are tested for; an expected earnings level of the individual and the expected average earnings of peers. We conduct an incentivised experiment with a demographically representative sample and show that both candidate reference levels are equally prominent among our sample. We also find that demographics and personality characteristics influence the formation of one's reference payoff level and exhibiting a particular reference payoff level. Lastly, we show that individuals with a higher income level at the outset of the experiment are more likely to form a reference level.

In Chapter 4, we study the effect of ambiguous asset fundamentals on the dissemination of private information in experimental asset markets. Asset prices do not reach fundamental value levels in markets with risk and markets with ambiguity. This effect is amplified in markets with ambiguity than in markets with risk where probabilities about odds are known. There is an asymmetry between states, i.e. asset prices deviate more from fundamentals in periods with high asset values. Therefore, insiders have more potential to exploit their superior information when fundamentals are high. In markets with risky fundamentals we document information mirages. Traders incorrectly infer information from the trading of other market participants when no insiders are present in the market. Ambiguous fundamentals eliminate misguided inference of private information from observed trading prices. When asset fundamentals are ambiguous and there are no insiders, prices are close to the expected value. This result also holds for risky markets.

In Chapter 5, we investigate time preferences under ambiguity. Changing time preferences under risk has been widely documented in various studies with which some discounting phenomena are explained. In a laboratory experiment we elicit discount rates for risky and ambiguous prospects. We find that individual discount rates are lower when subjects face a decision task with ambiguous payoffs compared to a risky decision making task. This difference decreases when stakes are higher. Our results show that, next to risk, time preferences are also affected by the presence of ambiguity. We also find that subjects perceive ambiguous payoffs differently when ambiguity is not explicitly made salient.

Chapter 2

# Reference Point Heterogeneity

## 2.1. Introduction

Reference dependence, an asymmetry in the treatment of payoffs above vs. below a benchmark payoff level, has been a robust finding in both economics and psychology, since it was first proposed and documented by (Kahneman and Tversky, 1979). Reference dependence is a cornerstone of prospect theory, the most influential behavioral model of decision making under risk. Empirical work has suggested that when judging and evaluating a risky lottery, reference payoff levels are critical. A payoff appears to be evaluated based on how it compares to a reference level, with a reference point serving to separate desirable from undesirable outcomes, according to some criterion.

Reference points have been shown to characterize decision making in laboratory research, surveys, and in field data from numerous domains. These domains include household saving, labor market participation, consumer behavior, education, and investment decisions (see e.g. (Camerer, 2004), (Starmer, 2000), (Grinblatt and Han, 2005), (Hardie et al., 1993), (Camerer, 1997)). Experimental studies have documented the effect of reference point formation on the provision of effort ((Abeler et al., 2011)), the pricing of securities (Kahneman, Knetch and Thaler, 1990) and the exchange and valuation of consumer products ((Ericson and Fuster, 2011)). Thus, understanding how payoff levels come to be viewed as reference points is a key step in uncovering the cognitive process that generates decisions taken under risk.

While there is general agreement that reference points are important, little is known about which payoff levels will come to serve as reference points. Typically, in empirical work, the reference points of the decision maker are taken as evident given the decision context. This is reasonable in some settings, though less plausible in others. There are no widely-accepted, general accounts of how a particular payoff level emerges as a reference point.

Furthermore, it is not clear that in a particular given decision context, only one unique reference point is relevant. (Kahneman, 1992) raises the possibility of multiplicity of reference points and characterizes this as an important topic for future study. (Sullivan and Kida, 1995) demonstrate that corporate managers form multiple reference points, specifically the historical profit level, as well as profit and revenue targets. In an experimental study, (Baucells et al., 2011) show that the reference trading price of a financial asset is a combination of multiple potential reference prices.

One class of prominent theories of reference point formation is based on the expectations of the decision maker herself ((Bell, 1985), (Loomes and Sugden, 1986), (Kőszegi and Rabin, 2006), (Kőszegi and Rabin, 2007), (Heidhues and Kőszegi, 2008)). Expectations-based reference points have been used to explain insurance choices ((Barseghyan et al., 2011)), and labor supply decisions ((Farber, 2005), (Farber, 2008), (Crawford and Meng, 2011)). However, the payoffs that peers receive are also relevant. Experimental work has largely supported the models of inequity aversion proposed by (Fehr and Schmidt, 1999) and (Bolton and Ockenfels, 2000), which assume that the average payoff of peers serves as a reference point. Furthermore, expectations can be formed through a history of social interaction, e.g. contracts, experiences, past trends, or the recommendations of others ((Gali, 1994), (Abel, 1990), (Vendrik and Woltjer, 2007), (Linde and Sonnemans, 2012), (Post et al., 2008), (Carmeli and Schaubroeck, 2007), (Davies and Kandel, 1981)). (Kőszegi and Rabin, 2006) point out that there are multiple candidates that can serve as expectation-based reference points. They emphasize that candidate reference points might also coincide. For example, the expectations of an individual about her own and her peers' payoffs may be the same in some instances. The reference point in effect is obviously consequential. For example, Rabin (2006) as well as Koszegi and Rabin (2007), argue that the implications of reference dependence differ depending on the specification of the reference point.

Thus, there are several candidate expectation-based reference levels that appear to be prominent. The purpose of the paper is to study which reference points characterize decisions in a setting in which there are several plausible reference levels of payoff. The question we consider here is whether such heterogeneity in reference points is a consequence of the different contexts in which decisions take place, or arises because individuals differ from each other in their propensity to use different reference points.

We consider which, if any, of four candidate reference points is most likely to emerge in a decontextualized setting. If the reference points that emerge vary greatly by individual, it can only be due to differences arising from the individuals themselves, rather than the task or the setting.

To investigate this, we conduct an experiment which allows a participant to use any or all of four competing reference points in a risky decision making task. The first is the payoff level for the individual anticipated by the experimenter (who may be interpreted as an authority figure or an employer). We abbreviate this reference point as IE, or Individual Expectation. This level, indicated on each subject's instructions, is a natural candidate for a reference point, since it directly ascribes a benchmark for the individual to attain. The second potential reference point is the anticipated average payoffs of peers in the same decision situation (PE, Peer Expectation). This is also indicated in writing on an individual's instructions, with equal prominence as IE. Note that expectations, as used here, do not refer to an individuals own beliefs or aspirations, or to a mathematical expectation of their payoff. The third is the historical average payoff of others in the same position in past sessions (HA, Historical Average), also indicated in the instructions, and the fourth is the average performance of a relatively large population (PA, Population Average), which is known to subjects at the time of recruitment to the session. PE, HA, and PA all represent payoffs of other individuals in the same or similar experiments, but vary in the social distance between the parties they apply to and the individual herself. Because there is no compelling rationale for believing that one reference point would dominate the others, we refrain from advancing hypotheses in advance about which reference points would be most consistent with the data.

In our experimental design, we present three of the reference points simultaneously, in order to conduct a horse race between the alternatives. In some session we presented PA, IE and HA, while in others session the payoff levels displayed were PA, IE and PE. We elicit the certainty equivalents of a large number of lotteries and obtain estimates of individual reference points. The design permits the detection of individuals who use none or one unique reference point, as well as those who employ multiple reference points concurrently. By using one fixed probability for gains and losses of 0.5 throughout the experiment, we attenuate the impact of probability weighting on our results.

It is also important to understand whether reference points change in response to shocks to wealth levels. Some studies have considered this topic. (Arkes et al., 2008) show that subjects are more likely to adapt their reference points to gains in their wealth than to losses. (Chen and Rao, 2002) stress the importance of the order of presentation of two equally-sized gains and losses. They suggest that the first payoff that is presented leads to a more significant adaptation of the reference point than the second. In a financial market setting, (Baucells et al., 2011) show that reference prices for a financial asset are a function of the first and the last trading price. (Masatlioglu and Ok, 2005) model the theory of choice in a static setting where the initial endowment or status quo plays a key role. They show that an agent with reference-dependent preferences prefers to stay at his status quo as long as another option does not dominate it in all dimensions. (Post et al., 2008) find evidence of path dependence in reference levels in choices under risk. One of the treatments in our experiment is complementary to this strand of research, and allows us to study the adjustment of the reference point after a shock to one's income level.

Our results show that if all individuals are classified by the one reference point that they adhere to most closely, the population average (PA) is employed most frequently followed by the individual expectation (IE), and then by the historical average (HA). The social comparison group which is the most distant though also the largest, the population of experimental subjects, appears to be the most relevant. Multiple reference points are observed for a sizable share of individuals, while some others show no evidence of having any reference point. Many individuals use a heuristic, in which they value a lottery at a fixed percentage of its expected value. Finally, we find evidence that reference points do not change after a shock to income has occurred. Overall, these results reveal that there is individual-level heterogeneity in the use of reference points within a fixed decontextualized setting. Thus, reference point choice is driven in part by personal inclination.

The remainder of this paper is organized as follows. Section 2.2 describes the experimental design. In Section 2.3 we discuss the results, and Section 2.4 concludes the paper.

# 2.2. Materials and Methods

## 2.2.1. Conduct of sessions and procedures

A total of 44 sessions were conducted at the Centerlab at Tilburg University in The Netherlands, between November 2013 and June 2014. Subjects were all Bachelor's and Master's students in Economics and Business Administration, and therefore were relatively homogeneous in their training. A total of 163 subjects participated. Fifty-five percent were male. The average age of member of the subject pool is 22. The experiment was executed with the z-Tree computer program ((Fischbacher, 2007)). There was a varying number of participants per session and each subject acted independently of others in this individual decision making experiment. Each session lasted approximately 45 minutes, including the time during which the experimenter read the instructions. The payoffs in the experiment were expressed in terms of an experimental currency, which was converted to a Euro payment to subjects at the end of the sessions. The average earnings per subject were 16 Euros (1 Euro = \$1.30 approximately at the time the experiment was conducted).

A session consists of 60 periods. In each period $t$, subjects are presented with a binary prospect (1/2, $y_t$), which results in outcome $y_t$ with probability .5 and in outcome 0 with probability .5. This prospect is paired with eight different certain payment levels, $x_{jt}, j = 1, ..., 8$ in a price list format, during each of the 60 periods. In each period, each subject must make eight choices. Each choice in period $t$ is between (1/2, $y_t$) and $x_{jt}$. The eight choices are displayed on the subject's computer screen simultaneously. The magnitude of $x_{jt}$ ranges in value from 40 percent to 180 percent of $y_t/2$, the expected value of the prospect. The certain payments appear in ascending order of magnitude in the price list on the computer screen. The main advantage of using a multiple price list format to elicit risk preferences is that it is relatively transparent and easy to understand to subjects and provides simple incentives for truthful revelation. On the other hand, the main disadvantage is potential susceptibility to framing effects as revealed preferences might be sensitive to procedures, subject pools, and the format of the multiple price list table (Andersen et al., 2006). However, their results show that the general finding of risk aversion by subjects is robust. In addition, (Charness et al., 2013) show that the multiple price list format is good in capturing differences in individual risk preferences and that elicited preferences through this method have also been shown to correlate with other individual characteristics and real world risk-taking behavior.[1].

The sixty periods are divided into three 20-period segments. The certain payments $x_{jt}$, as well as the amount that the lottery can pay out $y_t$, increases in constant increments from one period to the next within each segment. The lowest certain amount $x_{jt}$ chosen by the subject over $(.5, y_t)$ in period $t$, serves as our measure of the certainty equivalent for the prospect $(.5, y_t)$ for that subject. The expected value of the prospects and the potential certainty equivalents span the four potential reference points. Thus, the expected values of $(.5, y_t)$, as well as the value of $x_{jt}$, are in some instances in the domain of gains and at other times in the domain of losses relative to each of the four reference points we consider.

At the beginning of a session, the experimenter read the instructions for the experiment aloud. The instructions included key statements about earnings, which were intended to introduce the candidate reference points. The instructions are given in the appendix.

Subjects registered through an online system and at that time were informed of the average earnings in Euros for experiments of similar length conducted at the laboratory, 12 Euros. This is the overall average payoff of subjects participating in an experiment at Centerlab, and we interpret this level as the PA reference point.

At the start of the experiment, each subject was given information about his/her initial cash balance, which was hers to keep. This information remained on her computer screen for the duration of the session. The initial balance was always less than the PA reference level. Therefore, to reach the PA level, the subject had to earn the difference between this level and the initial balance.

The level of the IE reference point was indicated in bold font on the instructions that subjects received at the beginning of the session. It was also displayed on participants' computer screens for the entire session. It was emphasized that this individual expectation was not based on any specific knowledge about the realized final outcome, but

[1]We don't think that switching in the middle is driven by a bias as only 20 percent switch in the middle. Given the overall distribution of choices, there does not seem to be a specific spike about he middle. y, having 20 percent of the switches in the middle does not create a suspicion of a bias.

only about what could be expected beforehand based on the way the experiment was designed.

In sessions 2 - 24, the historical average of earnings of participants from previous sessions of the experiment (the HA reference point) was also emphasized in the instructions and indicated on the computer screens. In sessions 25 - 44, the PE reference point was presented similarly.

We varied the magnitudes of the four reference points in different sessions. The values of each of the four candidate reference points are shown in Table 2.1. The first column of Table 2.1 indicates the session, and each row groups together sessions conducted under identical parameters. The next three columns contain the monetary values, in terms of experimental currency, of each of the reference points. All four reference points are net of the initial endowment, which differs by individual. The PE and IE were adjusted to reflect the different parameters in effect in different sessions, and the HA differed because earnings of individuals in previous sessions varied. Each reference point was always a at a unique value for an individual subject, and the intervals in the table indicate the range of differing unique reference points among subjects in the session indicated. The ranges within each session are indicated in columns 2 and 3. Columns 5 and 6 give the exchange rate between experimental currency and Euros in effect, and whether there was an income shock after period 40. The payoffs were denominated in terms of an experimental currency that was convertible to Euro at the end of the session, at a conversion rate indicated in the second-to-last column of Table 2.1.

At the end of the session, the computer randomly chose one period $t$ and one of the decisions within that period to count as each subject's earnings. Depending on the choice of the subject, the subject either played the lottery and received one of the outcomes of the prospect, 0 or $y_t$, or obtained the certain amount $x_{jt}$ .[2]

### 2.2.2. Treatments

There were two treatments in the experiment, called Baseline and Shift. The last subsection described the Baseline treatment. In the sessions of the Shift treatment, we induced an exogenous shock to income after the 40th period by paying a bonus that was unantic-

[2]Paying only one period removes wealth effects. Starmer and Sugden (1991) have shown that this procedure generates behavior that is similar to that when all periods are paid.

ipated by subjects. The bonus for each individual was equal to 50 percent of the initial endowment. It was emphasized that the shock was independent of the earlier choices participants made. The shock was described to participants by the following announcement made by the experimenter before period 1. “If during the course of the experiment any new information will be shown to you on the screen, please note that this is not due to the decisions you have previously made in the experiment. The computer does not do anything with your decisions until the experiment finishes.”

## 2.3. Results

This section is organized in the following manner. We first informally describe the data from two typical subjects. Section 2.3.1 describes and documents the widespread use of a rule, called the Proportional Discounting Heuristic, employed by 38 percent of our participants. Section 2.3.2 contains our analysis of the prevalence of the four different reference points. Choices revealing inconsistent preferences, e.g. switching multiple time within one period, were discarded for the analysis. The inconsistency rate was 2 percent.

Figures 2.1 and 2.2 illustrate two of the typical decision profiles in our data. The horizontal axis gives the period number, while the vertical axis shows monetary amounts expressed in terms of experimental currency. The points displayed in black are the expected values of the prospects presented in the period indicated. The certainty equivalents elicited from the subject in the period are given by the grey points. The leftmost panel shows the expected values of the prospects and the certainty equivalents elicited in the first twenty periods. The expected values of these prospects include values both above and below a candidate reference level. The figure shows that the certainty equivalents of subject 16, who is depicted in the figure, are greater than the expected value of the prospects, whenever the expected value lies in the domain of losses relative to the PA reference point. Thus, the subject exhibits risk seeking behavior in this domain. When the expected value of the lottery lies above the PA, the observed certainty equivalents are less than the expected value of the prospects, which is consistent with risk averse preferences. Thus, we observe here that the subject changes her attitude towards risk at the PA payoff level.[3]

[3]One measure of consistency of choices that can be applied to the data is whether subjects' certainty

Table 2.1: Parameters used in the experiment

| Session | Expectation of Own Earnings (IE) | Historical Average (HA) | Expectation of Peers (PE) | Population Average (PA) | Exchange Rate | Treatment | |
|---|---|---|---|---|---|---|---|
| 1* | 3500-6500 | 5500-8500 | - | - | 9100-12100 | 1300 | Baseline |
| 2-3 | 4500-7000 | 7000-9500 | 15600 | - | 8600-11100 | 1300 | Baseline |
| 4-5 | 4500-7000 | 7000-9500 | 13500 | - | 8600-11100 | 1300 | Baseline |
| 6-7 | 4500-7000 | 7000-9500 | 12700 | - | 8600-11100 | 1300 | Baseline |
| 8-10 | 8500-10500 | 15500-17000 | 13100 | - | 7500-9500 | 1500 | Baseline |
| 13-24 | 35000-45000 | 45000-60000 | 28500 | - | 33000-43000 | 6500 | Baseline |
| 25-32 | 50000-60000 | 70000-85000 | - | 100000 | 42000-52000 | 8500 | Shift |
| 33-44 | 50000-60000 | 70000-85000 | - | 100000 | 48000-58000 | 9000 | Shift |

* Session 1 is excluded from the analyses due to the absence of a historical peer average. IE is the earnings level that the experimenter indicates to individual that is expected of her. PE is the earnings level that the experimenter indicates that he/she expects others participating in the same session to earn. HA is the average earnings of individuals in all prior sessions. PA is 12 Euros, the average earnings in all experimental studies conducted at the laboratory, minus the initial endowment. All reference points are similarly expressed net of initial endowment and income shock. Within a session different individuals had different initial balances, IE and PA reference points. Thus the indicated values are ranges. However each individual himself had a unique initial balance, IE and PA level.

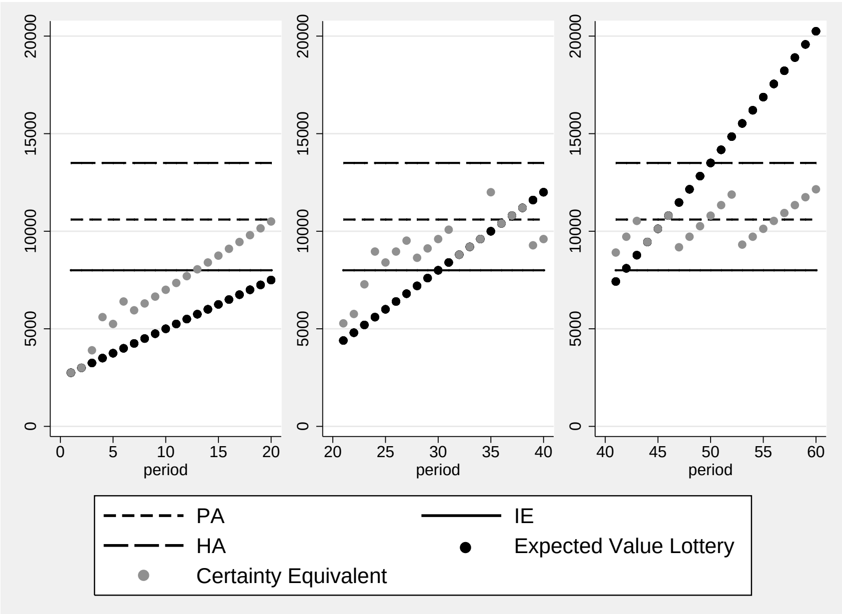


Figure 2.1: Certainty equivalents of subject 16, who participated in session 5

Another example, for subject 13, is presented in Figure 2.2. The certainty equivalents of this subject are all equal to the expected value of the prospect, whenever the expected value of the prospect is less than the Historical Average. This indicates that the individual is risk neutral in the domain of losses, relative to the HA reference point. When the expected value of the prospect is greater than HA, the individual becomes risk averse.

### 2.3.1. The Proportional Discounting Heuristic

A very common decision rule, employed by 38 percent of individuals, is the Proportional Discounting Heuristic. This rule involves setting a certainty equivalent equal to a constant fraction of the expected value of the lottery (or alternatively to a constant fraction of the maximum possible outcome of the lottery), as is depicted in Figure 2.3. The agent depicted in this figure has no reference point in the range spanned by the possible certain payments offered in the experiment (although we cannot rule out the possibility that the agent has a reference point at 0, for example). The certainty equivalent of individuals who proportionally discount is given by:

equivalent increases from one period to the next within each 20-period segment. By this criterion, 14 subjects are consistent for all 60 decisions, 46 have fewer than 5 inconsistencies, and 98 have fewer than 10.

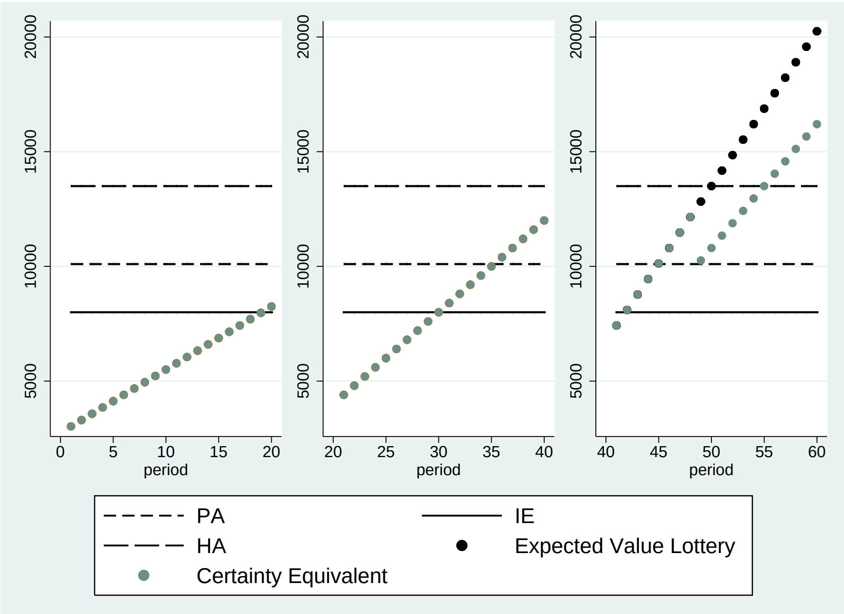


Figure 2.2: Certainty equivalents of subject 13, who participated in session 3

$$\textit{Certainty equivalent} = \alpha * \textit{Expected value of lottery} = \alpha * y_t/2 \tag{2.1}$$

If $\alpha = 1$, the individual is risk neutral. Another heuristic which is observationally equivalent is the rule that $\textit{Certainty equivalent} = \theta * y_t$, where $\theta = \alpha/2$. Our setting is conducive to observing the proportional discounting heuristic, because of the price list format and the sequence of presentation of the choices. This is because if a subject switches from the safe choice $x_{jt}$ to the risky choice $y_t$ at the same row on the table in all periods, his behavior is consistent with the heuristic. Thus, an individual who wishes to apply the heuristic would not find it excessively cognitively demanding to do so. The average $\alpha$ parameter for this subsample is 0.92, equalling 0.96 for male and 0.90 for female subjects.

It is possible, if individuals have reference-dependent preferences, that $\alpha$ can differ between the domains of losses and gains, as proposed by (Iturbe-Ormaetxe et al., 2011), (Iturbe-Ormaetxe Kortajarene et al., 2015). Such a shift in the discount proportion can be seen in the right panel of Figure 2.2. This behavior reveals a discrete change in attitude toward risk above vs. below the reference point. However, in data such as ours, a classification of individuals according to the behavioral rules they employ, such as the Proportional Discounting Heuristic, must allow for some trials to exhibit deviations from

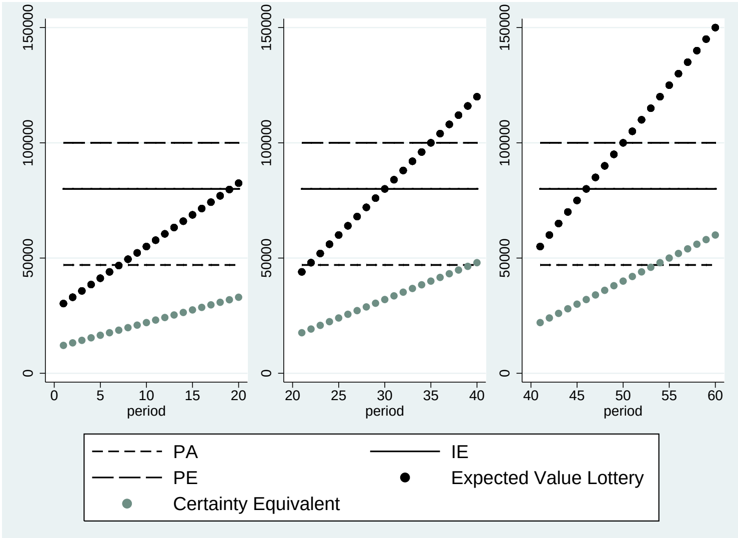


Figure 2.3: Certainty equivalents of subject 100, who participated in session 32 and did not employ a reference point

the exact decision consistent with the heuristic. To classify individuals as users of the Proportional Discounting Heuristic, we calculate the following:

$\Delta$ *proportional valuation* = (*certainty equivalent/expected value lottery*)$_t$ - (*certainty equivalent/expected value lottery*)$_{t-1}$

$$x^*_{jt}/(.5 * y_t) - x^*_{j,t-1}/(.5 * y_{t-1}), x^*_{jt} = min_j\{x_{jt}|x_{jt} \succcurlyeq 0.5 * y_t\} \qquad (2.2)$$

If the agent uses the proportional valuation heuristic, valuing every lottery at the same constant fraction of its expected value, then $\Delta$ *proportional valuation* always equals zero. We classify an individual as a proportional discounter if she exhibits no more than six instances over the 60-period session, in which equation (2) does not equal 0. Figure 2.4 illustrates the stability of the strategy employed on the part of users of the heuristic. The figure is a histogram of ($\Delta$ *proportional valuation*) for the 38 percent of the sample that are proportional discounters. The change in proportional valuation is zero in the great majority of cases.

### 2.3.2. Reference points employed

To identify the reference points subjects are using, we focus on the manner whereby a reference point influences decisions. A reference level is an important input for the preference between receiving a certain amount or playing the gamble. When individuals

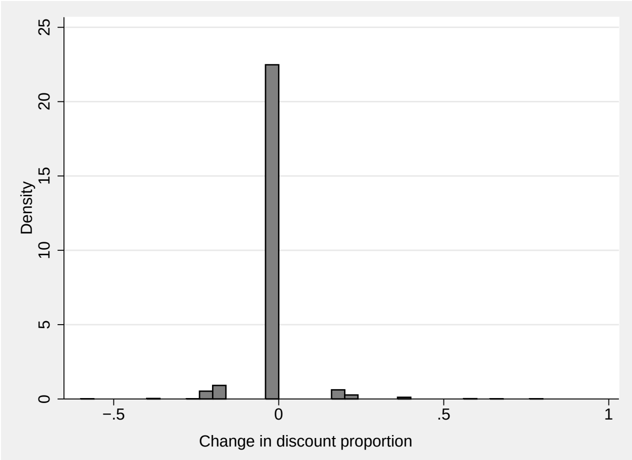


Figure 2.4: Density of changes in discount proportion parameter $\alpha$ between periods $t$ and $t$+1

Table 2.2: Example of choices when the reference level equals 90

| Lottery Outcome | Expected Value | Certain Amount | Choice |
|---|---|---|---|
| .5*240 | 120 | 48 | Lottery |
| .5*240 | 120 | 72 | Lottery |
| .5*240 | 120 | 96 | Certain Amount |
| .5*240 | 120 | 120 | Certain Amount |
| .5*240 | 120 | 144 | Certain Amount |
| .5*240 | 120 | 168 | Certain Amount |
| .5*240 | 120 | 192 | Certain Amount |
| .5*240 | 120 | 216 | Certain Amount |

have to choose between a prospect and a certain amount, this choice will depend on whether the individual can receive his reference level by accepting the certain amount. If not, the individual will prefer playing the lottery and aiming for a favorable outcome in order to reach his reference payoff level. On page 273 of Prospect Theory, (Kahneman and Tversky, 1979) point out that the certainty of receiving one's reference level will always be preferred to playing a prospect with equal expected value, given that an individual is risk averse.

Hypothesis 1: When the certain amount offered exceeds the reference level of an individual, the certain amount will be preferred to playing the gamble.

We test for the presence of a target payoff level by investigating the choice between playing the lottery and receiving the certain payment. Therefore, we expect that a reference point will influence decisions when the certain payment is just above the reference level. In such cases, risk averse agents might forego some expected payoff and choose the certain payment, in order to reach their reference payoff with certainty. Depending on the risk aversion level of the individual, the certain amount will be preferred to gambles with an expected value higher than the reference point. For our analysis this results in the following predictions; if the certain amount offered is less than the reference point of the individual, then the gamble will be preferred. On the other hand, whenever the certain amount is equal or larger than the reference point, the individual will prefer the certain amount offered and will forego some expected value of the gamble. Table 2.2 provides an illustrative example of a hypothetical subject.

To test for this pattern, we model the choice between the certainty equivalent and the lottery of each individual as a function of the value of the certainty equivalent, the expected value of the lottery and a dummy variable indicating whether the safe option $x_{jt}$ exceeds the reference point.

$$Z_{ijt} = \alpha_i + \beta_{1,i}.5 * y_t + \beta_{2,i} x_{jt} + \gamma_k D_k + \epsilon \tag{2.3}$$

where

$$D_k = \begin{cases} 1; \textit{if Certain amount} > \textit{reference point } k \\ 0; \textit{if Certain amount} \leq \textit{reference point } k \end{cases}$$

$Z_{ijt}$ is a binary variable which represents the choice of individual $i$ between the prospect $(.5, y_t)$, and the certain amount on offer, $x_{jt}$[4] , in period $t$. $Z_{ijt}$ takes the value 1 if the individual chooses the prospect, and 0 otherwise. Recall that all reference points are net of the initial endowment. A significant coefficient for the $\gamma_k$ term would indicate the use of reference point $k$, as it reveals a change in the likelihood of choosing the lottery when the certain payment it is paired with exceeds the reference level. In the regression, we control for the expected value of the lottery and the level of the certain payment.

The model is estimated for each individual $i$ and each reference point $k$ separately. An F-test is performed to test for the significance of the restriction $D_k = 0$. If the resulting F-statistic is above the critical level, and the estimated gamma coefficient is negative,

[4]the correlation between $x_{jt}$ and $(.5, y_t)$ ranges between 0.67 and 0.76, which seems to be in an acceptable range

we will say that $k$ is a reference point for the individual. When this test is significant for candidate reference point $k$, we say that the individual is using $k$ as a reference point.[5] Based on the result of this test, we assign an individual to either none, one, or multiple reference points. For each individual, the regression is estimated for each of the potential reference points. Table 2.1 shows the incidence of each possible reference point profile in the sample.

The table shows that the PA is the most common reference point for individuals who used only one reference level, followed by IE and HA. PE does not seem to serve as a reference point. A sizable portion of subjects use multiple reference points, and most of these individuals use PA paired with HA. Lastly, a non-negligible portion of individuals do not appear to employ any of the candidate reference points. Gender differences are not significant, with Fisher exacts tests resulting in p-values of .61 for sessions 2 - 24, and .097 for sessions 25 - 44.

Regressions with the specification in 2.3 on the aggregate pooled data from all individuals classified as using each reference point provide an overall picture of the estimated parameters, and of the strength of the attraction of each reference point. Recall that each reference point, other than PA, is specified as in addition to the initial endowment. The estimates are shown in Tables 2.4 and 2.5. The results show that an increase in the expected value of the lottery increases the probability of choosing the lottery. On the other hand, increasing the value of the certain alternative decreases the probability of choosing the lottery. Each of the reference points is negative and significant in both tables. This indicates that for each of the reference points PA, HA, and IE, a subset of subjects exhibits changes in behavior for payoff levels above vs. below the reference point. When the certain payoff exceeds the reference point, it is more likely to be chosen.

### 2.3.3. Income shock

In the Shift treatment, we study the effect of a shock to an individual's income level and investigate whether it changes the likelihood of choosing a particular reference point. In this treatment, at the end of period 40, subjects experience a change in their wealth. We increase their cash balance by fifty percent of their initial endowment, an amount which differs among subjects. Then, in the last 20 periods of the session, the same set of choices

[5] 8 percent of the subjects exhibited a positive gamma

Table 2.3: Reference point use by subjects

| | Session | All sample | Female | Male* |
|---|---|---|---|---|
| | 2-24 | | | |
| None | | 17.83% | 16.66% | 20.57% |
| Population Average (PA) | | 15.05% | 23.29% | 10.26% |
| Individual Expectation (IE) | | 21.93% | 26.69% | 20.52% |
| Historical Average (HA) | | 8.23% | 6.69% | 7.69% |
| PA and IE | | 2.75% | 3.34% | 2.58% |
| PA and HA | | 34.21% | 23.34% | 38.39% |
| IE and HA | | 0% | 0% | 0% |
| All | | 0% | 0% | 0% |
| | 25-44 | | | |
| None | | 26.61% | 37.42% | 17.79% |
| Population Average (PA) | | 62.27% | 52.53% | 73.38% |
| Individual Expectation (IE) | | 2.23% | 0% | 2.23% |
| Peer Expectation (PE) | | 0% | 0% | 0% |
| PA and IE | | 8.88% | 10.05% | 6.61% |
| PA and PE | | 0% | 0% | 0% |
| IE and PE | | 0% | 0% | 0% |
| All | | 0% | 0% | 0% |

The gender variable contains 5 missing values.

Table 2.4: Estimated effect of reference point in sessions 2 - 24

| | (1) | (2) | (3) |
|---|---|---|---|
| | choice | choice | choice |
| EV Lottery ($.5 * y_t$) | 0.05*** | 0.09*** | 0.06*** |
| | (7.48) | (14.04) | (10.39) |
| $x_{jt}$ | -0.05*** | -0.07*** | -0.06*** |
| | (-9.55) | (-16.09) | (-13.61) |
| $D_{PA}$ | -0.42*** | | |
| | (-16.01) | | |
| $D_{IE}$ | | -0.37*** | |
| | | (-15.69) | |
| $D_{HA}$ | | | -0.35*** |
| | | | (-11.04) |
| Gender | -0.05 | -0.02 | -0.03 |
| | (-1.51) | (-0.54) | (-0.84) |
| Constant | 0.61*** | 0.49*** | 0.64*** |
| | (19.95) | (13.65) | (18.02) |
| Observations | 16720 | 8616 | 12896 |
| $R^2$ | 0.514 | 0.544 | 0.538 |

$t$ statistics in parentheses

Robust standard errors

$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Table 2.5: Estimated effect of reference point in sessions 25-44

| | (1) | (2) |
|---|---|---|
| | choice | choice |
| | (1) | (2) |
| | choice | choice |
| EV Lottery ($.5 * y_t$) | 0.06*** | 0.07*** |
| | (11.63) | (11.00) |
| $x_{jt}$ | -0.05*** | -0.05*** |
| | (-13.85) | (-14.01) |
| $D_{PA}$ | -0.46*** | |
| | (-26.64) | |
| $D_{IE}$ | | -0.33*** |
| | | (-16.01) |
| Gender | 0.02 | -0.01 |
| | (0.81) | (-0.32) |
| Constant | 0.56*** | 0.43*** |
| | (22.18) | (9.91) |
| Observations | 29192 | 3824 |
| $R^2$ | 0.552 | 0.579 |

$t$ statistics in parentheses

Robust standard errors

$^{*}$ $p < 0.1$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$

Table 2.6: Reference points of subjects in Shift treatment before and after the income shock

| | Period 1-20 | Period 41-60 |
|---|---|---|
| None | 36.07% | 41.00% |
| Population Average (PA) | 59.00% | 57.35% |
| Individual Expectation (IE) | 1.64% | 0% |
| Peer Expectation (PE) | 3.29% | 0% |
| PA and IE | 0% | 0% |
| PA and PE | 0% | 0% |
| IE and PE | 0% | 1.64% |
| All | 0% | 0% |

as in the first 20 periods are presented to the subjects again. We consider the effect of the shock on the choices of individuals in the last twenty periods of the experiment and compare these to the choices elicited in the first segment of twenty periods, with respect to which reference points most accurately characterize the decision pattern. Shocking the initial balance level creates a restart and provides a shock to incentives. By doing so, we are able to investigate whether experience affects the employed reference point. This would also indicate if reference points are easily adapted and how sticky they are. We expect that the employed reference points will not show any difference.

We report the proportions of reference points that fit best the decisions of these individuals in Table 2.6. The first column reports a classification of individuals in relation to reference points in periods 1 - 20 in the Shift treatment. The second column contains analogous data from periods 41 - 60. The results show no significant difference in the incidence of the use of each reference point before, compared to after, the shock. A Fisher exact test of the equality of the distribution of reference points between periods 1 - 20 and 41 - 60 results in $p = 0.481$. This may reflect the fact that the shock, like initial income, is treated as a separate source of wealth than the earnings from the experimental task.

## 2.4. Discussion

In this paper, we document heterogeneity among individuals in their personal inclination to use particular reference points. It is known from previous work that the reference point that characterizes a set of data best differs, depending on the setting in which the decision is taking place. However, we show here that the reference point that best fits the decision pattern of an individual also differs by individual, keeping the decision setting constant.

Our results do indicate that when individuals use a single reference point, the population average payoff level is the most frequently employed. This is followed by the anticipated payoff level indicated for the individual, and in turn by the average that comparable individuals have earned in past similar tasks. No participant used the earnings of peers in the same session as a reference point. The results are similar for men and women and we observe no significant gender differences in the use of reference points.

We also observe that a sizable fraction of individuals employs multiple reference points. The most common combinations of reference points are the population average with the historical average, and the population average with the individual expectation. It is striking to us that PA is such a strong attractor, in light of the fact that the social distance between an individual and the population average is arguably the greatest among all of the reference points that we have considered. The experimental design we have does not allow us to isolate the precise reason that PA is more prominent than the others. However, it does have the feature that it, along with HA, is historical and therefore certain, while IE and PE are anticipated future payoff levels. Furthermore, PA is always constant and known to be the same for all individuals, while the three other reference points can vary among individuals. Perhaps a reference payoff is more compelling when it is common knowledge that it is the same for everyone.

We also find that a considerable share of subjects tend to proportionally discount their certainty equivalent by a constant percentage of the expected payoff of the risky lottery. Some of these individuals also discount by a different fraction, depending on whether payoffs are above or below one or more of the reference points. The widespread use of the Proportional Discounting Heuristic seems intuitive as a behavioral rule, because it is simple to calculate and apply, though to our knowledge its use has not been documented in previous research.

Thus, our experiment illustrates two types of heterogeneity in how individuals perceive risky decision making tasks. The first is that some individuals differ in whether or not they apply a simple heuristic, proportional discounting, to value the lottery, while others adopt more complex or inconsistent valuation methods. The second is that the reference level of earnings that individuals use is idiosyncratic, with some individuals targeting one or more from among a set of prominent reference points, while others do not.

While most studies have focused on estimating the mean and median loss aversion parameters of a particular sample, a growing number of studies have documented heterogeneity in the loss aversion level of individuals ((Fehr and Goette, 2007), (Gächter et al., 2007), (Von Gaudecker et al., 2011)). Building on this, other studies have investigated factors affecting the degree of individual loss aversion and have found that demographic characteristics play an important role ((Hjorth and Fosgerau, 2009), (Payne et al., 2015)). Our results complement this line of research by providing evidence that individuals exhibit different reference points in a similar task. This is important because loss aversion only has meaning relative to a reference point.

## 2.5. Appendix

### 2.5.1. Instructions

This experiment is about decision making. The experiment consists of 60 periods. Each period you will be presented a sequence of choices. The currency used in the experiment is francs. The amounts which are presented to you are all in terms of francs. You will be paid in cash in Euro's according to your realized earnings by bank transfer the very same day. The conversion rate is 8500 francs to 1 Euro. You start with an initial amount of      francs. The experimenter expects you to earn      francs. The average amount earned in this experiment by other participants is      francs.

Each presented choice consists of two options. One option is a sure amount of francs, the other option is a lottery with two possible outcomes. Each outcome of the lottery has a probability of one half to be realized. This is true for all lotteries presented to you throughout the experiment. In each period you have to indicate for each choice whether you prefer the lottery of that period, as shown at the upper part of the screen, or the certain amount of money. At the end of the experiment, the computer will randomly select one period and one choice of that period to determine your earnings of this experiment. Each period has equal probability of being selected by the computer and each choice has equal probability of being be selected by the computer. Then, depending on how you decided in the period and choice that counts, you either receive the sure payment or the lottery.

You will start with an initial balance of      francs. After you have finished the experiment by indicating your choices, the outcome of the round which will be played for real will be added to your initial earnings and this will become your final earning of the experiment.

The experimenter expects that you will earn      francs in this session. However, please notice that the expectations of the experimenter are not driven by any knowledge about the outcome.

THE NEXT PARAGRAPH WAS ONLY INCLUDED IN SESSIONS 1 - 24

Average earnings in previous sessions of this experiment have been      francs. However, conditions may be changed from session to session and average earnings may be considerably different in this session from previous ones.

THE NEXT PARAGRAPH WAS ONLY INCLUDED IN SESSIONS 25 - 44

The experimenter expects that other participants in this session will earn on average francs. However, conditions may be changed from session to session and average earnings may be considerably different in this session from previous ones.

Chapter 3

# Reference Point Formation and Demographics

## 3.1. Introduction

We differ in evaluating the outcome of a risky choice around a reference point, which we use as a benchmark to evaluate our well-being. Reference dependent preferences, which was pioneered by the work of (Kahneman and Tversky, 1979), have been widely documented in decision making under risk. Experimental studies have demonstrated the effect of reference point formation on effort provision ((Abeler et al., 2011)), the pricing of securities ((Kahneman et al., 1991)) and consumer products ((Ericson and Fuster, 2011)). Studies conducted with field data have presented evidence of reference point formation in household saving, labor market participation, consumer behavior, education, and investment decisions (e.g. (Camerer, 2004), (Starmer, 2000), (Grinblatt and Han, 2005), (Hardie et al., 1993), (Camerer et al., 1997)).

The selection of a pay-off level as a reference point by an individual remains an open question to be explored. In this study we investigate the exhibition of employing a particular reference point when subjects face a risky decision making task in a decontextualized setting among a demographically representative Dutch sample. We conducted an experiment designed to investigate which of two competing reference points dominates in a risky decision making task among a representative Dutch sample. The two reference points are: (1) an earnings level that is expected by the experimenter for the individual, (2) the expected average earnings level of peers. In the experiment, we elicit certainty equivalents of a number of lotteries and obtain estimates of individual reference points. The design permits detection of individuals who use no or one unique reference point. Eliciting reference points in a decontextualized environment also eliminates potential heterogeneity of using different sources for a peer group reference level depending on the domain of risky choice as different peer groups could be used as ones social comparison level depending on the domain of choice under risk. As is shown in previous studies, the social comparison benchmark could be in lateral, downward or upward direction. A downward comparison level leads to a more favorable perception about one's own well-being and induces positive emotions (e.g., (Wood et al., 1985). On the contrary, an upward social comparison level serves as a driver of improvement strivings ((Collins, 1996), (Helgeson and Mickelson, 1995) and (Taylor et al., 1995)). We find heterogeneity in the reference point employed and correlation between certain demographic and personality traits and the employment of a reference point. The individual expected payoff level and the expected payoff level of peers are equally likely to be employed as a reference level. Our results also show that the income level of an individual does not play a role in the exhibiting the use of a payoff level as reference point. Our results are highly relation to the study by (Baillon et al., 2015) who investigate a similar question. Their study also shows that reference points are heterogeneous among individuals. However, their study exploits different payoff levels which can serve as potential reference points. With our experimental design we also rule out overlapping reference points since we test for potential reference points which are all driven by expectations.

Reference points might differ depending on the domain of risky choice and have been typically given as exogenous or defined for a particular situation in previous studies(Kőszegi and Rabin, 2006). In providing evidence of reference point formation, the reference points of the decision maker are in general taken as evident given the decision context. Expectation bases payoff levels are shown to be successful in serving as a reference point. The expectation level of the individual have been modeled as a reference point in prominent theories of reference point formation ((Bell, 1985), (Loomes and Sugden, 1986), (Kőszegi and Rabin, 2006), (Kőszegi and Rabin, 2007), (Heidhues and Kőszegi, 2008)). In empirical work, expectations-based reference points have been able to explain insurance choices ((Barseghyan et al., 2011)), and labor supply decisions ((Farber, 2005), (Farber, 2008), (Crawford and Meng, 2011)). Another strong candidate which serves as a reference level is the social peer group payoff level ((Gali, 1994), (Abel, 1990), (Vendrik and Woltjer, 2007), (Linde and Sonnemans, 2012)). Experimental studies have mainly supported the models of inequity aversion proposed by (Fehr and Schmidt, 1999) and (Bolton and Ockenfels, 2000), in which the average payoff of peers serve as a reference point. In a decontextualized risky lottery choice experiment, we test for the inclination to choose between the individual expectation level and or an expected payoff level of a social peer group and investigate which demographic and personality traits determine the choice of reference point.

Our study imposes different initial income levels to subjects without informing subjects about any differences in the status quo level between subjects. This allows us to test for the effect of an initial endowment on the likelihood of targeting a reference point and if targeted, the employment of a reference point based on peer group expectation or a more internally driven expectation about one's own earnings. (Ordóñez et al., 2000) focuses on differences in status quo levels between the individual and a peer group in a hypothetical choice experiment and find that differences between the status quo level of the individual and the peer group had significant impact on their pay satisfaction. They also show that this effect is asymmetric i.a. having a higher status quo level than the peer group produced weaker positive satisfaction. (Masatlioglu and Ok, 2005) model the theory of choice in a static setting where the initial endowment or status quo plays a key role. They show that the reference dependent agent prefers to stay at his status quo as long as another option is not better in all dimensions from his current endowment. Terzi et al (2015) demonstrates that changing income levels do not change the reference point employed by the subject at the outset of the experiment. By varying the initial endowment provided to subjects without informing them about the initial endowment of peers, we can analyze any income effect on reference point employment where the initial endowment to peers cannot affect the employed reference point as in (Ordóñez et al., 2000). Our study finds that the a higher initial endowment level at the outset of the experiment has a positive effect on exhibiting the use of a reference point but does not affect the use of a particular payoff level as a reference point.

We also explore the correlates of personality traits and the employment of reference points. Previous literature has documented several relationships between personality dimensions and economic outcomes or preferences, including the accumulation of wealth ((DeNeve and Cooper, 1998), (Steel et al., 2008), (Ameriks et al., 2007)), wages ((Mueller and Plug, 2006)), and risk preferences ((Borghans et al., 2009)). Various studies tried to identify economic mechanisms associated with the big five personality traits ((Denissen and Penke, 2008), (DeYoung et al., 2010), (Van Egeren, 2009)). They documented that extraversion relates to responsiveness to reward and incentives. Neuroticism mainly concerns the feeling of threat and punishment. Agreeableness is reflected in the affinity toward altruism and cooperation. Conscientiousness results in controlled behavior and goals and openness originates in the high utilization and absorption of information. Our results show that personality traits seem to have a considerable effect on the formation and the selection of a particular reference point. We find that individuals who score high on neuroticism are less likely to form a reference point. Additionally, we find strong correlation between extraversion and the selection of a payoff level as a reference point. Extravert individuals are more inclined to use the peer group average as their reference levels.

The remainder of this paper is organized as follows. Section 3.2 will describe the subject pool and experimental design. In Section 3.3 we will discuss the results on the prevalence of reference point employment among the sample and the correlation between demographic and personality traits and Section 3.4 will conclude.

## 3.2. Experiment

### 3.2.1. Design

The experiment consisted of 20 periods, in which subjects are presented with a binary prospect (1/2, $y_t$) which results in outcome $y_t$ with probability .5 and in outcome 0 with probability .5. The probability p is set to equal to 0.5 throughout the experiment. This feature allows us to sidestep the issue of probability weighting. This prospect is paired with eight different certain payment levels, $x_{jt}, j = 1, ..., 8$ in a price list format. In each period, each subject is asked to make eight choices. Each choice in period $t$ is between (1/2, $y_t$) and $x_{jt}$. The eight choices are displayed on the subject's computer screen simultaneously. The magnitude of $x_{jt}$ ranges in value from 20 percent to 140 percent of $y_t/2$, the expected value of the prospect. The certain payments appear in ascending order of magnitude in the price list on the computer screen. Participants face 8 questions per period which adds up to a total of 160 questions. The main advantage of using a multiple price list format to elicit risk preferences is that it is relatively transparent and easy to understand to subjects and provides simple incentives for truthful revelation. On the other hand, the main disadvantage is potential susceptibility to framing effects as revealed preferences might be sensitive to procedures, subject pools, and the format of the multiple price list table (Andersen et al., 2006). However, their results show that the general finding of risk aversion by subjects is robust. In addition, (Charness et al., 2013) show that the multiple price list format is good in capturing differences in individual risk preferences and that elicited preferences through this method have also been shown to correlate with other individual characteristics and real world risk-taking behavior.[6].

The binary prospect $(.5, y_t)$ increases in constant increments from one period to the next. The lowest certain amount $x_{jt}$ chosen by the subject over $(.5, y_t)$ in period $t$, serves as our measure of the certainty equivalent for the prospect $(.5, y_t)$ for that subject. The expected value of the prospects and the potential certainty equivalents span the two potential reference points. Thus, the expected values of $(.5, y_t)$, as well as the value of $x_{jt}$, are in some instances in the domain of gains and at other times in the domain of losses relative to each of the two reference points we consider. When the expected value of the prospect lies below a particular reference points, this domain will form the loss domain that belongs to this particular reference point. The expected value of the subsequently presented prospects will exceed the value of the reference point. Thus, these prospects lie in the mixed domain of gains and losses.

At the start of the experiment each subject was given information about their initial balance, which was a lump sum payment. Next to this information, we provided subjects with the expectation of the experimenter about the individual earnings of the subject (IE) and the expectation of the experimenter about the earnings of peers participating at the same experiment (PE). While both potential reference levels rely on an expectation level, the orientation of the payoff levels differ. The first statement focused on an internal expectation level, whereas the latter concerned a peer group expectation. By having both potential reference points depending on an expectation level of the experimenter we can rule out overlapping expectation based reference levels. I.e. an individual could extrapolate that the peer group expected earning is a good indicator of his/her own expected earning. If this is the case, expected individual earnings and expected peer

[6]We don't think that switching in the middle is driven by a bias as only 15 percent switch in the middle. Given the overall distribution of choices, there does not seem to be a specific spike about he middle. y, having 15 percent of the switches in the middle does not create a suspicion of a bias.

Table 3.1: Parameters used in the experiment

| Subsample | Initial Balance | IE | PE | Shock |
|---|---|---|---|---|
| 1 | 20 | 30 | 40 | Yes |
| 2 | 20 | 40 | 30 | No |
| 3 | 30 | 20 | 40 | No |
| 4 | 30 | 40 | 20 | No |
| 5 | 40 | 30 | 20 | No |
| 6 | 40 | 20 | 30 | No |

earnings would coincide, see (Kőszegi and Rabin, 2006). The two candidate reference points were also available on the subjects' screen during the course of the experiment.

We varied the magnitudes of the initial balance level and the two reference points in different treatments. These values are shown in Table 3.1. The first column of Table 3.1 indicates the subsample, and each row groups together the sample conducted under identical parameters. Column 2 shows the initial balance level which is provided to subjects and could be considered as a minimum income level. Columns 2-4 contain the monetary values of each of the candidate reference points.

The levels of the potential reference points varied for different subsamples in order to identify the employment of a reference point while controlling for the relative position w.r.t the other reference point. The parameters for each subsample are shown in Table 3.1. Payoffs are denominated in Euros. To identify the selection of a certain reference point regardless of its' relative position, we vary the magnitude of the reference points by assigning different payoff levels to the potential reference points for different subsamples. This design allows the hypotheses that individuals have a tendency to use the highest or lowest from the set of plausible reference points to be evaluated. We also varied the level of initial balance in order to investigate the effect of different lump sum payments at the outset of a decision task on the employment of reference points.

### 3.2.2. Hypothesis

To identify the reference points subjects are using, we focus on the manner whereby a reference point influences decisions. A reference level is an important input for the preference between receiving a certain amount or playing the gamble. When individuals have to choose between a prospect and a certain amount, this choice will depend on whether the individual can receive his reference level by accepting the certain amount. If not, the individual will prefer playing the lottery and aiming for a favorable outcome in order to reach his reference payoff level. On page 273 of Prospect Theory, (Kahneman and Tversky, 1979) point out that the certainty of receiving one's reference level will always be preferred to playing a prospect with equal expected value, given that an individual is risk averse.

Hypothesis 1: When the certain amount offered exceeds the reference level of an individual, the certain amount will be preferred to playing the gamble.

We test for the presence of a target payoff level by investigating the choice between playing the lottery and receiving the certain payment. Therefore, we expect that a reference point will influence decisions when the certain payment is just above the reference level. In such cases, risk averse agents might forego some expected payoff and choose the certain payment, in order to reach their reference payoff with certainty. Depending on the risk aversion level of the individual, the certain amount will be preferred to gambles with an expected value higher than the reference point. For our analysis this results in the following predictions; if the certain amount offered is less than the reference point of the individual, then the gamble will be preferred. On the other hand, whenever the certain amount is equal or larger than the reference point, the individual will prefer the certain amount offered and will forego some expected value of the gamble.

### 3.2.3. Procedure

The computerized experiment was conducted online using the Center Panel managed by CentERdata. We randomly invited a subsample from this panel to participate at our experiment. In total, 1056 individuals who were member of the Center Panel participated in the experiment. The experiment was incentivised, next to a yearly payment which members receive for participating regularly in surveys. A large number of demographic variables of these respondents are available which were collected at earlier surveys. Next to the socio-economic background variables, we matched our sample with personality data on the Big Five Personality Factors. This data of the individuals is collected by the Dutch Household Panel, which is also managed by CentERdata. Both panels contain a representative sample of the Dutch population in terms of observable background characteristics of respondents. Our matched dataset includes a large number of demographic variables and data on the big five personality traits. 10 percent of the revealed preferences was inconsistent and therefore deleted for the analysis. We found correlation between the number of inconsistent revealed preferences and demographic factors. Namely, men were less likely to provide inconsistent preferences. The age of an individuals seemed to correlate with inconsistent preferences with a correlation coefficient of .27. Income and eduction level correlated negatively with the number of inconsistent answers with a correlation of -.05 and -.11 respectively.

The experiment had real incentives as 10 percent of the respondents were paid out their earnings of the online experiment. The earnings of the participants were randomly determined by the computer at the end of the experiment. The computer chose one period and one of the decisions of that period to determine each subject's earnings. Depending on the choice of the subject, the subject either played the lottery and received the outcome of the prospect or received the certain amount.[7]

## 3.3. Results

To elicit the reference point subjects employed in the experiment, we focus on the preference of subjects between playing the lottery or accepting the certain amount offered. We test for the presence of a target payoff level by investigating the choice between playing the lottery and receiving the certain payment. We expect that the presence of a reference point will influence decisions when the certain payment is just above the reference level. In such cases, depending on the loss aversion of the agent he might forego some expected payoff and choose the certain payment, in order to reach his reference payoff. To test for this pattern, we model the choice between the certainty equivalent and the lottery of each individual as a function of the value of the certainty equivalent, the expected value of the lottery and a dummy variable indicating whether the safe option $x_{jt}$ exceeds the reference point.

$$Z_{ijt} = \alpha_i + \beta_{1,i}.5 * y_t + \beta_{2,i} x_{jt} + \gamma_k D_k + \epsilon \tag{3.1}$$

[7]This procedure removes wealth effects. Starmer and Sugden (1991) have shown that this procedure is successful in revealing the monetary preferences of subjects under uncertainty.

where

$$D_k = \begin{cases} 1; \textit{if Certain amount} > \textit{reference point } k \\ 0; \textit{if Certain amount} \leq \textit{reference point } k \end{cases}$$

$Z_{ijt}$ is a binary variable which represents the choice of individual $i$ between the prospect $(.5, y_t)$, and the certain amount on offer, $x_{jt}$, in period $t$. $Z_{ijt}$ takes the value 1 if the individual chooses the prospect, and 0 otherwise. A negative and significant coefficient for the $\gamma_k$ term would indicate the use of reference point $k$[8][9], as it reveals a change in the likelihood of choosing the lottery when the certain payment it is paired with exceeds the reference level. In the regression, we control for the expected value of the lottery and the level of the certain payment.

The model is estimated for each individual $i$ and each reference point $k$ separately. When the estimated gamma coefficient is negative and significant for candidate reference point $k$, while also having the highest absolute value among the two estimated gamma terms we will say that $k$ is a reference point for the individual. Based on the result of this test, we assign an individual to either the reference level based on the individual expected payoff level or the expected payoff level of peers. We have chosen for a conservative approach in which we did not allow for the probability of multiple reference points. Given that we have 20 observations per subject, we focused on the best fitting potential reference point. Table 3.2 shows the incidence of each possible reference point profile in the sample.

Both candidate reference points seem to be equally prominent in serving as a reference level. We find a small difference in the utilization of reference points when we split the sample according to gender. However, inspecting differences in reference point formation between younger and older individuals shows that older individuals are more likely to use the social comparison level. However this difference is not significant given a P-value of .831 of a KS-test.

Regressions with the specification in 3.1 on the aggregate pooled data from all individuals classified as using no reference point, IE or PE provide an overall picture of

[8] the correlation between $x_{jt}$ and $D_k$ lies between 0.59 an 0.72 depending on the reference level, which is within acceptable range

[9] 11 percent of the individuals have exhibited a positive $\gamma_k$

Table 3.2: Reference points employed by subjects

| | No reference point | Individual Expectation (IE) | Peer Expectation (PE) |
|---|---|---|---|
| Full sample | 61.72% | 19.71% | 18.57% |
| Female subsample | 59.87% | 19.53% | 20.60% |
| Male subsample | 63.45% | 19.88% | 16.67% |
| Age<40 | 60.12% | 23.68% | 16.20% |
| Age=>40 | 62.52% | 17.73% | 19.75% |

the estimated parameters, and of the strength of the attraction of each reference point. The estimates are shown in Table 3.3. The results show that an increase in the expected value of the lottery increases the probability of choosing the lottery. On the other hand, increasing the value of the certain alternative decreases the probability of choosing the lottery. Each of the reference points is negative and significant in both tables. This indicates that for each of the reference points a subset of subjects exhibits changes in behavior for payoff levels above vs. below the reference point. When the certain payoff exceeds the reference point, it is more likely to be chosen.

### 3.3.1. Reference point formation, demographics and personality

#### Personality variables

As a measure of personality, we use the Big Five Factor model. This is the most widely used concept to describe personality condensed in big five traits, namely conscientiousness (C), openness (O), agreeableness (A), neuroticism (N) and extraversion (E). Most personality dimensions can be extracted from this model. These factors can be described as follows: Conscientiousness focuses on self-discipline, planning, organized behavior, and carefulness, whereas the opposite includes laziness, less goal oriented and unreliable. Openness encloses high fantasy levels, intellectual curiosity, openness to new experiences versus being rational, conventional and practical. Agreeable individuals are soft-hearted, trusting, cooperative and helpful versus ruthless, disagreeable and aggressive. Neuroticism includes anxiety, insecurity, nervousness, depressions and moodiness as opposed to emotional stability, being calm and self-confident. Extraversion encompasses

Table 3.3: Properties of preferences

| | (NO) | (IE) | (PE) |
|---|---|---|---|
| EV Lottery ($.5 * y_t$) | 0.0087*** | 0.0095*** | 0.0098*** |
| | (20.92) | (15.38) | (15.30) |
| $x_{jt}$ | -0.0148*** | -0.0102*** | -0.0107*** |
| | (-29.92) | (-13.29) | (-12.34) |
| $D_{IE}$ | | -0.5485*** | |
| | | (-27.08) | |
| $D_{PE}$ | | | -0.5181*** |
| | | | (-24.68) |
| Constant | 1.6373*** | 1.6883*** | 1.6722*** |
| | (119.38) | (90.57) | (91.99) |
| Observations | 95984 | 30198 | 28371 |
| $R^2$ | 0.153 | 0.529 | 0.506 |

$C$olumn 1 includes data on individuals who did not form a reference level. Column 2 and 3 include observations of subject who have based their reference levels on IE or PE respectively. t statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors clustered at subject level.

sociability and assertiveness, attention versus reservation and timidity. Using the first principal component extracted by applying a Principal Component analysis, we condense the self-reported responses of individuals to various questions related to each personality trait to one score level per personality trait. This principal component is used to determine the score of an individual on a specific personality trait.

After determining the incidence of reference point formation and selection of a particular payoff level as a reference point, we investigate demographic factors and personality traits containing explanatory power in using a payoff level as a reference point. We investigate the correlates between the inclination of exhibiting a reference level and the demographic and personality traits of an individual using a Logit estimation. Our dependent variable equals 1 if the individual has employed a reference point in the decision making task, and 0 otherwise. Several demographic variables $W_d, d = Income, Age, Gender$ and the big five personality factors $P_b, b = A, O, E, N, C$ are considered. We also include a variable on self esteem levels. Lastly, we include a variable on the initial balance to test for wealth effects. Table 3.4 presents the results of this specification. We observe that neurotic individuals are less likely to employ a reference level. An increase in the income level of an individual increases the likelihood that an individual employs a reference level. This shows that initial endowment levels do change incentives and have an effect on targeting a payoff level as a reference point. This effect might be driven by optimisim created by a higher initial wealth level.

$$Z = \alpha + \beta_w w_i + \beta_{P_b} P_b i + \beta_{IB} IB_i + \epsilon \tag{3.2}$$

Furthermore, we asses the employment of a particular payoff level as a reference point. We restrict our sample to individuals who have employed a reference level. Using a similar approach as specification 3.1 we investigate the inclination of exhibiting a particular reference level. Our dependent variable takes on a value of 0 if the individual has employed the individual expectation level as a reference point, and 1 if the individual has employed the expected average peer earnings as a reference level. Table 3.5 shows the results of the specification explaining the employment of a particular reference level as a function of demographic factors and personality traits. We observe that older individuals are more likely to employ a peer group average earning level as their reference point. The initial balance level given at the start of the experiment does not contain explanatory

Table 3.4: Demographics, personality and the formation of a reference point

| | (1) | (2) | (3) |
|---|---|---|---|
| EUR 1151 - EUR 1800 | 0.109 | 0.119 | 0.009 |
| | (0.35) | (0.37) | (0.03) |
| EUR 1801 - EUR 2600 | 0.332 | 0.349 | 0.324 |
| | (1.15) | (1.18) | (1.10) |
| More than EUR 2600 | 0.294 | 0.304 | 0.221 |
| | (1.09) | (1.08) | (0.78) |
| Female | 0.170 | 0.212 | 0.246 |
| | (1.26) | (1.43) | (1.56) |
| Age | -0.004 | -0.004 | -0.006 |
| | (-0.89) | (-0.94) | (-1.29) |
| O | | 0.009 | 0.014 |
| | | (0.22) | (0.33) |
| A | | 0.011 | 0.009 |
| | | (0.27) | (0.23) |
| E | | 0.002 | 0.016 |
| | | (0.05) | (0.42) |
| C | | -0.029 | -0.024 |
| | | (-0.73) | (-0.57) |
| N | | -0.072* | -0.077* |
| | | (-1.73) | (-1.73) |
| Self esteem | | -0.032 | -0.046 |
| | | (-0.85) | (-1.19) |
| Initial Balance | | | 0.086*** |
| | | | (9.97) |
| Constant | -0.636* | -0.647* | -3.128*** |
| | (-1.81) | (-1.75) | (-6.80) |
| Observations | 963 | 954 | 954 |
| $R^2$ | | | |

$t$ statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ Robust standard errors

power in exhibiting a particular payoff level as a reference point.

Given that our sample includes many elderly aged individuals, we conduct the same analysis for the working population only by restricting our sample to individuals up to the age of 65. Table 3.6 demonstrates the results on employing a reference level for this subsample. We observe that neuroticism remains a significant personality trait in explaining the exhibition of a reference level. Another important personality trait seems to be self esteem. Individuals with a low self esteem are more likely to employ a reference payoff level. The results on the employing a particular reference level are demonstrated in Table 3.7. Also for this subsample, age has a significant effect on the inclination to employ a particular reference payoff level. Older individuals are more inclined to employ the peer group expectation as a reference point. The results also demonstrate that extravert individuals are more likely to base their reference payoff level on the expected peer group average. Typically, these individuals are prone to seek stimulation from others It appears that when facing a decision making task under risk, extravert individuals use the expected payoff of peers as an important input on which they base their reference level. Lastly, we observe that individuals who score high on openness employ less often peer group comparison as their reference level.

Finally we estimated the risk aversion coefficients of the subjects. The estimated risk aversion coefficients lie between 0.1 and 0.55. We find that risk aversion is negatively correlated to education level with a correlation coefficient equal to -.07 and income with -.01, while being positively correlated to age with a correlation coefficient of .03. In our sample men tend to exhibit slightly higher risk aversion levels.

## 3.4. Conclusion

In this study, we have measured the inclination of employing a particular reference levels in a demographically representative sample of the Dutch population. We find that reference points are partly determined by individual heterogeneity in the inclination to employ a specific reference level. An individual expected earnings levels and the expected earnings of peers have equal power in serving as a reference level. We find that older individuals are more inclined to base their reference payoff level on a peer group expected

Table 3.5: Demographics, personality and the selection of a payoff level as a reference point

| | (1) | (2) | (3) |
|---|---|---|---|
| EUR 1151 - EUR 1800 | 0.245 | 0.155 | 0.153 |
| | (0.47) | (0.29) | (0.29) |
| EUR 1801 - EUR 2600 | 0.144 | 0.071 | 0.078 |
| | (0.31) | (0.15) | (0.16) |
| More than EUR 2600 | 0.079 | -0.019 | -0.016 |
| | (0.18) | (-0.04) | (-0.03) |
| Female | 0.254 | 0.295 | 0.293 |
| | (1.17) | (1.24) | (1.23) |
| Age | 0.017** | 0.017** | 0.017** |
| | (2.45) | (2.38) | (2.37) |
| O | | -0.027 | -0.027 |
| | | (-0.42) | (-0.43) |
| A | | -0.011 | -0.011 |
| | | (-0.18) | (-0.18) |
| E | | 0.074 | 0.072 |
| | | (1.28) | (1.24) |
| C | | 0.013 | 0.012 |
| | | (0.20) | (0.19) |
| N | | -0.009 | -0.005 |
| | | (-0.13) | (-0.08) |
| Self esteem | | -0.013 | -0.012 |
| | | (-0.24) | (-0.22) |
| Initial Balance | | | -0.006 |
| | | | (-0.40) |
| Constant | -1.104* | -1.053* | -0.847 |
| | (-1.94) | (-1.73) | (-1.07) |
| Observations | 368 | 365 | 365 |
| $R^2$ | | | |

$t$ statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ Robust standard errors

Table 3.6: Demographics, personality and the formation of a reference point of the working age population

| | (1) | (2) | (3) |
|---|---|---|---|
| EUR 1151 - EUR 1800 | 0.055 | 0.079 | -0.030 |
| | (0.16) | (0.22) | (-0.08) |
| EUR 1801 - EUR 2600 | 0.307 | 0.332 | 0.333 |
| | (0.97) | (1.01) | (1.01) |
| More than EUR 2600 | 0.189 | 0.205 | 0.137 |
| | (0.64) | (0.66) | (0.44) |
| Female | 0.145 | 0.193 | 0.221 |
| | (0.99) | (1.20) | (1.28) |
| Age | -0.003 | -0.004 | -0.006 |
| | (-0.45) | (-0.62) | (-0.88) |
| O | | -0.020 | -0.013 |
| | | (-0.46) | (-0.28) |
| A | | 0.022 | 0.026 |
| | | (0.52) | (0.58) |
| E | | 0.010 | 0.023 |
| | | (0.27) | (0.56) |
| C | | -0.054 | -0.056 |
| | | (-1.26) | (-1.22) |
| N | | -0.109** | -0.119** |
| | | (-2.35) | (-2.44) |
| Self esteem | | -0.055 | -0.075* |
| | | (-1.37) | (-1.77) |
| Initial Balance | | | 0.090*** |
| | | | (9.35) |
| Constant | -0.588 | -0.578 | -3.207*** |
| | (-1.47) | (-1.35) | (-6.06) |
| Observations | 789 | 782 | 782 |
| $R^2$ | | | |

$t$ statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ Robust standard errors

Table 3.7: Demographics, personality and the selection of a payoff level as a reference point of the working population

| | (1) | (2) | (3) |
|---|---|---|---|
| EUR 1151 - EUR 1800 | 0.505 | 0.410 | 0.408 |
| | (0.89) | (0.70) | (0.70) |
| EUR 1801 - EUR 2600 | 0.253 | 0.182 | 0.185 |
| | (0.50) | (0.34) | (0.34) |
| More than EUR 2600 | 0.149 | 0.041 | 0.041 |
| | (0.32) | (0.08) | (0.08) |
| Female | 0.260 | 0.370 | 0.369 |
| | (1.11) | (1.42) | (1.42) |
| Age | 0.022** | 0.023** | 0.023** |
| | (2.28) | (2.28) | (2.28) |
| O | | -0.050 | -0.050 |
| | | (-0.69) | (-0.69) |
| A | | -0.052 | -0.052 |
| | | (-0.82) | (-0.82) |
| E | | 0.132** | 0.131** |
| | | (2.02) | (2.00) |
| C | | 0.075 | 0.075 |
| | | (1.03) | (1.03) |
| N | | -0.044 | -0.041 |
| | | (-0.59) | (-0.54) |
| Self esteem | | -0.033 | -0.032 |
| | | (-0.53) | (-0.51) |
| Initial Balance | | | -0.004 |
| | | | (-0.23) |
| Constant | -1.387** | -1.393* | -1.260 |
| | (-2.10) | (-1.94) | (-1.39) |
| Observations | 308 | 305 | 305 |
| $R^2$ | | | |

$t$ statistics in parentheses * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$ Robust standard errors

average payoff level. We also find that exhibiting a reference level could be related to the personality trait neuroticism. Neurotic individuals are less likely to employ a reference point. It could point towards the fear and anxiety of forming an expected payoff level when facing a risky decision making task. In addition, we find that extraversion is positively related to employing a peer group average as a reference level. We cannot find any gender differences.

We also find that lump sum payments has an effect on the employment of a reference payoff level. Higher lump sum payment levels lead to higher likelihood of forming a reference level. On the other hand, lump sum payments do not seem to have an effect on the employment of a particular payoff level as a reference point. Individuals with a higher lump sum payment at the outset are more likely to target a particular payoff level when facing risky choices.

Hence, we find a clear relationship between the demographic profile and personality traits of economic agent and their inclination of employing a (particular) reference level. As reference levels are crucial in the perception of risk and thereby affects the attitude of the individual towards risk, possessing information about these characteristics will enable us to predict the personal inclination of using reference points in evaluating an outcome of a risky choice.

## 3.5. Appendix

### 3.5.1. Instructions

Inleiding

Belangrijke informatie

**U start de vragenlijst met 20 Euro.**

**Wij verwachten dat u bovenop het bedrag waar u mee start 30 Euro zult verdienen met het invullen van deze vragenlijst.**

**Wij verwachten dat anderen die deze vragenlijst invullen gemiddeld 40 Euro zullen verdienen.**

In deze studie vragen wij u om een spel te spelen of voor een zeker bedrag te kiezen. Op ieder scherm ziet u een spel. Dit is gekoppeld aan acht zekere bedragen. Het spel heeft twee mogelijke uitslagen. Beide uitslagen hebben 50% kans om uitgekeerd te worden. Wij vragen u om op ieder scherm acht keer te kiezen tussen het spelen van het spel en het zekere bedrag. U krijgt in totaal 20 schermen te zien.

Verdiensten

Uw verdiensten worden op de volgende manier bepaald: Nadat u de vragenlijst hebt ingevuld en opgestuurd zal er een willekeurig scherm geselecteerd worden door de computer. Daarna selecteert de computer één keuze van dat scherm. Als u in die keuze heeft aangegeven om het spel te spelen, dan wordt het spel gespeeld en ontvangt u de uitslag van dat spel van het geselecteerde scherm. Als u in de keuze heeft gekozen voor het zekere bedrag dan ontvangt u het zekere bedrag. Het bedrag in munten dat u met de vragenlijst hebt verdiend wordt opgeteld bij het bedrag waar u mee bent begonnen. Dit is dan het eindbedrag in Euro's wat u zult verdienen met deze vragenlijst. Dit eindbedrag wordt op uw rekening gestort. Eén op de tien respondenten zal zijn/haar verdiensten uitgekeerd krijgen. De computer bepaalt dit. Uw antwoorden hebben hier geen invloed op.

| |
|---|
| U bent gestart met **20 Euro** |
| Wij verwachten dat u bovenop het bedrag waar u mee start **40 Euro** zult verdienen met het invullen van deze vragenlijst |
| Wij verwachten dat anderen die meedoen gemiddeld **30 Euro** zullen verdienen |

| |
|---|
| SPEL |
| 50% kans op het verdienen van 0 Euro |
| 50% kans op het verdienen van 20 Euro |

Geef aub uw voorkeur aan in de onderstaande gevallen:

| | | | |
|---|---|---|---|
| Ik ontvang het zekere bedrag van 2 Euro | ☐ | Ik speel het spel | ☐ |
| Ik ontvang het zekere bedrag van 4 Euro | ☐ | Ik speel het spel | ☐ |
| Ik ontvang het zekere bedrag van 6 Euro | ☐ | Ik speel het spel | ☐ |
| Ik ontvang het zekere bedrag van 8 Euro | ☐ | Ik speel het spel | ☐ |
| Ik ontvang het zekere bedrag van 10 Euro | ☐ | Ik speel het spel | ☐ |
| Ik ontvang het zekere bedrag van 12 Euro | ☐ | Ik speel het spel | ☐ |
| Ik ontvang het zekere bedrag van 14 Euro | ☐ | Ik speel het spel | ☐ |

Chapter 4

# Ambiguity and Information Aggregation in Asset Markets

## 4.1. Introduction

The informational efficiency of asset prices has been a subject of intense discussion, where the transmission and the value of private information in asset markets is of crucial importance. [10] A number of studies have demonstrated that ambiguity influences information aggregation. Ambiguity in asset markets might originate from beliefs, fundamentals or information and manifests itself into i.a. prices, volatility and portfolio holdings through information processing (Leippold et al. (2008), Ju and Miao (2012), Epstein and Schneider (2008) and Ui et al. (2011)).

In this study, we investigate the role of ambiguous beliefs (information) about fundamentals on the informational efficiency of prices and the occurrence of information mirages in experimental asset markets with private information. When asset market participants falsely infer information from the trading activity of other investors, it might cause trading and price movements which is not based on any signal about the fundamentals of the asset. This type of trading is driven by non-existent information and therefore the price path which results from these errors is called an information mirage Camerer and Weigelt (1991). We design two similar double auction asset markets, risky and ambiguous, played sequentially where in some periods a number of traders possess private information and thereby act as insiders. In markets with risk state probabilities, and payoffs at those states, are known to subjects. In markets with ambiguity, subjects received either (1) a range of probabilities for the two possible states or (2) a range of

[10]Observational and experimental studies present mixed evidence. Some studies show that insiders can exploit their private information (Jaffe (1974), Jeng et al. (2003)), whereas others claim that prices support fully revealing rational expectations (Copeland and Friedman (1992), Plott and Sunder (1982)).

possible payoff levels at each of the two possible states. This setting allows us to identify the role of ambiguity in fundamentals on the informational efficiency of prices when there are insiders. Prices deviate most from fundamentals in periods with insiders and high asset values. This finding holds for both risky and ambiguous markets, although being more pronounced for markets with ambiguous fundamentals. Prices are closer to fundamentals in periods with insiders and low asset values in both markets. However, convergence is slightly less in markets with ambiguity. Our findings suggest that good news is perceived with more caution by uninformed traders under ambiguity which keeps prices suppressed and lower than fundamentals. This gives more room for the exploitation of private information of insiders. Furthermore, we find for both markets that prices converge to fundamental levels in periods when there are no insiders. On the other hand, information mirages occur when no market participant has private information and asset payoffs are risky but not ambiguous, whereas the presence of ambiguity deters individuals from inferring private information from observed trading prices. This drives prices more to their expected values and eliminates information mirages to a large extent.

The preferences of an ambiguity averse investor are mostly depicted by "maxmin" expected utility. Facing uncertainty, individuals maximize their expected utility by evaluating an uncertain outcome by restricting their set of priors to the range of worst case beliefs (Gilboa and Schmeidler (1989)). This leads to discounting the expected payoff of an ambiguous asset and affects the absorption of new information in the market. An extensive literature has focused on the informational efficiency of prices in the presence of ambiguity. In their study, Epstein and Schneider (2008) and Leippold et al. (2008) rely on a framework in which individuals do not apply Bayesian updating when processing imprecise information and illustrate that reaction to incomplete public information is asymmetric, i.e. reaction to negative news by investors is stronger as bad news is overweighted. A related paper by Illeditsch (2011) shows that risk and ambiguity aversion deters individuals from processing ambiguous public information and hence missing extra information about the asset distribution which may lead to excess volatility of asset prices. Similarly, Caskey (2009) emphasizes that the information aggregation function of prices is impeded due to discarding valuable information by investors with ambiguity averse preferences. A related line of research investigated information transmission in asset markets with private information of unknown quality which is treated as ambiguous by the investor. Early work of Radner (1979) demonstrates that rational expectations equilibria are generically fully revealing given that information is unambiguous. Ozsoylev and Werner (2011) focus on the process of private information transmission when informed agents receive private information which resolves the ambiguity. They show that the rational expectations equilibrium is partially revealing. In a similar setting, Condie and Ganguli (2011) provide a robust example of partially revealing equilibria in the Radner (1979) model with ambiguous information. (Mele and Sangiorgi, 2015) focus on the effects of ambiguity on information acquisition and the value of fundamental information. They illustrate that uncertainty intensifies the need of acquiring private information in order to interpret the informational content of prices. Tallon (1998) shows redundant private information acquisition by uninformed ambiguity averse traders while prices fully reveal information. Our study contributes to this literature by testing the information aggregation properties of an asset market when the beliefs about the payoff of an asset is ambiguous and there is precise private information in the market. We demonstrate that individuals under-react to good news, which can be explained by the max-min expected utility of ambiguity averse investors who typically lack confidence in their information.

A different channel through which asymmetric information affects market prices might be "self-generated" trading which leads to information mirages. Various studies suggest that asset prices are too volatile to be explained by rational reaction to news (Camerer et al. (1989), LeRoy and Porter (1981)). Under and overreaction to news have been explained with cognitive biases in previous studies. Barberis et al. (1998) show that traders excessively extrapolate trends in asset prices which is caused by the representativeness bias. The presence of information mirages in experimental asset markets have been recorded by experimental studies where the prices of the traded asset were risky rather than ambiguous (Camerer and Weigelt (1991) and (Sunder, 1992)). These studies are evidence of self-generated trading in asset markets which might in part explain excess volatility of stock and bond prices. We find that the occurrence of information mirages drastically decreases in experimental asset markets under ambiguity. This effect might be driven by discarding the informational content of prices and therefore trading at expected value levels.

A large theoretical literature shows far-reaching implications of ambiguity in asset markets. This line of research attempts to explain among others, the equity premium puzzle where ambiguity averse investors require a premium for the presence of ambiguity in asset performance(Epstein and Wang (1994), Cagetti et al. (2002), Maenhout (2004) and Epstein and Schneider (2008)). Easley and O'Hara (2009) shows that heterogeneous attitudes towards ambiguity will determine the number of investors who take the aggregate risk in the market, thereby determining the risk premium in markets. Furthermore, varying risk premia Gagliardini et al. (2009) and the equity home bias have been explained with the presence of ambiguity aversion of investors in asset markets (Epstein and Miao (2003) and Myung (2009)). Illeditsch (2011) shows that the hedging demand of investors against ambiguity causes portfolio inertia for risky portfolios, while Ozsoylev and Werner (2011) shows that for some range of private information and asset supply uninformed traders choose not to trade which comes with lower market depth. Other studies on the implications of ambiguity on market liquidity demonstrate that market microstructure plays a role in limited participation under ambiguity (Easley and O'Hara (2009)). In our experimental asset market we find that the mean quantity of submitted quotes is lower in markets with ambiguity, however the mean quantity traded is similar in both riksy and ambiguous markets.

Our study is also related to a bourgeoning literature exploring the role of ambiguity in asset experimental asset markets. Bossaerts et al. (2010) and Ahn et al. (2014) show that ambiguity aversion affects portfolio choice. While Sarin and Weber (1993) find lower prices for ambiguous assets compared to risky assets, Füllbrunn et al. (2013) find no effect of ambiguity on trading prices and trading volume. Furthermore, Corgnet et al. (2013) investigate the effect of public information revelation on asset prices in an experimental setting where the dividend distribution of the asset is ambiguous. They find no differences in prices, volatility and trading volume when compared to an asset market with a risky dividend structure. We document significant lower prices for ambiguous assets, which is mainly driven by periods with high asset values, while finding no difference in volume and volatility as well. In our study we analyse the effect of ambiguous fundamentals on the dissemination of private information and find that ambiguity affects the absorption of private information into asset prices.

The remainder of this paper proceeds as follows. In section 4.2 the experimental design is explained. Section 4.3 presents and discusses the results. Section 4.4 concludes.

## 4.2. Experiment

Sessions were conducted in the CentERlab of Tilburg University in the fall of 2015. A total of 144 subjects have participated in the experiment. Subjects were mainly Economics and Business Administration students. Each session consisted of 12 students. An instruction sheet was read out loud by the experimenter at the beginning of the session during which students were allowed to ask questions. The experiment was designed and conducted using z-Tree by Fischbacher (2007). Trading was executed in experimental francs which were converted to Euros at the end of the session. Sessions lasted on average 2 hours and the average payment was 21 Euros.

### 4.2.1. Design

The experiment was designed as a double auction market and consisted of 2 sequential markets of 15 trading periods, which lasted 180 seconds each. At the beginning of each period subjects were endowed with 5000 francs of working capital and 5 units of stocks. The value of the stocks traded in the experiment was solely determined by the dividend payment at the end of each period. There were two possible states, a good state with high dividend (H) and a bad state with low dividend (L). At the end of each period, each stock paid out dividend and expired with no expiration value after the market closed. Given a certain state, the stock paid out different values of dividend to subjects, where some subjects received a higher dividend than others. However, all subjects received lower dividend in the bad state and higher in the good state. This heterogeneity promotes the exchange of assets and was used in previous studies (e.g. Plott and Sunder (1982)). Subjects did not know the dividend level of other participants. The working capital and profits earned from buying and selling stocks and receiving dividend for the end holdings were accumulated in a separate account and could not be used for trading purposes during the course of the experiment.[11]. At the end of the experiment the accumulated francs in this account were converted to Euros, which were the final earnings of the subject. Shorting assets and borrowing money was not allowed. As we had one-period assets, holdings in assets and cash are not carried over from one period to the next, but

[11]By not allowing for accumulating earnings to be included in an account used for purchases, we eliminate potential house-money effects

subjects received an initial endowment each trading period. Subjects did not observe any historical prices or trading volumes.

In fifty percent of the trading periods insiders were present in the market who knew the dividend of that period. Which subject, if any, possessed information about the state of the economy was each period randomly determined by the computer per period. Each subject only knew about his/her own information set and did not know which subjects, if any, were insiders. Inside information was equally distributed among individuals with different dividend payoff levels at the beginning of each period. With the disclosure of the dividend per asset after trading ended, the state of the economy was revealed.

### 4.2.2. Treatments

A session consisted of two sequential asset markets of 15 periods, which only differed in the dividend payoff uncertainty being either risky or ambiguous. In the market with risk subjects were provided with the probabilities of the two states occurring and the dividend payoffs in those states, which results in uncertainty with known probabilities. Two different treatments were conducted to vary the source of ambiguity in asset fundamentals and test for different forms of ambiguity. In the first treatment the dividend payoffs at both states were known, while the probabilities of both states occurring was given within a range and therefore unknown or ambiguous to the subject. In the second treatment, the probabilities of both states were known. However, given a particular state the dividend payoff in that state was drawn from a range of values. Having no information about the probabilities or values which might be realized, all potential outcomes should be perceived as equally possible. Since subjects are not given a distribution of probabilities and we have vague uncertainty, the expected value under ambiguity is not well-defined. The market with risky dividend payoff was similar in both treatments. This setup results in two markets with identical expected asset values being solely different in the uncertainty levels of payoffs and enables us to identify the effect of ambiguity on information dissemination.

### 4.2.3. Predicted prices and asset holdings

In analyzing the observed behavior of prices and trading in both asset markets, we will use three different utility models. These models mainly differ in belief formation

Table 4.1: Parameters used in the experiment

| Treatment / Session | Ex. rate | Market | Dividend prob. [H, L] | Type A [H, L] | Type B [H, L] | Type C [H, L] |
|---|---|---|---|---|---|---|
| | | | Dividend | | | |
| 1 /1-7 | 9500 | Ambiguity | [0-100, 0-100] | [350,100] | [275,125] | [225,150] |
| 1 /1-7 | 9500 | Risk | [50,50] | [350,100] | [275,125] | [225,150] |
| 2 / 8-12 | 9500 | Ambiguity | [50, 50] | [600-690,0-90] | [460-550, 100-190] | [350-440, 200-290] |
| 2 / 8-12 | 9500 | Risk | [50,50] | [645,45] | [505,145] | [405,245] |

and updating. The rational expectations (RE) model assumes that beliefs are formed endogenously and individuals update their beliefs in standard Bayesian fashion. This model hypothesizes that all individuals know the information present in the market, regardless of the fact to have received the information directly or via prices, and trade accordingly. On the other hand, the prior information (PI) and maxmin model (MM) assume that beliefs are exogeneously formed and in equilibrium individuals trade based on their own prior set of information. Both models divert in the emergence of their expected utility, where the maxmin model assumes individuals restrict their beliefs on the minimum of probable outcomes, whereas the prior information model assumes traders are maximizing their expected utility. We use these three competing models as asset prices and asset holdings might converge towards the fully revealing rational expectations equilibrium or alternatively to the predicted prices based on prior beliefs, where we distinguish between the effect of ambiguity using the maxmin model which is typically used when modeling utility under ambiguity.

Asset prices and asset allocations in our experiment can follow three patterns depending on the absorption of private information in the market according to the predictions of the three competing models. While all models predict Walrasian prices which equal the highest expected value of dividend for the RE and PI models and the maximum of the minimum dividend an individual can earn in a market for the maxmin model. All models (partially) predict different prices and buyers of the asset as the highest expected value depends on the information aggregation in the market, while the maxmin model differs in valuing an asset based on the minimum probable outcome. According to the RE equilibrium public and private information about the state of nature is fully revealed in price data as individual complement their own information set with the private information of others retrieved from price signals. Given a certain state, the equilibrium price is equal to the highest dividend which a trader can earn in the market across all traders. These traders will also hold all assets, independent of being the informed trader. On the contrary, the prior information hypothesis assumes that individuals trade on their own set of prior information. Therefore, prices will equal the highest dividend an informed trader can earn, when this value is larger than the expected value of the asset, or the expected value of the asset and the informed trader will hold all assets. Traders with a similar dividend payment but who are not informed will value the asset according the expected value unconditional on the state and therefore will sell the asset to the informed trader. The maxmin model predicts that for both states, prices will converge to the maximum of the minimum of all traders in a market. The predicted prices and asset holdings by the three models are summarized in Table 4.2 and Table 4.3 and should be analyzed together to reach a conclusion. Not finding evidence for the RE model could point towards behavior in which individuals only use their prior beliefs and do not trade based on signals observed from market prices. To be able to identify the effect of ambiguity on belief formation, we have to focus on the predictions of the MM and PI model in periods with insiders and low dividend values and in periods with no private information. Previous studies have mainly found support for the RE model ((Plott and Sunder, 1982), Plott and Sunder (1988), Friedman et al. (1984)).

To our knowledge, there is no theoretical or experimental study which could provide price predictions for an experimental asset market under ambiguous asset fundamentals with perfectly informed insiders and uninformed subjects. However, given the many existing theoretical studies on the effects of ambiguity on information dissemination, we expect that it is less likely that asset prices will include private information and reach a RE equilibrium level under ambiguity Ozsoylev and Werner (2011)Illeditsch (2011). This effect is expected to be more pronounced in periods with private information and high asset fundamentals as individuals will be less likely to incorporate positive information about asset prices Epstein and Schneider (2008) and Leippold et al. (2008). Therefore the observed prices will be lower than in markets with risk.

Hypothesis 1: In periods with private information asset prices will be closer to expected value levels given no information dissemination in markets with ambiguity than in markets with risk.

Hypothesis 2: In periods with private information asset prices will deviate further away from RE levels in market with ambiguity when asset fundamental values are high than when asset fundamental values are low.

During periods in which no inside information is given to any subject mirages might occur. This happens when subjects believe that there are insiders present in the market and try to obtain signals from submitted quotes and prices. This results in prices and asset allocations which are driven towards the predictions of the RE hypothesis with private information about the dividend payoff. We define that trading is driven by

Table 4.2: Predicted prices according to the PI, RE and Maxmin model

| | | | Insider information | | |
|---|---|---|---|---|---|
| Treatment | Session | | No Information | Good State | Bad State |
| 1 | 1-7 | RE | 225 | 350* | 150 |
| | | PI | 225 | 350 | 225 |
| | | Maxmin | 150 | 350 | 150 |
| 2 | 8-12 | RE | 345 | Dividend Type A | Dividend Type C |
| | | PI | 345 | Dividend Type A | 345 |
| | | Maxmin | Dividend Type C | Dividend Type A | Dividend Type C |

Buying asset at the high value requires 14000 Experimental Francs which is less than the amount of cash subjects of Type A are endowed with at the beginning of each period.

Table 4.3: Predicted allocations according to the PI, RE and Maxmin model

| | | Insider information | |
|---|---|---|---|
| | No Information | Good State | Bad State |
| RE | Type A | Type A | Type C |
| PI | Type A | Type $A_{informed}$ | Type $A_{uninformed}$ |
| Maxmin | Type C | Type $A_{informed}$ | Type C |

an information mirage if prices are closer to the predicted prices of RE instead of the expected dividend values in periods without information. Next to this condition, at least two thirds of the assets should be collected by traders which are predicted to hold the asset according to the RE hypothesis.

## 4.3. Results

This section is organized in the following manner. Section 4.3.1 describes the data. Section 4.3.2 contains our analysis of information dissemination. Section 4.3.3 reports the profitability of private information. Lastly we investigate the occurrence of information mirages in both markets.

### 4.3.1. Trading activity

Table 4.4 presents some descriptive statistics of the trading activity. The mean and median transaction prices are remarkably lower in the market with ambiguity and these differences are significant at 1 percent. This difference is even larger in periods when there are traders with information. Furthermore, we observe that trading volume relatively similar in risky and ambiguous markets in both treatments. In particular, periods with ambiguity show to have a lower transaction volume. Lastly, the mean submitted quote quantity is lower in markets with ambiguity which points to a thin market.

### 4.3.2. Prices and information dissemination

To measure the convergence of prices to the predicted prices by all models, we calculate the deviation of the traded prices from the predicted prices by the RE, maxmin and PI model. The results are demonstrated in Table 4.11 in the Appendix which shows the Mean Squared Error of the traded prices in the last half of each period. We focus on the last 90 seconds as we expect a convergence of prices towards an equilibrium price after some trading activity. To investigate the aggregation of information in the market, we focus on periods with private information when the dividend is low and on periods when there is no private information. As in these periods, the models predict divergent prices. Prices are closer to their predicted levels by the RE and PI model in periods without insiders and close to RE/maxmin levels in periods with insiders when the dividend is low. This is true for both markets. However, in markets with ambiguity prices deviate more from the predicted price in periods with insiders with high dividend. In this period, all models predict the same price which is equal to the fundamental value of the asset. This higher deviation is mainly caused by transaction prices which are lower than the predicted values. In periods with ambiguity this 'discount' is higher and prices are suppressed more heavily. The deviations of prices shows that prices reach their RE level in periods without private information and in periods with insider information when the asset value is low. However, when asset fundamental values are high and there are insiders in the market, prices are lower than fundamentals, and this effect is strengthened in markets with ambiguity.

Table 4.5 reports the row averages of the MSE for the aggregate sample of prices in periods with information where we narrow the analysis to the last minute of trading. Prices deviate more from predicted prices in periods with ambiguity. Furthermore, given the predictions of both models, the difference in MSE between the good and the bad state is more pronounced in the market with ambiguity. Inspecting this finding more closely

Table 4.4: Descriptive statistics

| | All | Ambiguity | Risk | Informed | Informed Ambiguity | Informed Risk | Uninformed | Uninformed Ambiguity | Uninformed Risk |
|---|---|---|---|---|---|---|---|---|---|
| Treatment 1 | | | | | | | | | |
| Mean transaction price | 235,23 | 231,03 | 239,73 | 239,61 | 233,11 | 246,01 | 228,62 | 228,21 | 229,12 |
| Med. transaction price | 225 | 210 | 245 | 240 | 210 | 250 | 210 | 200 | 220 |
| Standard deviation | 69,92 | 76,20 | 62,18 | 70,24 | 74,30 | 65,38 | 68,91 | 78,65 | 54,74 |
| Trading volume | 10876 | 5629 | 5247 | 6544 | 3247 | 3297 | 4332 | 2382 | 1950 |
| Mean Time Interval Quote | 0,49 | 0,59 | 0,42 | 0,49 | 0,59 | 0,41 | 0,50 | 0,59 | 0,42 |
| Mean Quantity submitted | 357 | 301 | 418 | 359 | 299 | 419 | 355 | 303 | 416 |
| Mean Time Interval Trade | 3,12 | 3,14 | 3,11 | 2,99 | 3,04 | 2,93 | 3,34 | 3,27 | 3,40 |
| Mean Quantity Traded | 54 | 54 | 54 | 56 | 56 | 56 | 50 | 51 | 49 |
| Treatment 2 | | | | | | | | | |
| Mean transaction price | 374,49 | 365,40 | 382,47 | 395,58 | 377,84 | 411,53 | 349,36 | 350,19 | 348,65 |
| Med. transaction price | 370 | 360 | 380 | 400 | 390 | 440 | 350 | 353 | 350 |
| Standard deviation | 104,48 | 98,58 | 108,82 | 116,06 | 109,14 | 119,74 | 81,95 | 81,26 | 82,54 |
| Trading volume | 9167 | 4686 | 4547 | 4983 | 2358 | 2625 | 4184 | 1928 | 2256 |
| Mean Time Interval Quote | 0,67 | 0,81 | 0,57 | 0,63 | 0,78 | 0,52 | 0,73 | 0,85 | 0,64 |
| Mean Quantity submitted | 264 | 219 | 310 | 284 | 228 | 344 | 244 | 207 | 277 |
| Mean Time Interval Trade | 2,80 | 3 | 2,62 | 2,65 | 2,89 | 2,42 | 2,98 | 3,14 | 2,85 |
| Mean Quantity Traded | 61 | 57 | 65 | 65 | 60 | 71 | 57 | 55 | 59 |

Table 4.5: MSE trading prices in last minute of periods with information

| | | | Bad state | |
|---|---|---|---|---|
| Treatment | Market | Good state | RE | PI |
| 1 | Ambiguity | 90,10 | 88,96 | 69,47 |
| | Risk | 67,36 | 75,41 | 64,42 |
| 2 | Ambiguity | 194,4 | 94,35 | 115 |
| | Risk | 126,21 | 71,07 | 120,96 |

reveals that prices are more suppressed in the presence of ambiguity as individuals tend to restrict prior probabilities more pessimistically.

Table 4.6 summarizes the mean allocations per type of trader. In periods without private information we do not observe that asset holdings cluster either around Type C traders, as predicted by the maxmin model, or Type A traders as predicted by the RE model. In periods with private information and high dividend, traders with private information collect the assets in the market. This finding is consistent with the holdings predictions of the maxmin/PI model and holds for both markets. When the private information reveals that the dividend is low, there is no clear difference between the average asset holdings of Type C and uninformed Type A traders. The asset allocation predictions of one model does not outperform the other. Our main finding based on the asset allocations points towards the predictions of the maxmin and PI model in which traders use their prior beliefs when trading.

$$Deviation = \beta_1(1/t) + \beta_2[(t-1)/t] + \epsilon \tag{4.1}$$

We test whether asset prices converge to the fundamental value levels by investigating whether there is a time trend present in asset prices and whether prices converge to a specific value predicted by one of the three models. We construct a variable *Deviation*, which is equal to the deviation of trading prices from predicted values by all models separately and test for a starting value of prices estimated by the first term of equation (1) and a converging value, which is captured by the second term. The first two columns of Table 4.7 show that in periods with no insider information there is no significant starting and convergence value of trading prices for either the market with

Table 4.6: Mean allocations of assets per trader group

| Market | | No Information | Low Dividend | High Dividend |
|---|---|---|---|---|
| Ambiguity | Type A | 5,36 (RE=15, PI=15) | 4,79 | 6,86 (RE=15) |
| | Type $A_{inf}$ | | 3,20 | 10,65 (PI=30, MM=30) |
| | Type $A_{uninf}$ | | 6,39 (PI=30) | 3,11 |
| | Type C | 4,60 (MM=15) | 5,13 (RE=15, MM=15) | 2,52 |
| Risk | Type A | 6,26 (RE=15, PI=15) | 4,29 | 10,50 |
| | Type $A_{inf}$ | | 2,20 | 15,03 (PI=30, MM=30) |
| | Type $A_{uninf}$ | | 6,40 (PI=30) | 5,49 |
| | Type C | 4,14 (MM=15) | 5,78 (RE=15, MM=15) | 1,19 |

The predicted values are between brackets.

risk and ambiguity. However, prices do converge to expected value levels and we do not find that subjects trade based on pessimistic beliefs. Column 3 and 4 show that prices deviate further from fundamentals in market with ambiguity, while not reaching fundamentals in both markets. In periods with private information and a low asset value closing prices are slightly higher than fundamentals which could point towards prices reaching the expected value given no insider information. The PI predictions in periods with low asset values are equal to the expected value of the asset. Considering deviations from the expected value, which is presented in the last two columns, we can observe that prices are lower than expected levels. We can infer that prices typically lie below fundamental values when asset prices are high, which is amplified in markets with ambiguity. One possible explanation could be that subjects realize there are individuals with private information and tend to believe that this information is negative due to the inclination of believing that minimum outcomes are more likely to occur. This effect suppresses prices. And in periods with low fundamental values asset prices are closer to the expected value levels in the presence of ambiguity which points towards discarding information signals from trading activity in the market. These two findings show that subjects indeed are more likely discard valuable information in submitted trading prices under ambiguity or to hold a more pessimistic belief once they are convinced about the presence of private information in markets.

As trading price do not seem to converge to fundamental values i.e. are underpriced

Table 4.7: Convergence of trading prices

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
|---|---|---|---|---|---|---|---|---|
| Starting prices Amb ($\beta_1$) | 118 | | -710*** | | 357*** | | 237** | |
| | (1.00) | | (-5.94) | | (3.64) | | (2.90) | |
| Starting prices Risk ($\beta_1$) | | -198*** | | -951*** | | 595** | | 504** |
| | | (-5.80) | | (-7.86) | | (2.88) | | (2.45) |
| Convergence Ambiguity ($\beta_2$) | 1 | | -152*** | | 52** | | -28 | |
| | (0.04) | | (-6.18) | | (2.54) | | (-1.32) | |
| Convergence Risk ($\beta_2$) | | 8 | | -98*** | | 33** | | -53*** |
| | | (0.44) | | (-5.01) | | (2.23) | | (-3.11) |
| Observations | 2382 | 1950 | 2938 | 3687 | 2950 | 2634 | 2950 | 2634 |
| $R^2$ | 0.003 | 0.013 | 0.706 | 0.719 | 0.359 | 0.354 | 0.088 | 0.298 |

Notes: The dependent variable in all regressions is the deviation from predicted prices. The first two columns show the results for periods with no information with the predicted prices of the RE and PI model. Column 3 and 4 show the deviation for periods with insider information and high asset values. Column 5 and 6 show values depending on RE predictions for periods with private information and low asset values. The last two columns show values on PI predictions when asset values are low and there are insiders. $t$ statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors.

in periods with high asset fundamental value and slightly overpriced in periods with low asset fundamental value and asset holdings do not reflect the predictions of the RE model, we investigate the effect of ambiguity on the likelihood of trading around prices predicted by the MM model versus prices predicted by the PI model. We employ the subsample when there is private information in the market and the dividend is low as both models predict different prices in the bad state with private information. To exploit the likelihood of prices being at the MM levels we estimate the following equation using a Logit regression:

$$Z = \alpha_i + \beta_1 Time + \beta_2 D_{Ambiguity} + \beta_3 Time * Ambiguity + \epsilon \tag{4.2}$$

$$Z = \begin{cases} 1; \textit{if price closer to Maxmin level} \\ 0; \textit{if price closer to PI level in period without information} \end{cases}$$

We introduce a dummy variable which takes the value one if a trading price is closer to the maxmin level than to the PI level. The *Time* variable captures the effect of time, which is in this setting close to trading activity, on the convergence of prices. The dummy variable *Ambiguity* equals 1 if for observations in the market with ambiguity and 0 otherwise. If discarding information overrules the pessimistic beliefs under ambiguity, we expect that ambiguity will have a negative effect on the likelihood of prices reaching the MM prices. Furthermore, we include an interaction term of ambiguity and time to consider the effect of time under ambiguity since the pace of convergence might be affected by the presence of ambiguity. The regression results are presented in Table 4.8. The probability that prices at MM levels is positively affected by time, which holds for all specifications. This finding is quite intuitive as some trading activity should precede before private information will be disseminated in markets. For the aggregate sample the effect of ambiguity in payoffs decreases the likelihood of information dissemination in markets. This result also holds for the first treatment in which there is ambiguity about the state probabilities. Including the interaction term shows that the effect of time in the absorption of information is impeded by ambiguity. In treatment two ambiguity has a positive effect on information absorption. This effect might be driven by increased pessimistic beliefs as depicted by maxmin expected utility where prices equal the maximum price of the minimum outcome between all traders.

Restricting the analysis to the subsample of private information with low dividend discards trading in periods with high dividend. In these periods we expect that ambiguity

Table 4.8: Convergence of prices to RE/Maxmin levels relative to PI prices

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Time | 0.008*** | 0.010*** | 0.005*** | 0.006*** | 0.013*** | 0.015*** |
| | (13.54) | (11.00) | (7.51) | (5.41) | (12.68) | (10.40) |
| Ambiguity | -0.221*** | 0.076 | -0.229*** | -0.123 | -0.088 | 0.329* |
| | (-3.88) | (0.66) | (-3.25) | (-0.86) | (-0.87) | (1.66) |
| Time*Ambiguity | | -0.003*** | | -0.001 | | -0.005** |
| | | (-2.92) | | (-0.84) | | (-2.40) |
| Constant | -0.542*** | -0.702*** | -0.425*** | -0.485*** | -0.843*** | -1.044*** |
| | (-8.55) | (-8.41) | (-5.37) | (-4.57) | (-7.82) | (-7.63) |
| Observations | 5197 | 5197 | 3406 | 3406 | 1791 | 1791 |

Notes: The dependent variable in all regressions is the dummy variable taking the value 1 if trading price is closer to RE instead of PI level. Column 1-2 contain the aggregate data, in column 4-5 the sample is restricted to treatment 1. The last two columns contains the sample of treatment 2. $t$ statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors.

has a more pronounced effect as the aversion to ambiguity leads to pessimistic belief forming and discarding valuable information in asset prices which has more downward potential in periods with high asset values. To test this we construct another dependent variable which equals 1 if a price deviates at most 10 percent from the predicted level of RE. With this specification we test whether ambiguity affects the likelihood of inferring information from trading prices. Except for the difference in the construction of the dependent variable we also include a dummy variable *Dividend*, which takes the value 1 if the dividend is high and 0 otherwise, to investigate the effect of high and low dividend. In addition, we include an interaction term which captures a potential effect of asymmetric reaction to news under ambiguity. The results, as demonstrated in Table 4.9, show that time has a similar positive effect on the convergence of prices towards the RE prices. The divergence from predicted levels is higher in period with high dividend. Ambiguity in markets decreases the likelihood of prices being at RE levels and this effect is more pronounced in periods with high dividend.

### Profits of informed vs uninformed traders

The models also predict a divergent outcome regarding the value of inside information. According to RE model predictions, insider information should not contain an extra

Table 4.9: Convergence of prices to RE/Maxmin levels

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| Time | 0.007*** | 0.006*** | 0.006*** | 0.007*** | 0.005*** | 0.005*** | 0.009*** | 0.009*** | 0.009*** |
| | (15.57) | (10.30) | (10.08) | (11.48) | (6.84) | (6.94) | (10.75) | (8.20) | (7.36) |
| Ambiguity | -0.163*** | -0.335*** | -0.171 | -0.238*** | -0.510*** | -0.147 | -0.062 | 0.022 | -0.117 |
| | (-3.36) | (-3.18) | (-1.48) | (-4.00) | (-3.91) | (-1.03) | (-0.72) | (0.12) | (-0.56) |
| Time*amb | | 0.002* | 0.002* | | 0.003** | 0.003** | | -0.001 | 0.000 |
| | | (1.84) | (1.79) | | (2.36) | (2.16) | | (-0.51) | (0.03) |
| Dividend | | | -0.410*** | | | 0.364*** | | | -1.949*** |
| | | | (-6.16) | | | (4.36) | | | (-14.76) |
| Dividend*amb | | | -0.542*** | | | -0.713*** | | | 0.119 |
| | | | (-5.37) | | | (-5.73) | | | (0.62) |
| Constant | -2.072*** | -1.995*** | -1.752*** | -1.716*** | -1.594*** | -1.816*** | -2.685*** | -2.723*** | -1.779*** |
| | (-36.95) | (-29.43) | (-22.66) | (-24.90) | (-19.21) | (-18.93) | (-27.23) | (-21.80) | (-12.36) |
| Observations | 11527 | 11527 | 11527 | 6544 | 6544 | 6544 | 4983 | 4983 | 4983 |

Notes: The dependent variable in all regressions is the dummy variable taking the value 1 if the price does not deviate more than 10 percent from the RE price. Column 1-2 contain the aggregate data, in column 4-5 the sample is restricted to treatment 1. The last two columns contains the sample of treatment 2.$t$ statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors.

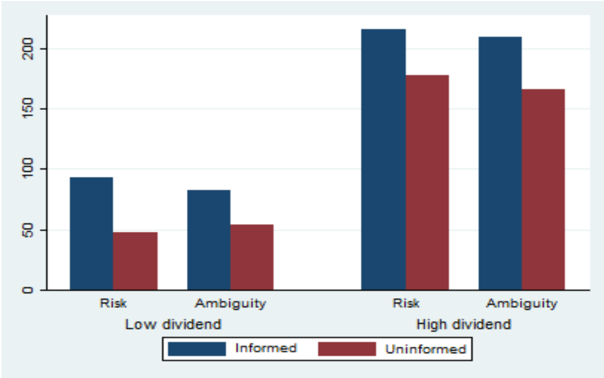


Figure 4.1: Profits of subject with and without private information per state

dollar value as information is quickly spread in the market. Therefore, the trader with inside information should not outperform other market participants. On the contrary, the PI and maxmin model predict that insiders will outperform the rest of the market as this information will be kept private. Figure 4.1 shows that informed traders on average outperform uninformed traders in both markets. We observe that the gain from private information is related to the state of the economy. The difference in profits between informed and uninformed traders is larger in periods when the bad state occurs under risky payoff fundamentals. This points again to more suppressed prices under ambiguity which decreases potential profits from private information. In periods with a good state we observe that inside information is more valuable in markets with ambiguity as the downward deviation of prices creates more profit potential for insiders. In Figure 4.2 the profits of informed and uninformed traders are demonstrated for the Treatment 2. The graphs show that in the second treatment insiders are gain more profit from their private information. This is particularly true for periods with high dividend (good state). The graph shows that when the insider has positive information he makes larger profits when the payoff level is ambiguous. This could be explained by the conservative bidding of uninformed traders under ambiguity.

### 4.3.3. Prices and Information mirages

To test whether individuals falsely infer signal from prices and trade according to their beliefs in a period with private information, we focus on the predictions of the RE model. This model predicts that the expectations of an individual is endogenously determined and hence might create this pattern. We find that in 10 percent of the periods with

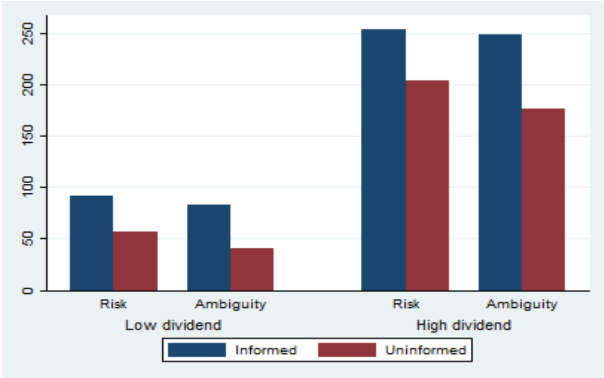


Figure 4.2: Profits of subject with and without private information per state - Treatment 2

no private information in the market an information mirage occurs. In periods with no informed traders we find that subjects tend to follow expected payoff prices more carefully when the underlying payoff distribution is uncertain rather than risky. Only 2 out of 16 periods are in markets with ambiguity. When payoff uncertainty increases due to ambiguity, individuals might restrain themselves from inferring signals from submitted prices as they put less value on other less precise sources of information and let themselves be guided by the information they are provided with. Individuals might be less likely to form beliefs based on potential signals as their initial knowledge and beliefs are shaped with less certainty and thereby are not anchored deeply. Another explanation might be that individuals tend to become less prone to biases, like overconfidence, when they are provided with more uncertainty. A third channel through which the wrong inference of positive information is suppressed in periods when there are no insiders in the market might be ambiguity aversion. As individuals tend to show aversion to ambiguity, they will be less likely to submit high prices and thereby prices will not be inflated and will approach their expected values. We test the effect of ambiguity on the likelihood of the occurrence of a mirage with the following specification:

$$Z = \alpha_i + \beta_{1,i} D_{Ambiguity} + \epsilon \tag{4.3}$$

$$Z = \begin{cases} 1; \textit{if mirage occurs} \\ 0; \textit{if no mirage} \end{cases}$$

Ambiguity in the payoff of an asset decreases the likelihood of the occurrence of a

Table 4.10: Information mirages

| | mirage | mirage | mirage |
|---|---|---|---|
| Ambiguity | -2.169*** | -1.053*** | -0.155*** |
| | (-2.79) | (-3.08) | (-3.30) |
| Constant | -1.520*** | -0.917*** | 0.179*** |
| | (-5.13) | (-5.51) | (4.10) |
| Observations | 160 | 160 | 160 |
| $R^2$ | | | 0.067 |

Notes: Column 1 shows the regression results of a Logit model, while column 2 demonstrates a Probit regression. The last column shows OLS results. $t$ statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors.

mirage. This effect is significant at a 1 percent level for different specifications. The marginal effect of ambiguity on the formation of a mirage is -0.155. The presence of ambiguity might increase the effect of holding on to one's prior beliefs. Mirages are 4 times more likely under ambiguity about the payoff range than about the probability range.

## 4.4. Conclusion

Previous research has documented that ambiguity impedes the information aggregation function of prices and the RE equilibrium is partially revealing. In an experimental double auction asset market we investigated the effect of ambiguous beliefs about fundamentals of an asset on private information dissemination. We isolated the effect of ambiguity by creating two identical asset markets which enabled us to impose different levels of uncertainty while investigating the dissemination of private information. In periods with insiders, prices do not converge to RE levels in risky nor ambiguous markets.

However, we find that ambiguity strengthens the deviation of trading prices from the fundamental value even more and thereby hampers the absorption of information more severely. This negative effect on the probability of a convergence towards RE prices is particularly true for periods when the value of the traded asset is high. Good news is perceived with more caution and under-weighted by uninformed traders which keeps prices suppressed and lower than fundamentals, while this result holds for both risky and ambiguous markets, it is stronger when ambiguity is present. This finding is coherent with previous findings on ambiguity and information aggregation in asset markets as the reaction to negative news by investors is stronger as bad news is over- weighted (Epstein and Schneider (2008)). Ambiguity also decreases the pace of information transmission in asset markets. The convergence towards fundamental values is at a slower level, insiders are given more potential to outperform other traders in the market. We should notice that more data is needed in order to rule out any order effects which might be present with the current experimental design.

Furthermore, we find that in markets with risky payoffs information mirages occur in periods when no private information is given, whereas individuals are more reluctant to infer private information from observed trading prices when facing ambiguity. This drives prices more to their expected values and eliminates information mirages to a large extent.

## 4.5. Appendix

### 4.5.1. Instructions

Dividend Payment In each period, the computer will randomly draw a value to determine the dividend payment of the asset. In each period the dividend of the asset can take a high value of 350 or a low value of 100 francs, depending on the random draw. These high and low dividend might differ per trader. In the first 15 periods, the probability with which the asset will pay a high dividend is an unknown percentage. The probability that the asset will pay high dividend lies between 0% and 100%. But we do not know the exact probability. It might be that the probability is 1% or 2% or 85% up till 100%. In the last 15 periods, the probability that the asset will pay high dividend is 50%. . Dividends Account The realized dividend in each period will be paid to you in a separate account and it counts towards your final earnings. That is to say you cannot use your dividends earnings to purchase assets. Furthermore, the dividend draws in each period are independent, meaning that the likelihood of a particular dividend in a period is not affected by the dividend in previous periods.

Each period, there is a 50% chance that the computer will provide the realized dividend to half of the randomly selected traders in this room. The selection is made independently in each period, so that the chance that you would be selected to know the dividend in a period is NOT affected by whether you were selected in any previous period. You will get to know whether half of the traders knew the realized dividend or not at the end of each period.

Your Earnings At the beginning of the experiment, you will be given 5000 francs in cash together with 5 units of the asset in your inventory. Your profits for the entire experiment come from two sources—from all the dividends you receive in your dividend account and from buying and selling assets. All money spent on purchases is subtracted from your cash account. All money received from sales is added to your cash account. Thus, you can gain or lose money on the purchase and resale of assets. Your profit per period equals the amount of francs in your cash account at the end of the period, plus all dividends you earned that period.

Trading In each period, you will see a computer screen like the one shown below. Each period will have a duration of 180 seconds. You are free to buy and sell assets during the trading period.

For purchasing the asset you can click on the offer which appears on your screen as a sell offer and click afterwards on the button BUY. For selling the asset you own you have to select a buy offer and afterwards click on the SELL button. The prices which appear on the screen are per-unit prices. The market price in the middle of the screen shows the last price at which the good has been traded in the market. At the end of each period you will be shown an earnings screen on which the realized dividend is shown along with your profits and the presence/absence of traders with information about the realized dividend during the last trading period.

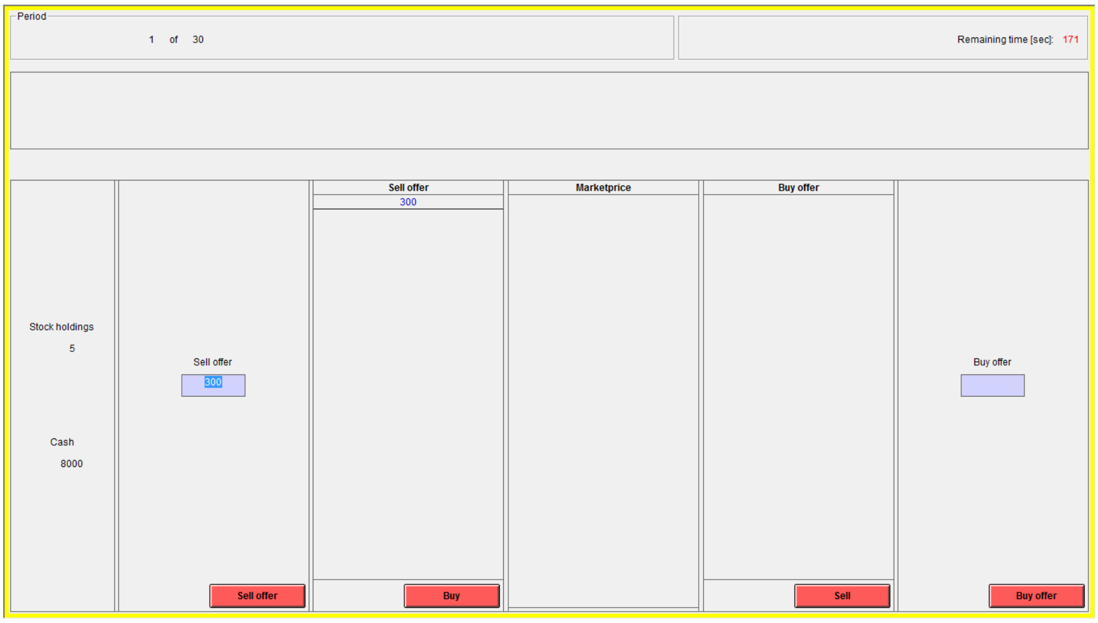
Period
1 of 30
Remaining time [sec]: 171
Sell offer
300
Marketprice
Buy offer
Stock holdings
5
Cash
8000
Sell offer
300
Buy offer
Sell offer
Buy
Sell
Buy offer

Table 4.11: MSE of prices from predicted prices by RE, Maxmin and PI model in the last 90 seconds

| | Ambiguity market | | | | | Risk market | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | No information | | | Bad state | | No information | | | Bad state | |
| Session | RE/PI | Maxmin | Good state | RE/Maxmin | PI | RE/PI | Maxmin | Good state | RE/Maxmin | PI |
| 1 | 54,18 | 58,01 | 91,47 | 44,19 | 48,69 | 41,02 | 110,92 | 141,48 | 48,05 | 42,02 |
| 2 | 81,97 | 134,13 | 53,57 | 79,98 | 76,02 | 102,52 | 66,34 | 86,98 | 138,04 | 97,89 |
| 3 | 56,29 | 31,61 | 68,64 | 41,09 | 38,45 | 39,68 | 38,13 | 131,03 | 35,58 | 36,17 |
| 4 | 91,35 | 173,88 | 59,36 | 153,43 | 86,94 | 118,31 | 177,75 | 57,85 | 159,80 | 114,30 |
| 5 | 46,89 | 53,59 | 77,48 | 58,48 | 40,76 | 31,93 | 62,55 | 131,32 | 82,30 | 46,07 |
| 6 | 55,41 | 47,12 | 80,09 | 41,67 | 35,24 | 36,81 | 93,76 | 145,32 | 33,30 | 37,17 |
| 7 | 80,06 | 79,68 | 106,55 | 67,17 | 56,02 | 76,50 | 52,79 | 174,91 | 80,07 | 72,72 |
| 8 | 63,71 | 137,76 | 234,76 | 72,39 | 88,41 | 61,09 | 134,23 | 149,46 | 127,70 | 41,41 |
| 9 | 50,09 | 73,15 | 161,81 | 41,67 | 91,90 | 77,03 | 69,58 | 131,50 | 36,17 | 99,49 |
| 10 | 60,12 | 112,17 | 138,41 | 58,94 | 108,26 | 103,92 | 160,87 | 97,37 | 36,10 | 79,15 |
| 11 | 51,56 | 111,25 | 222,50 | 23,54 | 69,11 | 99,74 | 174,66 | 125,126 | 58,10 | 72,44 |
| 12 | 123,71 | 160,83 | 213,14 | 192,59 | 149,29 | 95,71 | 123,35 | 144,97 | 68,67 | 141,02 |

Chapter 5

# Time Discounting under Ambiguity

## 5.1. Introduction

Discount rates allow individuals to compare outcomes occurring at different times. Many models of economic decision making include intertemporal utility functions. Predictions of intertemporal choice models are greatly subject to discount rate sensitivity. Therefore, the correct estimation of individual discount rates is crucial for economic modeling. Observed individual discount rates in experimental studies range from 1 percent (Thaler, 1981)to well over 1000 percent Holcomb and Nelson (1992), which is substantially higher than interest rates observed in markets. An extensive empirical and experimental literature has documented various anomalies in discounting behavior which questioned axioms in economic modeling of preferences. Motivated by these findings a line of research investigated the relationship and interaction of time and risk preferences.

In this paper we examine the role of ambiguity on individual time preferences. To our knowledge, there is no theoretical nor experimental study which shows predictions or experimental evidence on individual discounting behavior under ambiguity. In a laboratory experiment we assessed individual discount rates in the presence of risky or ambiguous prospects in order to identify differences in time preferences under different levels of uncertainty. Where the former describes an uncertain payment when probabilities about future outcomes are known, the latter concerns an uncertain payment when probabilities about future outcomes are not (fully) known. We investigate differences in individual discount rates inferred from risky and ambiguous decisions for a range of horizons. With our experimental design we can identify differences in discount rates by varying the uncertainty levels of payout probabilities, with other inputs held constant. Our results show that discount rates differ from discounting under risk when subjects have an imprecise knowledge of the payoff probabilities. This points to differences in discount rates driven by ambiguity and should be considered when modeling or estimating dynamic choices in economics.

A strand of literature studied the interaction of time and risk preferences as these cannot be considered as orthogonal dimensions of decision making under uncertainty. Some studies found correlation between risk and time preferences by linking risk aversion levels with discount rates of individuals. These studies show that risk aversion levels are positively correlated with discounting behavior of subjects ((Anderhub et al., 2001), (Andersen et al., 2008)). The framework of various dynamic choice models have incorporated risk preferences in explaining time preferences and estimating individual and social discount rates ((Kreps and Porteus, 1978), Epstein and Zin (1989)). (Epper et al., 2011) attempt to unify risk and time preferences and show that probability weighting is a common factor in shaping risk and discounting behavior. Experimental studies investigated people's choices in the presence of risk and delay ((Keren and Roelofsma, 1995),(Weber and Chapman, 2005), (Noussair and Wu, 2006), (Anderson and Stafford, 2009), (Baucells and Heukamp, 2010)). These studies generally conclude that there are interaction effects between time and risk, such as risk tolerance increasing with delay.

However, preferences towards risk should be distinguished from preferences towards ambiguity ((Knight, 2012) and (Ellsberg, 1961)). Therefore, time preferences should be disentangled from both preferences towards risk and ambiguity. Recent models have extended the notion of uncertainty and have replaced the unique probability function shaping the decision maker's beliefs by a set of probability functions. (Gierlinger et al., 2008) and (Traeger, 2014) show that the social discount rate is lower under ambiguity. In an experimental setting we test for the effect of ambiguity on the discount rates of individuals and find evidence that ambiguity plays a significant role in intertemporal decision making. While ambiguity typically induces pessimistic beliefs and thereby decreases the expected value of a decision task under risk, we find that individuals use lower or higher individual discount rates when prospects which will be paid out in the future are ambiguous rather than only risky, depending on how ambiguity is presented to subjects. A study by (Weber and Tan, 2012) shows that ambiguity aversion is also present for delayed options. Our study complements this finding by demonstrating that discount rates are affected by the presence of ambiguity.

Our study also contributes to a line of research showing the sensitivity of time preferences to different parameters of the decision task. Some anomalies which are documented in time discounting are process dependence, diminishing impatience ((Laibson, 1997)), the common difference effect ((Bleichrodt and Johannesson, 2001)), the common ration effect ((Kahneman and Tversky, 1979)) and the magnitude effect (Thaler, 1981)(Sun and Potters, 2016) (Halevy, 2015). Other studies have shown that discount rates tend to be higher for certain future payoffs than discount rates for risky future payoffs. People's preference for present certain outcomes over delayed ones, immediacy, weakens drastically when the outcomes become risky ((Keren and Roelofsma, 1995),(Weber and Chapman, 2005)). Our study relates to this literature as we introduce another dimension of uncertainty. We find a magnitude effect for risky and ambiguous prospects and thereby show that the magnitude effect is also present when payoffs contain ambiguity depending on how ambiguity is presented to subjects.

The rest of the paper is organized as follows. Section 5.2 describes the experimental design and procedures. Section 5.3 summarizes the data and estimations of individual discount rates. Section 5.4 concludes.

## 5.2. Experiment

### 5.2.1. Design

To elicit individual discount rates under risk or ambiguity, individuals had to reveal their preference between two prospects. In each period, subjects are presented with eight pairs of binary prospects $(p, x_t)_{T=2}$ and $(p, (x+b)_t)_{T=z}$, where Z=4,..,8 describes the payout date in weeks, t=1,..,80 represents the period in the experiment and $b = 0.025 * x_t, ..., 0.2 * x_t$, corresponds to the extra amount which is offered with the prospect which has a later payout date. The extra amount offered for the payment which lies further in the future increases in percentages of 2.5 percent of $x_t$. Each pair of prospects results in outcome x (or x+b) with probability p and in outcome 0 with probability 1-p. Subjects were asked to make a choice between the eight paired prospects displayed on each screen. If the subject prefers to play the lottery $(p, x_t)_{T=2}$ in two weeks, we can infer that the person has a higher discount rate than the interest rate which is offered with the paired lottery $(p, (x+b)_t)_{T=z}$. By increasing b we find the amount for which the individual switches from the early prospect to the prospect with the later payout date. We can then infer that the discount rate of the subject lies around this point. The parameters p, $x_t$, Z and T were fixed in each period t, while the extra amount b was varying per pair of prospect. At the end of the experiment, the computer randomly selected one period and one of the decisions of that period to determine the subject's earnings. Depending on the choice of the subject, the subject was paid out the outcome of the lottery at the date attached to that lottery.

In designing ambiguous lottery payments we have used to approach used by i.a. (Maafi, 2011) and citehuber2014experimental by implementing ambiguity by providing ranges for the probabilities of outcomes. Each session consisted of 80 periods and four different sections which differed in how p was determined, which reflected the nature of uncertainty. Per section of 20 periods the prospects contained either 1) only risk, where the probability of a positive payout p is known to the subject and fixed within these 20 periods 2) high ambiguity, where the probability of a positive payout p was given as a range between 0 and 100 which describes a probability of a positive payoff drawn from a probability distribution between 0 and 100. 3) lower levels of ambiguity, where the probability of a positive payoff was drawn from smaller distribution intervals. 4) Unknown levels of p where subjects were not provided with any information about the probability of the positive payout and p was missing. In this section subjects were informed that with some probability they would receive $x_t$ in two weeks or $(x + b)_t)_{T=z}$ in $z$ weeks time depending on their choice.

The parameters used in the experiment are summarized in Table 5.1. Each row indicates the range of values in the respective periods of the experiment. With this design we elicited discount rates for five different time horizons and four different amount of monetary stakes under 4 different uncertainty levels. Instead of extrapolating one discount rate to multiple horizons, we directly elicited discount rates for different horizons. The payout horizon of the early prospect was in all periods equal to two weeks, while the payout date of the prospects with the higher payment varied between four and eight weeks. By having both payouts in the future, we isolate time preferences which is only driven by the level of impatience. The choices in periods were similar and differed only in either 1) the monetary stakes $x_t$ varying between 1000 and 4000 Experimental Francs and $(x+b)_t)_{T=z}$ varying between 1025 and 4800 Experimental Francs, 2) the payout date of the later prospect to obtain discount rates for horizons of 2,3,4,5 and 6 weeks., or 3) the formulation of p with which different uncertainty levels were imposed. If subjects assume that all probabilities in between the given intervals are equally likely, they can calculate a probability value equal to .5. These parameters were used throughout the experiment and were repeated for each "type" of uncertainty.

The main advantage of using a multiple price list (MPL) format to elicit time preferences is that it is relatively transparent to subjects and provides simple incentives for truthful revelation. On the other hand, the main disadvantage is potential susceptibility to framing effects as revealed preferences might be sensitive to procedures, subject pools, and the format of the multiple price list table. In addition, using an MPL format to elicit discount rates appear less sensitive to details of the experimental design. A recent theoretical study by (Bade, 2015) suggests that there exists a problem with using the random lottery incentive system in ambiguity experiments, since it provides opportunities for subjects to hedge. The paper discusses preference reversals with randomized experiments in the presence of risk and ambiguity. It also allows for different utility derived from risk and ambiguity. In this experiment ambiguous payoffs are not assumed to provide different utility and in addition we investigate the time preference of individuals in isolation of either risk or ambiguous lotteries.

An example of the task in period subjects were facing is demonstrated in Table 5.2. In this period in the experiment the subject faced 8 choices between preferring to receive $x_t$ or $((x+b)_t)_{T=8}$. The early prospect was identical for all eight choices. In this particular period the prospect which was paid out at the early date would pay out 2000 Experimental Francs with p probability, where p=[0,100]. This prospect $x_t$ was paired with a prospect with payout date 8 weeks after the experiment, where the extra amount b was increasing per choice. The probability with which the later prospect paid out $((x+b)_t)$ was similar for both prospects. Subjects faced ambiguous payoffs for each alternative. For illustration purposes we included the annual interest rate belonging to each alternative. However this information was not present in the experiment.

### 5.2.2. Procedures

The experiment was conducted at the Centerlab of Tilburg University in The Netherlands. A total of 70 Economics and Business Administration students participated in 7 sessions. The sessions were conducted between March 2015 and May 2015. The experi-

Table 5.1: Parameters used in the experiment

| t | T | $x_t$ | $(x+b)_t$ | p |
|---|---|---|---|---|
| 1 - 5 | 2 - 6 | 2000 | 2050 - 2400 | 10% - 90% |
| 6 - 10 | 2 - 6 | 2000 | 2050 - 2400 | 20% - 80% |
| 11 - 15 | 2 - 6 | 2000 | 2050 - 2400 | 30% - 70% |
| 16 - 20 | 2 - 6 | 2000 | 2050 - 2400 | 40% - 60% |
| 21-25 | 2 - 6 | 1000 | 1025 - 1200 | 0% - 100% |
| 26-30 | 2 - 6 | 2000 | 2050 - 2400 | 0% - 100% |
| 31-35 | 2 - 6 | 3000 | 3075 - 3600 | 0% - 100% |
| 36-40 | 2 - 6 | 4000 | 4100 - 4800 | 0% - 100% |
| 41-45 | 2 - 6 | 1000 | 1025 - 1200 | 50% |
| 46-50 | 2 - 6 | 2000 | 2050 - 2400 | 50% |
| 51-55 | 2 - 6 | 3000 | 3075 - 3600 | 50% |
| 56-60 | 2 - 6 | 4000 | 4100 - 4800 | 50% |
| 60-65 | 2 - 6 | 1000 | 1025 - 1200 | Unknown |
| 66-70 | 2 - 6 | 2000 | 2050 - 2400 | Unknown |
| 71-75 | 2 - 6 | 3000 | 3075 - 3600 | Unknown |
| 76-80 | 2 - 6 | 4000 | 4100 - 4800 | Unknown |

Table 5.2: Example of the choices subjects had to make each period

| Choice | $x_t$ (payout in 2 weeks) | $((x+b)_t)_{T=8}$ (payout in 8 weeks) | p | Annual Interest rate |
|---|---|---|---|---|
| 1 | 2000 | 2050 | [0,100] | 16.25% |
| 2 | 2000 | 2100 | [0,100] | 32.5% |
| 3 | 2000 | 2150 | [0,100] | 48.75% |
| 4 | 2000 | 2200 | [0,100] | 65% |
| 5 | 2000 | 2250 | [0,100] | 81.25% |
| 6 | 2000 | 2300 | [0,100] | 97.5% |
| 7 | 2000 | 2350 | [0,100] | 113.75% |
| 8 | 2000 | 2400 | [0,100] | 130% |

The gender variable contains 5 missing values.

ment was executed with the z-Tree computer program (Fischbacher (2007)). There were a varying number of participants per session and each subject acted independently in this individual decision making experiment. Each session lasted approximately 45 minutes. The payoffs in the experiment were calculated in terms of experimental currency, which was converted to Euros at the end of the session. The average earnings per subject were 28 Euros. The exchange rate used in the experiment was 100 Experimental Francs to 1 Euro. In order to eliminate a potential present-bias effect by subjects to receive the earnings at the end of the experiment, the earliest payout date was set at 2 weeks from the date of participation. Subjects were paid by bank transfer on the date which was determined by their choices in the experiment.

## 5.3. Results

Data on the time preferences of 57 subjects were used for the analysis as the rest of our subject pool demonstrated repeated inconsistent responses. If a subject provided inconsistent preferences more than 5 times during the experiment, he/she was eliminated from the subject pool for the analysis, otherwise only the inconsistent choice was deleted. Given that there is no theory which models individual discount rates under ambiguity, we expect that elicited discount rates would be similar under risk as under ambiguity. The average annual discount rates which are inferred from the choices of subjects are reported in Table 5.3. The numbers demonstrate that individuals discount future payoffs at a lower level when payoffs are ambiguous rather than risky when ambiguous prospects are presented with a probability distribution. These differences average discount rates are in almost half of the cases also statistically significant. While this effect is true for different payoff levels, the difference in impatience decreases as payoffs increase. The difference in discount rates is also in non of the cases significant when stakes get large. When the late prospects is paid out in the more distant future we observe that the difference between discounting risky and ambiguous payoffs becomes less pronounced. Furthermore, these numbers point out that inferred annual interest rates show sensitivity to the horizon which is used to elicit discount rates. In line with studies showing a magnitude effect in discounting, we also find that higher payoff levels are less heavily discounted. Individuals show more patience when stakes are higher. When payoffs are ambiguous and there is no information about probabilities given to subjects, discount rates are lower and statistically significant when the payout horizon increases.

Figure 5.1 displays the distribution of individual discount rates per payoff level. The discount rate of each individual is calculated as the average discount rate for each payoff level inferred from choices with different payment horizons. The figure shows that a sizeable share of individuals use higher discount rates when facing a risky payoff decision. However, this difference vanishes when stakes get higher. With a Kolmogorov-Smirnov test we conclude that we cannot reject the hypothesis of the equality of both distributions with p=.29 for the aggregate data. The analysis in the paper implicitly assumes that subjects are risk neutral. However, if we allow for concavity of the utility curve of an individual, then receiving a higher amount in the future should first be corrected with the risk aversion level of the individual If we do not correct for this, we might wrongly elicit discount rates which are higher than the true discount rate of the subject. The stakes in my experiment are small enough to assume they are risk neutral.

In order to verify the effect of ambiguity on the discounting behavior of individuals we estimate specification 5.1. We regress discount rates as a function of ambiguity. We also control for the payoff level, $x_t$ and the horizon in weeks which is used to elicit the yearly discount rate. $D_a$ corresponds to the dummy variable taking the value 1 if the payoff is ambiguous, and 0 otherwise. $\epsilon$ is distributed iid. Table 5.3 and 5.5 demonstrate the results of this specification along with regression results of this specification when interaction effects are included as ambiguity might also effect discount rates through a potential magnitude effect or might change the effect which varying horizons have on time preferences. For these estimations we use the subsample of choices in which subjects either face risky prospects with p=0.5 or high ambiguous prospects with p=[0,100] or ambiguous prospects without any probability distribution separately. The results in Table 5.3 show that prospects with ambiguous payoffs are discounted at a lower rate when a range of probabilities is provided. On the contrary, Table 5.5 demonstrates that discounting under ambiguity without any probability range is higher. While higher stakes $x_t$ are discounted at a lower rate, we find that ambiguity only has an effect on this when there subjects are not given a probability distribution. We also observe that the horizon which is used to elicit discount rates seem to be important for the impatience

Table 5.3: Elicited Average Yearly Discount Rates

| | $x_t$ | $T = 4$ | $T = 5$ | $T = 6$ | $T = 7$ | $T = 8$ |
|---|---|---|---|---|---|---|
| Ambiguity p=[0,100] | 1000 | 227% | 161% | 146% | 124% * | 113% * |
| Risk | 1000 | 247% | 189% | 158% | 133% | 126% |
| Ambiguity p=unknown | 1000 | 147% | 124% | 147% * | 145% | 133% |
| | | | | | | |
| Ambiguity p=[0,100] | 2000 | 194% * | 135% * | 126% | 111% | 104 % |
| Risk | 2000 | 224% | 157% | 127% | 112% | 107% |
| Ambiguity p=unknown | 1000 | 161% | 123% | 142% * | 126% * | 120% * |
| | | | | | | |
| Ambiguity p=[0,100] | 3000 | 152% * | 110% * | 102% * | 94% * | 91% * |
| Risk | 3000 | 171% | 133% | 118% | 105% | 98% |
| Ambiguity p=unknown | 1000 | 149% | 112% | 125% * | 109% | 105% * |
| | | | | | | |
| Ambiguity p=[0,100] | 4000 | 134% | 110% | 102% | 98% | 90% |
| Risk | 4000 | 137% | 115% | 105% | 95% | 92% |
| Ambiguity p=unknown | 1000 | 122% | 99% * | 106% | 103% | 0.95% |

Each column corresponds to discount rates elicited from choices with horizon T.
* The difference in means between discounting under risk and discounting under ambiguity is statistically significant at 10% significance level.

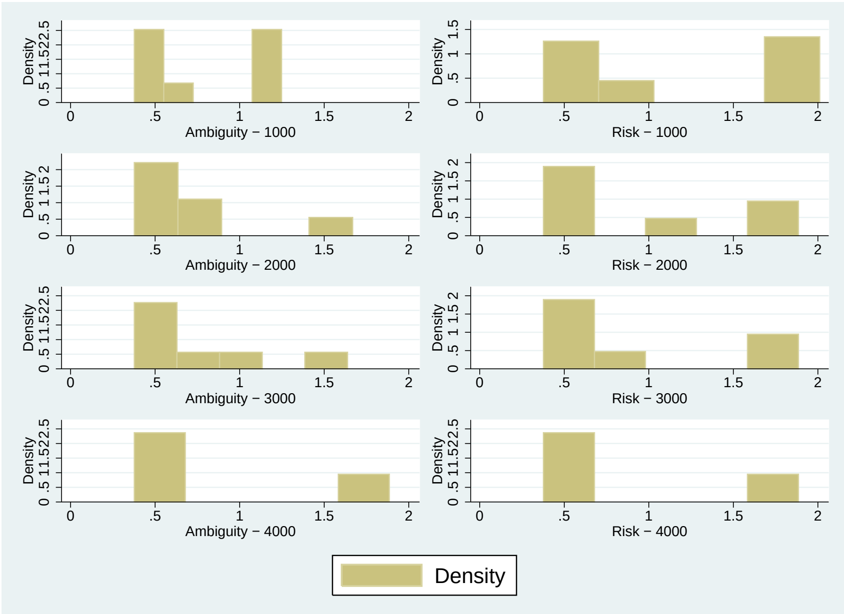


Figure 5.1: Distribution of average discount rate inferred from different horizons per payoff level for ambiguous and risky payoffs

level of subjects. Discount rates decrease as the later option is further away in the future. However, this effect diminishes when prospects are ambiguous and the horizon increases.

$$D_{i,t} = \alpha + \beta_1 D_a + \beta_2 x_t + \beta_3 Weeks_t + \epsilon \tag{5.1}$$

We also investigate whether individuals perceive ambiguity differently when they are provided with an interval range for the probability of $x_t$ to occur. In periods with high ambiguity subjects are given information about the range of values which p can take. This range captures all possible probabilities and is therefore equal to a setting in which subjects are not given any information about the value which p can take. If we observe difference in discounting behavior of prospects which are in fact equally ambiguous it might point towards a difference in the perception of the uncertainty level of the prospect due the fact that agents are not "probabilistically sophisticated" as (Machina and Schmeidler, 1992) point out. (Halevy, 2007) has demonstrated that there is a relationship between ambiguity aversion and compounding objective lotteries. In our study we did not elicit ambiguity aversion rates nor beliefs about probabilities, however this could be done in future research in order to examine the relationship between ambiguity aversion and belief formation where probabilistic sophistication is needed to cope with

Table 5.4: Discount rates where ambiguity corresponds to prospects with p=[0,100]

| | (1) | (2) | (3) |
|---|---|---|---|
| $D_a mbiguity$ | -0.117** | -0.236* | -0.479** |
| | (-2.43) | (-1.92) | (-2.09) |
| $x_t$ | -0.000*** | -0.000*** | -0.000*** |
| | (-5.85) | (-5.85) | (-5.85) |
| Weeks | -0.208*** | -0.208*** | -0.218*** |
| | (-5.94) | (-5.94) | (-6.20) |
| Ambiguity*$x_t$ | | 0.000 | 0.000 |
| | | (1.42) | (1.42) |
| Ambiguity*Weeks | | | 0.040** |
| | | | (2.01) |
| Constant | 3.129*** | 3.165*** | 3.226*** |
| | (8.20) | (8.27) | (8.34) |
| Observations | 4549 | 4549 | 4549 |
| $R^2$ | | | |

$t$ statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors clustered at subject level.

Table 5.5: Discount rates where ambiguity is defined without any probability distribution

| | (1) | (2) | (3) |
|---|---|---|---|
| $D_a mbiguity$ | 0.222*** | 0.467*** | 0.883*** |
| | (3.14) | (3.40) | (3.47) |
| $x_t$ | -0.000*** | -0.000*** | -0.000*** |
| | (-6.00) | (-5.71) | (-5.71) |
| Weeks | -0.208*** | -0.208*** | -0.190*** |
| | (-5.94) | (-5.94) | (-5.36) |
| Ambiguity*$x_t$ | | -0.000*** | -0.000*** |
| | | (-2.91) | (-2.91) |
| Ambiguity*Weeks | | | -0.069*** |
| | | | (-3.28) |
| Constant | 3.070*** | 2.995*** | 2.892*** |
| | (8.11) | (7.96) | (7.71) |
| Observations | 4549 | 4549 | 4549 |
| $R^2$ | 0.065 | 0.066 | 0.067 |

$t$ statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors clustered at subject level.

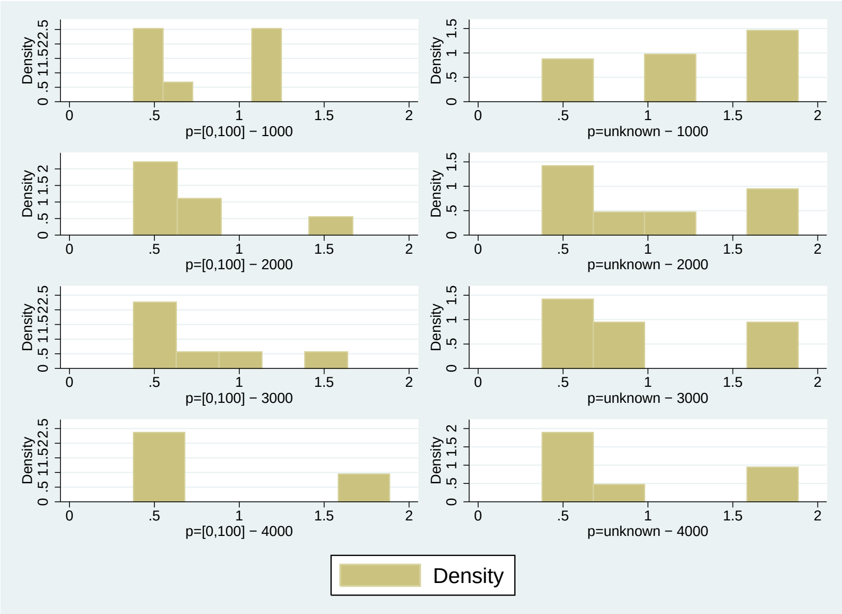


Figure 5.2: Distribution of average discount rate inferred from different horizons per payoff level for prospects with an interval of probabilities provided to subjects versus prospects without any information about payout probabilities

the descriptive problem. While (Krain et al., 2006) measure activation of orbitofrontal and lateral frontal cortices and show that decision making under ambiguity induce more cognitive load decision making under risk as the DLPFC activity is more intense with tasks involving ambiguity, another finding by (Benjamin et al., 2013) shows that the relationship between cognitive ability and time preferences is specific to intertemporal preferences when individuals reveal preferences between immediate and delayed payments. This relationship fades away when time preferences are measured between different delayed rewards, which is used in our experiment. Figure 5.2 demonstrates the distribution of individual interest rates for both settings. It is apparent that subjects use lower interest rates to discount prospects when the probability range for p is explicitly given. This points towards perceiving an ambiguous prospect without probabilities differently. With a Kolmogorov-Smirnov test we conclude that we can reject the hypothesis of the equality of both distributions with p=.000.

(Curley and Yates, 1985) and (Larson, 1980) have demonstrated that ambiguity avoidance increased with the range of probabilities. We asses whether the aversion to increasing ranges of probabilities has an effect on discounting behavior by investigating time preferences derived from prospects with different ambiguity levels and allowing for different coefficient estimates for varying ambiguity levels. We use a cross section of our data and include data on time preferences of individuals for a payoff level of 2000 Experimental Francs. For this cross section we have data on discount rates where the level of ambiguity of the payout probabilities stepwise vary. We use the degree of ambiguity as a categorical variable in explaining discount rates. The specification we run is the following:

$$D_{i,t} = \alpha_i + \beta_1 D_a + \beta_2 Weeks_t + \epsilon \tag{5.2}$$

where

$$D_a = \begin{cases} 0; \textit{p=[0.5]} \\ 1; \textit{p=[0.4,0.6]} \\ 2; \textit{p=[0.3,0.7]} \\ 3; \textit{p=[0.2,0.8]} \\ 4; \textit{p=[0.1,0.9]} \\ 5; \textit{p=[0,1]} \end{cases}$$

The results in Table 5.6 show that discount rates are only affected by ambiguity when the ambiguity level is highest. Subjects discount prospects with p=[0,1] at a lower rate. For these prospects our dummy variable is almost significant at the 10 percent level. This finding suggests that ambiguity does not have a linear effect on time preferences.

## 5.4. Conclusion

We investigated individual discount rates in the presence of ambiguous payoff probabilities. In a laboratory experiment we elicited discount rates for risky and ambiguous prospects separately. Our findings show that individuals use a lower discount rate when they face ambiguity in the payout probabilities of prospects and a probability distribution is provided. This effect changes sign when subjects are not provided with any information regarding the payout probabilities and subjects discount at higher rates. The difference in discounting behavior decreases as stakes get larger. Given that numerous inter-temporal decision making tasks in economics contain ambiguity, this finding shows that discounting under ambiguity differs from discounting under risk. This find-

Table 5.6: Discount rats

| | (1) |
|---|---|
| Weeks | -1.688 |
| | (-1.61) |
| $D_a$=0 | 0.000 |
| | (.) |
| $D_a$=1 | -0.077 |
| | (-1.18) |
| $D_a$=2 | -0.100 |
| | (-1.49) |
| $D_a$=3 | 4.347 |
| | (0.97) |
| $D_a$=4 | 4.343 |
| | (0.98) |
| $D_a$=5 | -0.114 |
| | (-1.62) |
| Constant | 11.587* |
| | (1.83) |
| Observations | 1710 |
| $R^2$ | 0.005 |

$t$ statistics in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Robust standard errors clustered at subject level.

ing shows that next to the vast literature investigating the correlates and interaction of risk and time preferences, the co-movements of time and ambiguity preferences might be investigated.

Our findings also show that ambiguity in the probabilities of a positive payoff are perceived differently when this feature is made salient as we find significant differences in discounting between cases when probabilities are given as a range between 0 and 100 and when no probability distribution is provided to subjects. This shows that the perception of ambiguity and thereby discounting is highly subject to the information framing and thereby might also affect time preferences.

Our results also have important implications for the current debate of informing retail investors about the risk of financial holdings in asset markets. (Kaufmann et al., 2013) shows evidence that the risk perception of financial products by investors is affected by different risk presentation modes. Our findings supports this and shows that individuals tend to perceive ambiguity differently depending on framing. If we would like to induce more patience and long term orientation on retail investors' financial decision making, then providing information about probabilities might hurt. Not providing any information about the probability distribution also decreases discount rates relative to discount rates under risky decisions. In order to control for order effects, learning effects and belief formation follow-up work should correct for belief formation under ambiguity and also very the order of the risky and ambiguous lotteries. This would provide a more comprehensive analysis of the effect of ambiguity on time preferences.

## 5.5. Appendix

### 5.5.1. Instructions

The Experiment

This experiment is about decision making. The experiment consists of 80 periods. Each period you will be presented a sequence of choices. The currency used in the experiment is francs. The amounts which are presented to you are all in terms of francs. You will be paid in cash in Euro's according to your realized earnings by bank transfer. The conversion rate is 100 francs to 1 Euro. In each period you will see a computer screen like the one shown below:

Each presented choice consists of two options. Both options are lotteries with two possible outcomes. A positive outcome with the probability(ies) given or 0 otherwise. The probability with which the lottery will pay out the positive outcome is stated on the screen. In each period you have to indicate for each choice which lottery you prefer. Please notice that the pay-out date of the paired lotteries are different! The probability with which the lottery pays out a positive amount is either 1) a known percentage 2) an unknown percentage or 3) an interval of percentages. For example, looking at Example 1 we see that Lottery 1 pays out 1000 Francs. The probability that it will pay out lies between 10% and 50%. It might be that the probability is 11% or 12% or 13% up till 50%. At the end of the experiment, the computer will randomly select one period and one choice of that period to determine your earnings of this experiment. Each period has equal probability to be selected by the computer and each choice has equal probability to be selected by the computer.

Your earnings

You will start with an initial earning of 500 francs. After you have finished the experiment by indicating your choices, the outcome of the round which will be played for real will be added to your initial earnings and this will become your final earning of the experiment.

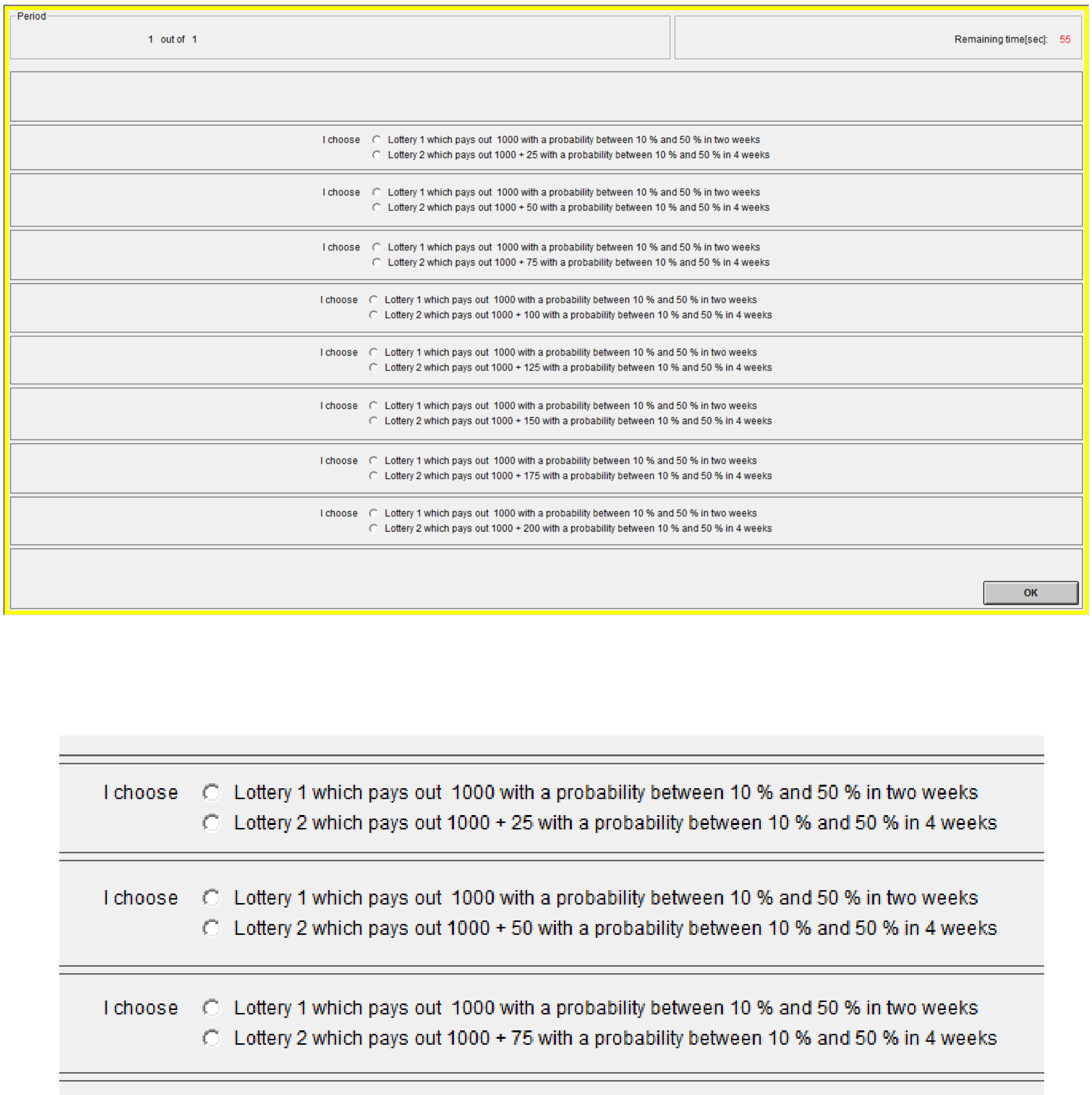


Figure 5.3: Example 1

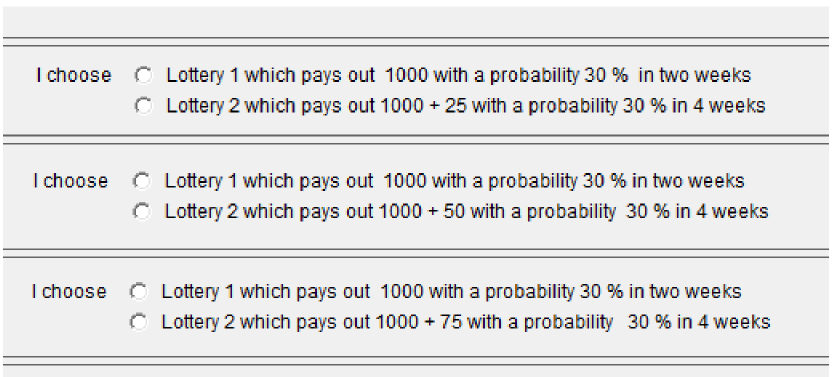


Figure 5.4: Example 2

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