

Huber, Christoph; Rose, Julia

**Working Paper**

## Individual attitudes and market dynamics towards imprecision

Working Papers in Economics and Statistics, No. 2019-06

**Provided in Cooperation with:**

Institute of Public Finance, University of Innsbruck

*Suggested Citation:* Huber, Christoph; Rose, Julia (2019) : Individual attitudes and market dynamics towards imprecision, Working Papers in Economics and Statistics, No. 2019-06, University of Innsbruck, Research Platform Empirical and Experimental Economics (eecon), Innsbruck

This Version is available at:

<https://hdl.handle.net/10419/207072>

**Standard-Nutzungsbedingungen:**

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

**Terms of use:**

*Documents in EconStor may be saved and copied for your personal and scholarly purposes.*

*You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.*

*If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.*



working paper

eeecon  
[triple:e:con]

# Individual attitudes and market dynamics towards imprecision

Christoph Huber, Julia Rose

Working Papers in Economics and Statistics

2019-06

University of Innsbruck  
<https://www.uibk.ac.at/eeecon/>



**University of Innsbruck**  
**Working Papers in Economics and Statistics**

The series is jointly edited and published by

- Department of Banking and Finance
- Department of Economics
- Department of Public Finance
- Department of Statistics

Contact address of the editor:  
research platform "Empirical and Experimental Economics"  
University of Innsbruck  
Universitaetsstrasse 15  
A-6020 Innsbruck  
Austria  
Tel: + 43 512 507 71022  
Fax: + 43 512 507 2970  
E-mail: [eeecon@uibk.ac.at](mailto:eeecon@uibk.ac.at)

The most recent version of all working papers can be downloaded at  
<https://www.uibk.ac.at/eeecon/wopec/>

For a list of recent papers see the backpages of this paper.

# Individual attitudes and market dynamics towards imprecision\*

Christoph Huber and Julia Rose<sup>†</sup>

*Department of Banking and Finance, University of Innsbruck,  
Universitätsstrasse 15, 6020 Innsbruck, Austria*

April 25, 2019

## Abstract

In real world financial markets, dividend processes as well as fundamental values are governed by imprecision; neither the objective probabilities of returns nor the actual amounts of possible returns are known for certain. With a novel experimental approach, we analyze the impact of risk, imprecision in probabilities (ambiguity), imprecision in outcomes, and a combination of the latter two in an individual decision task and in a market environment. In contrast to the previous literature, we do not find any significant imprecision premia for imprecise probabilities. However, we do find significant and persistent imprecision-in-outcomes seeking in the individual task as well as the market setting. Looking deeper into the combination of individual attitudes and market behavior, we find that these patterns survive despite a high level of heterogeneity in individual's beliefs about outcomes.

JEL: G11, G12, C92, D81

Keywords: ambiguity aversion, imprecision, uncertainty, asset markets, experimental finance

---

\*We thank Peter Bossaerts, Brice Corgnet, Mark DeSantis, Felix Holzmeister, Jürgen Huber, Michael Kirchler, Giorgia Romagnoli, Matthias Stefan, Stefan Trautmann, as well as conference participants at ESA 2018 in Berlin, Research in Behavioral Finance Conference 2018 in Amsterdam, and workshop participants at the University of Innsbruck for helpful comments and suggestions. Financial support from the Austrian Science Fund FWF (P29362-G27 J. Huber and SFB F63) and the University of Innsbruck (Aktion D. Swarovski KG 2017, J. Rose & C. Huber, and a grant from 'Bank Austria Stiftung der SoWi-Fakultaeten', C. Huber) is gratefully acknowledged.

<sup>†</sup>Email addresses: [christoph.huber@uibk.ac.at](mailto:christoph.huber@uibk.ac.at) (C. Huber), [julia.rose@uibk.ac.at](mailto:julia.rose@uibk.ac.at) (J. Rose).

# 1 Introduction

In financial markets, dividends as well as returns are inherently uncertain and therefore governed by *imprecision*.<sup>1</sup> Similarly, assets' fundamentals are also not precisely known but again uncertain. Neither the objective probabilities of the realization of returns nor the actual amounts of possible returns are known to investors with certainty. This means that real world settings not only include unknown probabilities, but to some extent also unknown outcome realizations. Investment opportunities, for example, often contain imprecise estimates about probabilities, outcomes, or both. Even though traders and investors might have some idea about the feasible ranges of returns, estimating precise outcomes is almost impossible. Therefore, investors' attitudes towards and sensitivity to imprecision, as well as their dynamics in a market setting are important factors in financial decision-making. The aim of this paper is to disentangle the effects of these two dimensions of uncertainty in individual decision-making and in an experimental market environment.

Most of the previous work in this field is based on the terminology of ambiguity in the setting of unknown probabilities (probability distributions, respectively). Due to its theoretical and even more practical relevance in financial contexts, recent research in experimental economics has incorporated, tested, and further developed the causes and consequences of ambiguity aversion in experimental asset markets in the laboratory.<sup>2</sup> However, results for ambiguity *aversion* remain mixed. In a seminal paper in this field, [Camerer and Kunreuther \(1989\)](#) conduct experimental markets for insurance against potential losses. They find mixed and rather minor effects of ambiguity on prices and the quantity of trades for insurance against potential hazards. [Weber \(1989\)](#) and [Sarin and Weber \(1993\)](#) then explore ambiguity effects in experimental asset markets in a multitude of different experimental designs. Their findings indicate that market prices for ambiguous assets are consistently below prices for risky assets and thereby identify a robust "ambiguity premium" for assets representing lotteries with a 50% winning probability.

In a more recent study, [Bossaerts et al. \(2010\)](#) explore the impact of ambiguity and ambiguity aversion on equilibrium asset prices and portfolio holdings in a simultaneous trading scenario. Their findings suggest that, given some state probabilities are unknown, sufficiently ambiguity averse subjects find open sets of prices for which they do not hold an ambiguous portfolio. In contrast to this simultaneous-trading setup, [Kocher and Trautmann \(2013\)](#) let subjects self-

---

<sup>1</sup>We primarily use the terms *imprecision* and *vagueness* but also interchangeably refer to *ambiguity*, as this terminology is common in the decision analysis and economics literature building on [Ellsberg \(1961\)](#). [Budescu et al. \(1988, p. 282, footnote 1\)](#), however, argue that "a statement, phrase, or event is *ambiguous* if it is capable of being understood in two or more different, but precise, ways. It is *vague* if it is not clearly defined or capable of being understood precisely." The terms *vagueness* and *imprecision* therefore capture our research objective more accurately.

<sup>2</sup>A comprehensive overview of (mostly) the theoretical standard economics literature can be found in [Barberis and Thaler \(2003\)](#), whereas [Guidolin and Rinaldi \(2013\)](#) provide a detailed review of related finance literature.

select into one of two mutually exclusive markets for either a risky or an ambiguous asset in first-price sealed bid market environments to avoid arbitrage between risk and ambiguity. They find no ambiguity premia in average market prices. [Corgnet et al. \(2013\)](#) run experiments to analyze trader reaction to ambiguity when dividend information is only revealed sequentially over three experimental periods. Their results suggest that the observed price changes in their experiment are consistent with the news revelation with respect to dividends; however, the degree of ambiguity does not have a significant influence. According to their findings, the role of ambiguity in explaining financial anomalies is limited. [Füllbrunn et al. \(2014\)](#) analyze ambiguity in two market institutions – call markets and continuous double auction markets – to incorporate the effects of market dynamics and transparency, and to explore whether ambiguity effects hold in either of the two institutions. Subjects simultaneously trade two asset types – risky and ambiguous assets using an Ellsberg setup – with either a low or high winning probability, but in separate markets; no arbitrage is possible. They find significant ambiguity effects in low-feedback call markets for assets which provoke high ambiguity aversion but no effects of ambiguity in high-feedback continuous double auction markets. [Huber et al. \(2014\)](#) investigate the influence of skewness in asset fundamentals on asset prices under different states of uncertainty in double-auction markets. They find that market prices for skewed assets initially differ from those of non-skewed assets for risky as well as for ambiguous assets. However, due to learning by repeated sampling of the distributions this difference in market prices mostly disappears towards the end of trading.

As previously stated, most of this work has been done on uncertainty about probabilities, despite the practical relevance of uncertainty or *imprecision* in outcome realizations. The study most closely related to our setting is [Du and Budescu \(2005\)](#), who compare preferences for precise and imprecise probabilities and outcomes, respectively, in individual choice tasks. In their experiment, subjects evaluated investment options varying in terms of their sources of imprecision (probabilities and/or outcomes) in the gain as well as the loss domain by employing two response modes (a certainty equivalent elicitation as well as a simple choice list method). In the certainty equivalent elicitation task, which is closest to ours, they find that subjects value the options with imprecise outcomes most, followed by the all-precise (risky) options, whereas they dislike most those options with imprecise probabilities.

The contribution of our paper to the literature is twofold – first, we want to analyze the impact of imprecise outcomes and/or probabilities in a standard asset market environment in a large-scale laboratory experiment. Second, we want to be able to relate individual attitudes towards imprecision across both dimensions to market outcomes as well as individual trading behavior. Therefore, we conduct a laboratory experiment consisting of both an individual decision task as well as a market experiment. In the individual task, we elicit subjects' certainty equivalents for risk/imprecision attitudes, whereas we incorporate exactly those types of imprecision in the subsequent market experiment by operationalizing imprecision in risky/imprecise buyback

prices. Lottery outcomes (respective buyback prices in markets) are either risky, imprecise in probabilities, imprecise in outcomes, or a combination of both imprecise probabilities and outcomes. With this novel setup, we cannot only observe and characterize individual behavior, but also the impact of individual attitudes towards risk/imprecision in the respective market setting.

Our main findings show that in the individual task subjects are on average imprecision-in-outcomes seeking, whereas we do not find any such pattern for risk, imprecise probabilities, or the combination of imprecise outcomes and probabilities. Additionally, this pattern translates to market outcomes: market prices are significantly higher than expected fundamentals in markets with imprecise outcome realizations. Also, as for individual certainty equivalents, we do not find significant deviations from expected fundamentals in any other treatment. The analysis of bid-ask spreads across treatments reveals that these are highest in markets with imprecision in outcome realizations. This pattern suggests the highest degree of heterogeneity in individual valuations in this setting, whereas we do not find any significant treatment differences in other market variables.

## 2 The Experiment

We conduct a laboratory experiment which consists of two main parts: (i) an individual decision task to elicit subjects' preferences towards imprecision, and (ii) a continuous double auction market to explore individual trading behavior and aggregate market outcomes in the face of imprecision. In both parts we aim to analyze the effects of either imprecise probabilities, imprecise outcomes, or both, in comparison to precise probabilities and outcome realizations (i.e., 'risk'). Thus, we run a  $2 \times 2$  between-subjects experimental treatment design as depicted in Table 1.

Table 1: **Experimental treatments.** Overview of the two treatment variables "Probabilities" and "Outcome Realizations", which determine the lottery in the individual decision task and for realizing the asset's buyback price in the market experiment. *Precise* probabilities and outcome realizations refer to exact values which are common knowledge among all participants. *Imprecise* probabilities and outcome realizations are defined by an unknown distribution over values within a specified range.

		Outcome Realizations	
		Precise	Imprecise
Probabilities	Precise	RISK	IO (Imprecise Outcomes)
	Imprecise	IP (Imprecise Probabilities)	IOP (Imprecise Outcomes and Probs.)

Each of the four treatments is defined by a distinct lottery. RISK represents what is commonly referred to as *risk* and what is the basis of the most prominent models in finance (e.g. Markowitz, 1952; Sharpe, 1964): subjects have precise information about the outcome realizations as well as about the respective probabilities over outcome realizations in this lottery. For IP (Imprecise Probabilities) and IO (Imprecise Outcomes), either the respective probabilities or the corresponding realizations are *imprecise*, i.e. in a certain interval and not known with certainty. In IOP, the lottery consists of both, imprecise probabilities and imprecise outcomes.

## 2.1 Individual Decision Task

In the first part of the experiment, we elicit individual attitudes towards imprecision via certainty equivalents (CE). We administer an individual decision task similar to Budescu et al. (2002) and Du and Budescu (2005). We chose to elicit risk and imprecision preferences by asking for a certainty equivalent, since we wanted to keep the task as closely as possible to the reasoning in the market setting. There, the decision whether to buy or sell an asset should be based on the exact same considerations as described in the following.

Subjects are offered a distinct lottery depending on their randomly assigned treatment and are asked to enter the Taler amount they are demanding in order not to enter the lottery. The entered amount is exactly the amount which gives a subject the same utility as entering the lottery. After each subject has entered their certainty equivalent (CE), a number between 8 and 208 is randomly drawn. If this random number is greater than a subject's CE, she receives the randomly drawn number in Taler. If the random number is smaller than a subject's CE, she enters the computerized lottery. The respective payouts in Taler are randomly determined and converted to euros with an exchange rate of 1:30 only at the end of the experiment.

In the individual decision task, we operationalize precise and imprecise outcomes and probabilities, respectively, as follows. For *precise outcomes* (RISK and IP), there are two possible realizations: either 58 or 158 Taler. In contrast, *imprecise outcomes* (IO and IOP) are operationalized by realizing a randomly distributed Taler value either in the range  $[8, 108]$  or in the range  $[108, 208]$  (in steps of 5). Regarding the respective probabilities we define *precision* as assigning probabilities  $p = 0.50$  and  $1 - p = 0.50$  to each of the two outcomes or outcome ranges, respectively. *Imprecise probabilities* are then characterized by randomly determined probabilities  $p \in \{0.00, 0.05, 0.10, \dots, 0.90, 0.95, 1.00\}$  and  $1 - p$ . Note that  $p$  is randomly distributed and can lie anywhere between 0 and 1 (in steps of 0.05). Similarly, any distribution of outcome realizations within each of the two outcome ranges is possible. With imprecision, neither subjects nor the experimenters know the distribution of  $p$  (in IP and IOP) or of outcome realizations (in IO and IOP), respectively. Both imprecise outcome realizations and imprecise



probabilities are drawn from random distributions at the end of the experiment.<sup>3</sup> Table 2 summarizes the lotteries’ parameters in Taler terms for each of the four treatments.

Table 2: **Treatment parametrization.** This table shows the parameters of the four lotteries each corresponding to one particular treatment. Outcome realizations are either 58 or 158 in treatments RISK and IP, or a randomly drawn value from either the range  $[8, 108]$  or  $[108, 208]$  in treatments IO and IOP. The probability  $p$  corresponding to the lower outcome or outcome range, respectively, is either .5 (RISK and IO), or takes a randomly drawn value from the range  $[0, 1]$  (IP and IOP).

Treatment	Possible Outcome Realizations	Possible Probabilities
RISK	58 158	50% otherwise
IO	$[8, 108]$ $[108, 208]$	50% otherwise
IP	58 158	$[0\%; 100\%]$ otherwise
IOP	$[8, 108]$ $[108, 208]$	$[0\%; 100\%]$ otherwise

## 2.2 Market Experiment

The second part of the experiment is an experimental asset market in which subjects trade one of four distinct types of assets, each corresponding to one of the four treatments. In each market there are eight subjects trading in a computerized continuous double auction environment with single-unit trading. Each trader is endowed with 5 units of the asset and 800 Taler in cash holdings. Subjects then trade for three minutes. At the end of trading, the experimenter buys back each unit of the asset for a liquidating, state-dependent buyback price to be determined by drawing balls from one or more non-computerized, opaque Ellsberg-type urns (Ellsberg, 1961). Thus, the asset’s buyback price is the result of a lottery as depicted in Table 2 for each treatment.

In each treatment one urn is filled with two types of balls – yellow or white – corresponding to two precise outcomes (RISK and IP) or to two outcome ranges (IO and IOP), respectively, as shown in Table 2. Before trading begins, subjects decide by majority voting which color,

<sup>3</sup>In particular, we use the Random Integer Generator from [www.random.org](http://www.random.org). For imprecise outcome realizations, we draw a series of 21 integers between 0 and 20, multiply each of them with 5 and add 8 for the outcome range  $[8, 108]$  and 108 for the outcome range  $[108, 208]$ . For imprecise probabilities, we draw a series of 20 integers of either 0 or 1 to determine  $p$  as the sum of the 20 integers over 20. The randomly drawn samples for each experimental session are available upon request.

if drawn, leads to which of the two possible outcome realizations or ranges of outcomes, respectively.

In the market experiment, we operationalize precise and imprecise probabilities, respectively, as follows. For precise probabilities (RISK and IO) the urn is filled with exactly 10 yellow and 10 white balls. With imprecise probabilities (IP and IOP) the urn contains a randomly determined composition of balls.<sup>4</sup> Neither subjects nor the experimenters know the proportion of balls in the urn. Thus, the urn might contain only white balls, only yellow balls, or a mixture of both. In treatments with precise outcome realizations (RISK and IP), the yellow or white ball drawn from the urn strictly determines the realization of the buyback price to be either 58 or 158 Taler. Conversely, in treatments IO and IOP – for which outcome realizations are imprecise –, there are two additional urns each of which are filled with 21 balls labelled with possible buyback prices, one with realizations in the range  $[8, 108]$  and one with realizations in the range  $[108, 208]$  (in steps of 5).<sup>5</sup> Again, neither subjects nor the experimenters know the distribution of buyback prices in the urns. The yellow or white ball then determines from which of the two additional urns – the one with realizations less than or equal to the expected value or the one with realizations greater than or equal to the expected value – the buyback price for the asset is drawn. Then, one of the randomly distributed outcome realizations in the relevant urn is randomly drawn to determine the buyback price of the asset.

### 2.3 Experimental Implementation

We ran 17 experimental sessions with a total of 320 students from different fields of study. 46.6% of subjects are female, with a mean age of 23. All sessions were conducted between March and October 2018 at Innsbruck EconLab at the University of Innsbruck. The experiment was conducted with z-Tree 3.6.7 by Fischbacher (2007) and employs the continuous double auction market environment of GIMS (Palan, 2015). Subjects were recruited using hroot by Bock et al. (2014).

In total, each experimental session lasted approximately one hour. After reading aloud and allowing sufficient time to study the written instructions of the individual decision task, subjects were asked to enter their respective CES. Then, subjects received written and read-aloud instructions for the trading environment of the market experiment and had the possibility to familiarize themselves with the market institution by trading in a neutral trial period of four minutes. After that, an additional set of detailed, written instructions on how the buyback

---

<sup>4</sup>Once again, we use the Random Integer Generator from [www.random.org](http://www.random.org) to draw series of 20 numbers of either 0 or 1 from a random distribution, which determine the number of yellow (0) and white (1) balls in the urn.

<sup>5</sup>For each of the two urns we draw 21 integers between 0 and 20 using the Random Integer Generator from [www.random.org](http://www.random.org) prior to each experimental session. The possible realizations written on the balls are then the drawn integers multiplied by 5 plus 8 for the outcome range  $[8, 108]$  and plus 108 for the outcome range  $[108, 208]$ . The randomly drawn samples for each urn of each session are available upon request.

price is determined by random draws from opaque urns and thus by realizations from a lottery was read aloud. Subjects then voted on which ball – yellow or white – should pay which of the two outcomes or outcome ranges, respectively. After revealing the majority decision, the three-minute trading period started. After trading concluded, one randomly chosen participant randomly draws one ball (yellow or white) from the urn relating to the asset’s type (all treatments), and also draws a ball labelled with a buyback price from the urn relating to the previously determined outcome range of the respective asset type (only treatments IO and IOP). The experimental instructions as well as screenshots of both experimental parts are available in Appendices A and B.

After the two main parts of the experiment, we elicit subjects’ cognitive reflection abilities using four items of a CRT task (Frederick, 2005; Toplak et al., 2014), financial literacy (Lusardi and Mitchell, 2007), as well as general demographics.

Subjects’ payouts comprise their earnings from the individual decision task and from the market experiment. For the latter, the buyback price determined by drawing balls from (an) opaque urn(s) was multiplied by a subject’s number of shares held at the end of the trading period and added to her end holdings of Taler. Finally, the Taler holdings from the market experiment were exchanged for euros at a rate of 180:1. Earnings from the individual decision task were exchanged for euros at a rate of 30:1. In total, subjects earned between 5 and 28 euros with a mean of 13.1 euros.

### 3 Results

In the following, we begin by discussing the results of the individual choice task. We then assess aggregate market outcomes. In particular, we examine whether and in what way subjects’ individual preferences are reflected in (i) their individual trading behavior and (ii) in aggregate outcomes in the dynamic market environment across all four treatments.

To eventually address points (i) and (ii) in the market environment, we designed the structure of the individual decision task to be as closely related to the individual buy and sell decision in the market as possible. For that reason, we asked subjects to enter their certainty equivalents for the respective lottery (with four treatments in total, conducted between subjects). Across all treatments, the expected value of the lottery is 108. If the elicited individual certainty equivalent is above (below) the expected value of 108, we consider this subject to have a preference towards (against) the respective combination of precise/imprecise probabilities and outcomes. In the following, we outline our main result for the individual task, considering mean certainty equivalents across conditions.

**Result 1.** *Individuals are imprecision-in-outcomes seeking but show no significant preferences towards risk, imprecise probabilities, or a combination of imprecise outcomes and probabilities in the individual decision-task.*

*Support:* Figure 1 shows mean deviations from the expected value of 108 across treatments. We observe that subjects' certainty equivalents are on average almost exactly at 108 in Treatment RISK, whereas they are slightly below 108 in treatments IP and IOP. Thus, subjects do not show strong indications of risk aversion or an aversion towards imprecision in probabilities in the individual decision-task. However, when it comes to imprecision towards outcomes (Treatment IO), we find that mean deviations from the expected value of 108 are significantly different from zero ( $p = 0.0277$ , Wilcoxon signed-rank test). The average difference between the certainty equivalent and the expected value amounts to an increase of 7.4%. In other words, subjects value the lottery with precise probabilities but imprecise outcome realizations significantly higher than its expected value. We do not find any significant imprecision in probabilities premium, which adds to the findings of Kocher and Trautmann (2013), Corgnet et al. (2013) and Füllbrunn et al. (2014).

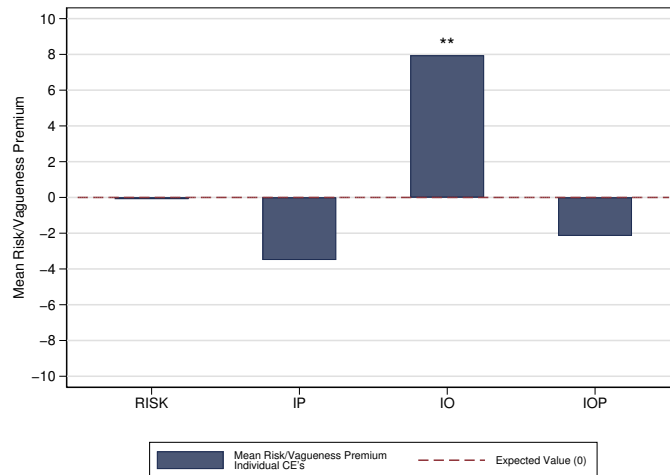


Figure 1: **Market medians of subjects' certainty equivalents across treatments.** This figure depicts the mean of median deviations of subjects' certainty equivalents (CEs) from the expected value of 108 for each treatment at the market-level. \*, \*\*, and \*\*\* represent the 10%, 5%, and 1% significance levels from two-sided Wilcoxon signed-rank tests against zero.

The result of a significant imprecision-in-outcomes seeking behavior on average is in line with the findings of Budescu et al. (2002) and Du and Budescu (2005), who report similar results in a comparable task framework by eliciting certainty equivalents for lotteries with imprecise probabilities and outcomes.

In the following, we will present the results of our market treatments based on the previously described individual outcomes. Our main goal is to analyze if the main result for the

individual analysis, the imprecision-in-outcomes seeking on average, still holds in a market framework or whether individual attitudes become smoothed out by market dynamics. For the market experiment following the individual decision task, subjects were randomly grouped into markets of eight traders each.

**Result 2.** *Market prices are significantly above expected fundamentals in asset markets with imprecision in outcome realizations. Other treatments reveal no significant deviation from the expected value.*

*Support:* Figure 2 shows mean deviations from the expected value of 108 in mean market prices (maroon bars) next to deviations in the individual certainty equivalents (blue bars, equivalent to Figure 1 above) and for each treatment. Mean market prices for all treatments are above the expected value of 108.<sup>6</sup> Prices are lowest in Treatment IOP with the mean price deviation being 0.84, increasing to 15.95 for Treatment IP and 18.92 for RISK; where none of these deviations is significant. Turning to Treatment IO, we find that deviations from the expected fundamental value in markets is as high as 38.98, which is also significantly different from zero with  $p = 0.0469$  (Wilcoxon-Mann-Whitney test). Taken together, these results correspond to the individual decision task and provide evidence that individual attitudes are not smoothed out by markets. Even in this dynamic setting, preferences for imprecision-in-outcomes seeking still hold.

As additional support for our findings, Figure 3 shows smoothed (that is, averaged per 30 seconds) market prices as a function of time for individual markets (grey lines) as well as treatment means and medians (colored, bold lines). Moreover, we plot the distributions of individual certainty equivalents of all market participants in the corresponding treatment (orange dots; larger and darker dots indicate higher density). Whereas for treatments RISK, IP, and IOP mean and median prices are almost perfectly aligned with the expected fundamental value of 108, for Treatment IO, however, mean and median market prices are continuously above the expected value (dotted lines).<sup>7</sup> Combining individual CES with these results, we find that the distribution of certainty equivalents also reflects this pattern. The distribution is markedly skewed in the direction above 108, which is the expected risk neutral value of the lottery.

Considering the distributions of individual CES further, we observe a high density around the expected value of 108 in all treatments, while certainty equivalents around the salient outcome realizations 58 and 108 in treatments RISK and IP also exhibit comparatively high densities.

---

<sup>6</sup>Note that, in contrast to the individual decision task, our market environment allows subjects to trade at prices above the maximum possible payout of 208 Taler per asset. Thus, as prices are bounded at a lower limit of zero but unbounded above, this could explain our observation of mean overvaluation across treatments.

<sup>7</sup>For Treatment IO it may seem that Figure 3 suggests market prices to be converging on average to 108 at the end of the trading period. However, the data does not sustain a convergence to 108, since only 11.47% of all trades are taking place in the last 30 seconds and hardly any individual markets show prices to convergence towards 108, as depicted in Figure C6 in the Appendix.

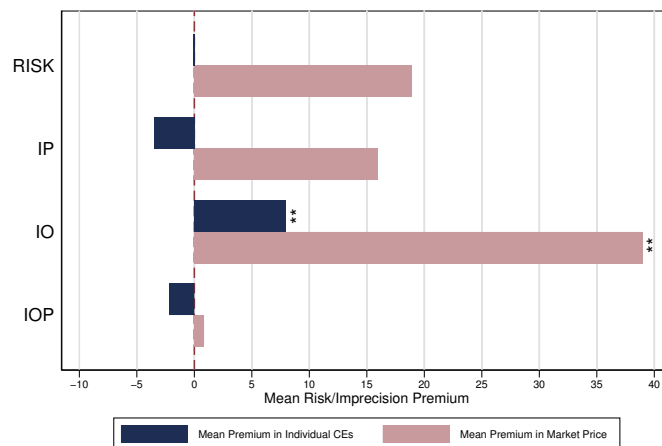


Figure 2: **Market medians of subjects' certainty equivalents and mean market prices across treatments.** This figure shows the mean of median deviations of subjects' certainty equivalents (CEs, blue bars) and mean deviations of market prices (maroon bars) from the expected value of 108 for each treatment at the market-level. \*, \*\*, and \*\*\* represent the 10%, 5%, and 1% significance levels from two-sided Wilcoxon signed-rank tests against zero. Table C2 in the Appendix provides the market medians of subjects' CEs and mean market prices across treatments with the corresponding test statistics from Wilcoxon signed-rank tests.

Unsurprisingly, subjects' CEs are most evenly distributed in Treatment IOP, which bears the highest level of uncertainty and thus reveals a vast heterogeneity in individuals' preferences. On average, however, both individual preferences and market prices in IOP are most closely aligned with those in IP, suggesting that subjects' preferences towards imprecision-in-outcomes could be offset by an aversion to imprecision-in-probabilities (i.e., ambiguity aversion). This reasoning finds support in the comparison of the development of market prices over time of treatments IP and IO. As mentioned above, Treatment IO exhibits prices constantly above the expected fundamental value of 108, whereas prices for IP are not deviating from 108. This suggests that for the overall effect, the imprecision-in-outcomes seeking is partly overridden by the indifference or even mild aversion towards imprecision in probabilities.

In a last step, we combine our analysis of individual attitudes with alternative aggregate market variables in addition to the price. In particular, we want to analyze whether subjects' beliefs about the expected value in markets become more heterogeneous with the type and level of imprecision. For that matter, we use the market variables share turnover (ST), the volatility of log-returns (VOLA), and the average bid-ask spread (SPREAD) to measure the degree of uncertainty among market participants (e.g. Xiong, 2013). Larger STs would indicate more heterogeneous valuations among subjects as there would be more trade in a market. Similarly, a higher VOLA and larger SPREAD suggest that participants are in vast disagreement about

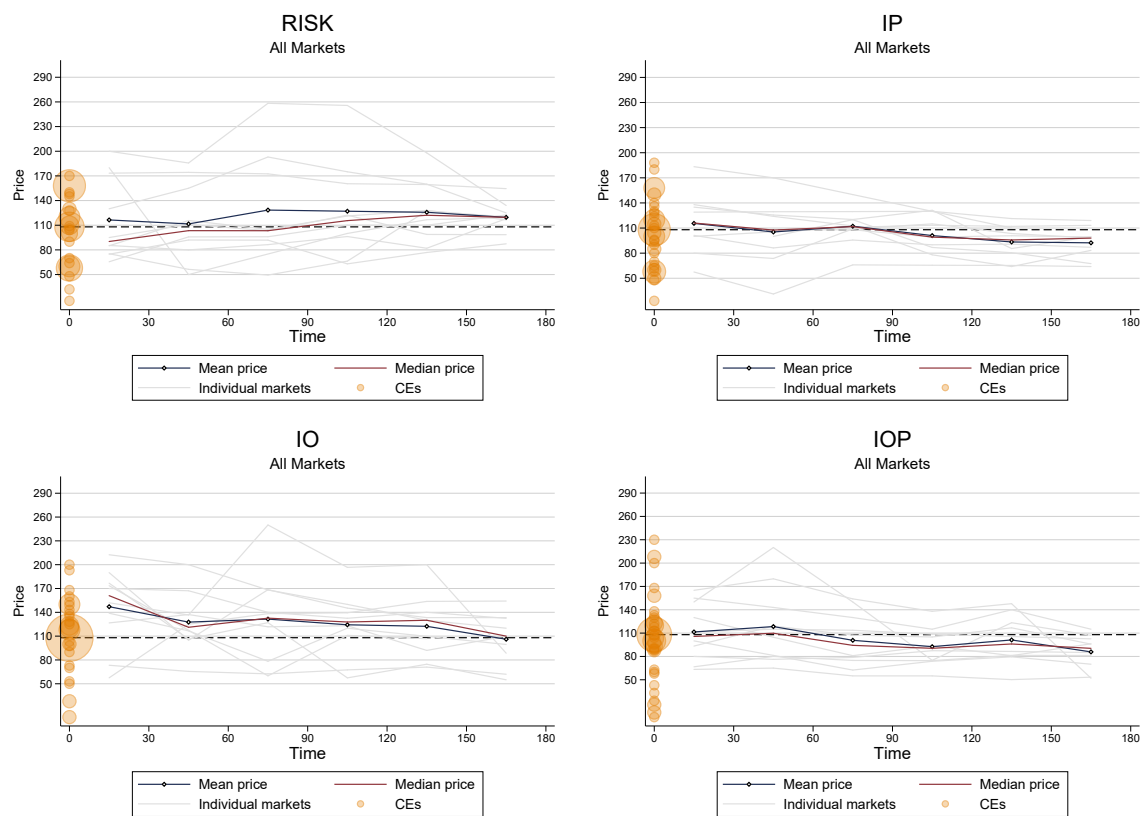


Figure 3: **Market prices as a function of time and individual preference densities across treatments.** This figure shows individual market prices (grey lines) as well as treatment means and medians (blue and red bold lines, respectively) as a function of time for each of the four treatments. In addition, the orange dots represent the respective distribution of individual certainty equivalents within a treatment, where larger and darker dots indicate a higher density.

the appropriate price for the traded assets and, thus, for the traded lottery bearing precise or imprecise probabilities and/or outcome realizations, respectively.<sup>8</sup>

**Result 3.** *Bid-ask spreads are highest in markets with imprecision in outcome realizations suggesting the highest degree of heterogeneity among market participants' valuations. We observe no significant treatment differences in other market variables.*

*Support:* In Table 3 we present treatment medians for ST, VOLA, and SPREAD as well as pairwise comparisons between treatments. While ST and VOLA take similar values in all treatments ( $p = 0.7148$  and  $p = 0.3685$ , Kruskal-Wallis tests), the average bid-ask spread (SPREAD) is considerably higher in Treatment IO, with imprecision in outcome realizations, compared to IP ( $p = 0.0101$ , WMW test) and IOP ( $p = 0.0753$ ). Hence, as buy and sell offers', respectively, are furthest apart, imprecise outcomes lead to disagreement between market participants about the traded asset's fair value. However, as pointed out above, the overall direction in the markets is still a mean pricing above the risk neutral fundamental value of 108.

Table 3: **Treatment medians for market variables.** This table shows in the upper panel the treatment medians for share turnover (ST), the volatility of log-returns (VOLA), and the bid-ask spread (SPREAD). In the bottom panel we present the results from pairwise Wilcoxon-Mann-Whitney (WMW) tests between treatments for each variable; the numbers represent the corresponding  $Z$ -values. \*, \*\*, and \*\*\* represent the 10%, 5%, and 1% significance levels from two-sided tests. The sample size  $N$  for each test is 20.

Treatment	ST	VOLA	SPREAD
RISK	0.61	0.41	45.50
IP	0.44	0.37	29.56
IO	0.56	0.46	67.73
IOP	0.64	0.35	32.13
Pairwise WMW tests			
RISK vs. IP	0.98	0.68	1.72*
RISK vs. IO	0.19	-1.21	-1.13
RISK vs. IOP	0.04	0.30	1.44
IP vs. IO	-0.87	-1.59	-2.53**
IP vs. IOP	-0.87	-0.15	-0.16
IO vs. IOP	-0.27	1.29	1.81*

Taken together, our results do not support previous findings of the literature with respect to ambiguity aversion on the individual level and, more specifically, in market environments. We neither find significant individual premia for imprecise probabilities, nor do we find any support in the subsequent market setting. However, what we find is a significant support for

<sup>8</sup>ST is defined by the total trading volume normalized by the total number of shares outstanding at the end of the period. VOLA measures the standard deviation of log-returns on all market prices within the period. SPREAD is calculated as the mean difference between the best bid and the best ask price.



what we call imprecision-in-outcomes *seeking*, both on the individual as well as the market level. Looking deeper into the combination of individual attitudes and market behavior, we find that these patterns survive despite a high level of heterogeneity in individual’s beliefs about outcomes in Treatment IO.

## 4 Discussion and Conclusion

We combine two experimental tasks to elicit attitudes towards four different kinds of imprecision – classical risk, imprecision towards probabilities (e.g. ambiguity in the general sense), imprecision towards outcomes, and imprecision towards a combination of outcomes and probabilities – in a between-subjects treatment design. In the first task, we elicit individual certainty equivalents towards the four different types of risk/imprecision; in the second task, we set up a dynamic market environment with the same characteristics (risk/imprecision operationalized via buyback prices of assets at the end of the trading period) to be able to connect individual attitudes with market outcomes.

We find that subjects are significantly imprecision-in-outcomes seeking in the individual task, in which we find neither aversion nor seeking towards risk, imprecision-in-probabilities, or the combination of imprecision in outcomes and probabilities. Going one step further, we find that these results also hold in a market setting. In trading assets with imprecision in fundamental values (buyback prices of remaining assets at the end of the period) in a market environment for a duration of 180 seconds, we find exactly the same pattern as in the individual decision task. Markets with buyback prices that are imprecise towards outcome realizations exhibit a significant overpricing, indicating an overall imprecision-in-outcomes seeking in markets.

While our results from the individual decision task corroborate the findings of Budescu et al. (2002) and Du and Budescu (2005), who also find that subjects exhibit the pattern of seeking imprecision in outcomes when eliciting certainty equivalents, their potential explanations for subjects preferring imprecision in outcomes relate to both experimental parts of the present study. First, building on Fox and Tversky’s (1995) comparative ignorance hypothesis, they suggest that the lack of salience in indirect comparisons in eliciting CEs drives the observed imprecision attitudes, which is potentially also the case in both the individual decision task as well as in the market experiment of this study. Moreover, subjects’ strong sensitivity to imprecision-in-outcomes in comparison with an insensitivity to imprecision-in-probabilities can be explained by the scale compatibility (Tversky et al., 1988) between responses (CEs) and the salient monetary outcome realizations (Budescu et al., 2002). While this nicely relates to our individual decision task, this notion is even more relevant in the market experiment, in which monetary outcomes are naturally salient.

Taking a closer look into the combination of individual attitudes and market behavior, we additionally find that imprecision in outcomes fosters disagreement about a lottery's valuation both in eliciting CES and in the dynamic markets' order books. Thus, the pattern of imprecision-in-outcomes seeking survives despite a high level of heterogeneity in individual's beliefs about outcomes in Treatment IO.

Taken together, our results do not support previous findings of the literature with respect to the imprecision in probabilities (e.g. ambiguity) in laboratory markets, which (depending on the specific setting) report lower prices for assets containing imprecision in probabilities. In contrast, we do not find any significant evidence for imprecision premia and rather insensitivity to this imprecision level in our market setting. However, we provide evidence that previously reported preferences for imprecision in outcome realizations are robust to market dynamics with market prices significantly above the expected fundamental value for imprecision-in-outcomes assets.

As information in financial markets is naturally imprecise and vague, the findings of our study are important for better predictions and understanding of both individual investment behavior and aggregate market dynamics. Preferences for imprecision in outcomes in the context of financial markets imply that investors are more likely to invest in assets characterized by imprecise information on their fundamentals and their prospective earnings, dividends, and stock returns. Note, however, that while our experiment uses symmetric lotteries, our results are limited to the gain domain – hence, we can only draw inferences about implications of imprecise information regarding (monetary) gains.<sup>9</sup>

Overall, our results for the imprecision-in-outcomes seeking behavior of individuals translating into markets is one step towards a new and so far mostly neglected direction of research, where imprecision and ambiguity has only been modeled in terms of probabilities, but never in the – as we find – even more important domain of outcomes.

---

<sup>9</sup>See Du and Budescu (2005) for a detailed examination of imprecision effects in individual decisions in the loss and gain domain.

## References

- Barberis, Nicholas, Richard Thaler. 2003. A survey of behavioral finance. *Handbook of the Economics of Finance* **1** 1053–1128.
- Bock, Olaf, Ingmar Baetge, Andreas Nicklisch. 2014. hroot: Hamburg registration and organization online tool. *European Economic Review* **71** 117–120. doi:10.1016/j.euroecorev.2014.07.003.
- Bossaerts, Peter, Paolo Ghirardato, Serena Guarnaschelli, William R Zame. 2010. Ambiguity in asset markets: Theory and experiment. *The Review of Financial Studies* **23**(4) 1325–1359.
- Budescu, David V, Kristine M Kuhn, Karen M Kramer, Timothy R Johnson. 2002. Modeling certainty equivalents for imprecise gambles. *Organizational Behavior and Human Decision Processes* **88**(2) 748–768.
- Budescu, David V, Shalva Weinberg, Thomas S Wallsten. 1988. Decisions based on numerically and verbally expressed uncertainties. *Journal of Experimental Psychology: Human Perception and Performance* **14**(2) 281.
- Camerer, Colin, Howard Kunreuther. 1989. Experimental markets for insurance. *Journal of Risk and Uncertainty* **2**(3) 265–299.
- Corgnet, Brice, Praveen Kujal, David Porter. 2013. Reaction to public information in markets: How much does ambiguity matter? *The Economic Journal* **123**(569) 699–737.
- Du, Ning, David V Budescu. 2005. The effects of imprecise probabilities and outcomes in evaluating investment options. *Management Science* **51**(12) 1791–1803.
- Ellsberg, Daniel. 1961. Risk, ambiguity, and the savage axioms. *The Quarterly Journal of Economics* 643–669.
- Fischbacher, Urs. 2007. z-Tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics* **10**(2) 171–178.
- Fox, Craig R, Amos Tversky. 1995. Ambiguity aversion and comparative ignorance. *The Quarterly Journal of Economics* **110**(3) 585–603.
- Frederick, Shane. 2005. Cognitive reflection and decision making. *Journal of Economic Perspectives* **19**(4) 25–42.
- Füllbrunn, Sascha, Holger A Rau, Utz Weitzel. 2014. Does ambiguity aversion survive in experimental asset markets? *Journal of Economic Behavior & Organization* **107** 810–826.

- Guidolin, Massimo, Francesca Rinaldi. 2013. Ambiguity in asset pricing and portfolio choice: A review of the literature. *Theory and Decision* **74**(2) 183–217.
- Huber, Jürgen, Michael Kirchler, Matthias Stefan. 2014. Experimental evidence on varying uncertainty and skewness in laboratory double-auction markets. *Journal of Economic Behavior & Organization* **107** 798–809.
- Kocher, Martin G, Stefan T Trautmann. 2013. Selection into auctions for risky and ambiguous prospects. *Economic Inquiry* **51**(1) 882–895.
- Lusardi, Annamaria, Olivia S. Mitchell. 2007. Financial literacy and retirement planning: New evidence from the rand american life panel. Working Paper.
- Markowitz, Harry. 1952. Portfolio selection. *The Journal of Finance* **7**(1) 77–91.
- Palan, Stefan. 2015. GIMS – Software for asset market experiments. *Journal of Behavioral and Experimental Finance* **5** 1–14.
- Sarin, Rakesh, Martin Weber. 1993. Effects of ambiguity in market experiments. *Management Science* **39** 602–615.
- Sharpe, William. 1964. Capital asset prices: A theory of market equilibrium under conditions of risk. *The Journal of Finance* **19**(3) 425–442.
- Toplak, Maggie E, Richard F West, Keith E Stanovich. 2014. Assessing miserly information processing: An expansion of the cognitive reflection test. *Thinking & Reasoning* **20**(2) 147–168.
- Tversky, A., S. Sattath, P. Slovic. 1988. Contingent weighting in judgment and choice. *Psychological Review* **95** 371–384.
- Weber, Martin. 1989. Ambiguität in Finanz- und Kapitalmärkten. *Zeitschrift für betriebswirtschaftliche Forschung* **41** 447–471.
- Xiong, Wei. 2013. Bubbles, crises, and heterogeneous beliefs. Working Paper, National Bureau of Economic Research.

# Appendix to 'Individual attitudes and market dynamics towards imprecision'

Christoph Huber and Julia Rose

## A Experimental Instructions

The following instructions have been translated to English. The original German instructions are available upon request. Text parts in standard font are identical for all treatments. Text parts in *italics* differ between treatments; margin notes on the left indicate the respective treatment.

### Individual decision task

#### Task

In this part of the experiment you get 1 decision problem on a screen. The decision contains a lottery. You will be asked to enter the exact Taler amount you would have to receive, to forgo the lottery. This Taler amount is equal to the sum, at which entering the lottery gives you the exactly the same utility than receiving this certain Taler amount you choose.

—RISK—

*The payment from the lottery amounts to either 58 or 158 Taler with equal probability. That is, with a probability of 50% you receive 58 Taler, and with a complementary probability of  $100\% - 50\% = 50\%$  you receive 158 Taler.*

—IP—

*The payment from the lottery amounts to either 58 or 158 Taler. The possible probabilities for the Taler amounts are realized in steps of 5, the possible probabilities for the realization of 58 Taler as a payment are in the range of [0%, 5%, 10%, 15%, ..., 85%, 90%, 95%, 100%]. The exact probability for the Taler amounts is therefore not known, that is, neither you nor the experimenter knows the probability with which each of the two amounts can be drawn.*

—IO—

*The payment from this lottery lies, with equal probability, either in the range [8;108] Taler or [108;208] Taler. That is, with a probability of 50% you receive an amount between 8 and 108 Taler, and with the complementary probability of  $100\% - 50\% = 50\%$  you receive an amount between 108 and 208 Taler. The possible Taler amounts are realized in steps of 5, the possible values are therefore either in the range of [8, 13, 18, 23, ..., 93, 98, 103, 108] or in the range of [108, 113, 118, 123, ..., 193, 198, 203, 208]. The distribution of the Taler values is not known, that is, neither you nor the experimenter knows the probability with which each of the respective values within the ranges can be drawn. It is possible that all values are equally likely, but it is also possible that only one value occurs; as well as all possible compositions between these two extremes.*

—IOP—

*The payment from this lottery lies either in the range [8;108] Taler or [108;208] Taler. The possible Taler amounts are realized in steps of 5, the possible values are therefore either in the range of [8,*

13, 18, 23, . . . , 93, 98, 103, 108] or in the range of [108, 113, 118, 123, . . . , 193, 198, 203, 208]. The distribution of the Taler values is not known, that is, neither you nor the experimenter knows the probability with which each of the respective values within the ranges can be drawn. It is possible that all values are equally likely, but it is also possible that only one value occurs; as well as all possible compositions between these two extremes.

The possible probabilities for the Taler amounts are realized in steps of 5, the possible probabilities for the realization of an amount in the range of [8, 13, 18, 23, . . . , 93, 98, 103, 108] Taler are in the range of [0%, 5%, 10%, 15%, . . . , 85%, 90%, 95%, 100%]. The exact probability for the ranges is therefore not known, that is, neither you nor the experimenter knows the probability with which each of the two ranges can be drawn.

The exchange rate from Taler to euros in this part of the experiment is

$$30 \text{ Taler} = \text{€}1$$

That is, your total payment from this part of the experiment is the Taler amount divided by 30 in euros.

Your decision is only valid when you made a decision and clicked on the OK button in the lower area of the screen.

### **Payment**

Your payment from this part of the experiment will be determined in the following way: the computer generates a random number with equal probability between 8 and 208.

If this number is greater than your entered Taler amount, you will be payed exactly the amount in Taler, which was drawn from the computer. You will get this amount at the end of the experiment in private in cash in addition to your earnings in the other parts of the experiment. Thereby, your payment in Taler will be exchanged for euros with the corresponding exchange rate from above.

If this number is smaller than your entered Taler amount, you will enter the lottery, your payment will be determined by the respective rules of the lottery. This lottery will be simulated and you get this amount at the end of the experiment in private in cash in addition to your earnings in the other parts of the experiment. Thereby, your payment in Taler will be exchanged for euros with the corresponding exchange rate from above.

If this number is equal to your entered Taler amount, a computer-simulated fair coin toss will determine, whether you enter the lottery or get your entered Taler amount. If the lottery is relevant for your payment, it will be simulated and you get this amount at the end of the experiment in private in cash in addition to your earnings in the other parts of the experiment. If your entered Taler amount is relevant for your payment, you will get this amount at the end of the experiment in private in cash in addition to your earnings in the other parts of the experiment. Thereby, your payment in Taler will be exchanged for euros with the corresponding exchange rate from above.

Therefore, note that it is in your interest to enter the amount in Taler, for which entering the lottery gives you exactly the same utility than receiving the Taler amount you chose with certainty.

Before the start of this part, please enter a couple of comprehension questions. In the following, you will see the decision screen in the program. You can get detailed information for this decision by clicking on the "Help" button.

## Market experiment

### Background of the experiment

The current experiment replicates an asset market in which 8 market participants can trade shares of a fictitious company over one period of 180 seconds. You receive an initial endowment of 5 units of the asset and 800 Taler when entering the market. Your asset and Taler holdings cannot drop below zero.

The exchange rate from Taler to euros in this part of the experiment is

$$180 \text{ Taler} = \text{€}1$$

That is, your total payment from this part of the experiment is the Taler amount divided by 180 in euros.

To familiarize you with the software and the trading mechanism there will be a trial period which is not relevant for your payment.

### Information on the market architecture and your task as a trader

#### 1) Trading

As a trader you can buy and sell assets. Trade is accomplished in form of a continuous double auction. That is, every trader can buy and sell assets. You can submit as many buy and sell orders (with at most 2 decimal places) as you like. Each order is for one unit of the asset.

If you buy assets, your Taler holdings will be decreased by the respective expenditures and the number of assets will be increased by one. Conversely, if you sell assets, your Taler holdings will be increased by the respective revenues and the number of assets will be decreased by one. Please note that you can only buy (sell) as many assets as are covered by your Taler (asset) holdings – this includes also your active offers in the market.

#### 2) Payment

At the end of trading a buyback price for the asset is realized. This buyback price determines the value of the assets, which you hold at the end of the trading period. These assets are bought back by the experimenter at this buyback price (price = buyback price). You receive the respective earnings, converted to euros, at the end of the experiment in cash. Before the start of the trading period you will get the information on how the respective buyback price will be determined. In addition, this information is displayed on the upper area of the screen during the trading period.

Thus, this buyback price is relevant for your payment. Your final wealth (= your Taler holdings plus the units of the asset multiplied with the respective buyback price) will be divided by 180 to determine your payment for this part of the experiment.

#### 3) Short overview

- The price of the asset is determined by supply and demand, that is, through the sell and buy orders entered by yourself and by the other traders in the market (each market consists of 8 market participants).
- In the following you will receive detailed information on how the buyback price at the end of the period will be calculated. This information is also displayed during the trading period.

#### 4) Determination of the buyback price

*The buyback price determines the value of the asset and thereby also your earnings, which you get at the end of the experiment. For each asset you are holding at the end of this period, you will receive the respective buyback price. This buyback price is either 58 or 158 Taler with equal probability. That is, with a probability of 50% you receive 58 Taler per unit of the asset, and with a complementary probability of  $100\% - 50\% = 50\%$  you receive 158 Taler per unit of the asset. The randomly determined buyback price is the same for all assets in this period. Thus, at the end of the period the assets you hold will be bought back from the experimenter at this buyback price, which will be determined as described above.*

*Short overview of the payment:*

- 1. In the front of the laboratory you see an urn.*
- 2. This urn is filled with 20 balls. 10 balls are white, 10 balls are yellow.*
- 3. Before the beginning of the trading period all participants of this experiment vote which color stands for a buyback price of 58 Taler. The other color then stands for a buyback price of 158 Taler. The decision is made by majority vote. If the same number of participants votes for white than for yellow, the computer randomly selects the color which stands for 58 Taler with equal probability.*
- 4. Then, participant in cubicle number 1 will be asked to draw a ball from the urn.*
- 5. If the ball drawn from the participant is of color with the majority of votes, the buyback price is 58 Taler; otherwise 158 Taler.*



The buyback price determines the value of the asset and thereby also your earnings, which you get at the end of the experiment. For each asset you are holding at the end of this period, you will receive the respective buyback price. This buyback price is either 58 or 158 Taler. The possible probabilities for the buyback prices are realized in steps of 5, the possible probabilities for the realization of 58 Taler as the buyback price are in the range of [0%, 5%, 10%, 15%, . . . , 85%, 90%, 95%, 100%]. The exact probability for the buyback prices are therefore not known, that is, neither you nor the experimenter knows the probability with which each of the two amounts can be drawn. The randomly determined buyback price is the same for all assets in this period. Thus, at the end of the period the assets you hold will be bought back from the experimenter at this buyback price, which will be determined as described above.

Short overview of the payment:

1. In the front of the laboratory you see an urn.
2. This urn is filled with 20 yellow or white balls. Neither you nor the experimenter know the exact composition of balls in this urn.
3. Before the beginning of the trading period all participants of this experiment vote which color stands for a buyback price of 58 Taler. The other color then stands for a buyback price of 158 Taler. The decision is made by majority vote. If the same number of participants votes for white than for yellow, the computer randomly selects the color which stands for 58 Taler with equal probability.
4. Then, participant in cubicle number 1 will be asked to draw a ball from the urn.
5. If the ball drawn from the participant is of color with the majority of votes, the buyback price is 58 Taler; otherwise 158 Taler.

The buyback price determines the value of the asset and thereby also your earnings, which you get at the end of the experiment. For each asset you are holding at the end of this period, you will receive the respective buyback price. This buyback price lies, with equal probability, either in the range [8;108] Taler or [108;208] Taler. That is, with a probability of 50% you receive an amount between 8 and 108 Taler per unit of the asset, and with the complementary probability of  $100\% - 50\% = 50\%$  you receive an amount between 108 and 208 Taler per unit of the asset. The possible buyback prices are realized in steps of 5, the possible values are therefore either in the range of [8, 13, 18, 23, . . . , 93, 98, 103, 108] or in the range of [108, 113, 118, 123, . . . , 193, 198, 203, 208]. The distribution of the buyback prices is not known, that is, neither you nor the experimenter knows the probability with which each of the respective values within the ranges can be drawn. It is possible that all values are equally likely, but it is also possible that only one value occurs; as well as all possible compositions between these two extremes. The randomly determined buyback price is the same for all assets in this period. Thus, at the end of the period the assets you hold will be bought back from the experimenter at this buyback price, which will be determined as described above.

Short overview of the payment:

1. In the front of the laboratory you see three numbered urns.
2. Urn 1 is filled with 20 balls. 10 balls are white, 10 balls are yellow.

3. Before the beginning of the trading period all participants of this experiment vote which color stands for a buyback price in the range between 8 and 108 Taler. The other color then stands for a buyback price in the range between 108 and 208 Taler. The decision is made by majority vote. If the same number of participants votes for white than for yellow, the computer randomly selects the color which stands for a buyback price in the range between 8 and 108 Taler with equal probability.
4. Then, participant in cubicle number 1 will be asked to draw a ball from Urn 1.
5. If the ball drawn from the participant is of color with the majority of votes, the buyback price is in the range between 8 and 108 Taler; otherwise in the range between 108 and 208 Taler.
6. To determine the exact buyback price, the same participants will draw a ball from Urn 2 or Urn 3.
7. Urn 2 is filled with 21 balls. The balls are labeled with buyback prices in the range from 8 to 108. Neither you nor the experimenter know the exact composition of balls in this urn.
8. Urn 3 is also filled with 21 balls. The balls are labeled with buyback prices in the range from 108 to 208. Neither you nor the experimenter know the exact composition of balls in this urn.
9. Depending on the drawn color from the first urn the participant will draw a ball from the urn with the relevant range and thereby determine the exact buyback price.

The buyback price determines the value of the asset and thereby also your earnings, which you get at the end of the experiment. For each asset you are holding at the end of this period, you will receive the respective buyback price. The payment from this lottery lies either in the range  $[8;108]$  Taler or  $[108;208]$  Taler. The possible buyback prices are realized in steps of 5, the possible values are therefore either in the range of  $[8, 13, 18, 23, \dots, 93, 98, 103, 108]$  or in the range of  $[108, 113, 118, 123, \dots, 193, 198, 203, 208]$ . The distribution of the buyback prices is not known, that is, neither you nor the experimenter knows the probability with which each of the respective values within the ranges can be drawn. It is possible that all values are equally likely, but it is also possible that only one value occurs; as well as all possible compositions between these two extremes. The possible probabilities for the buyback prices are realized in steps of 5, the possible probabilities for the realization of an amount in the range of  $[8, 13, 18, 23, \dots, 93, 98, 103, 108]$  Taler are in the range of  $[0\%, 5\%, 10\%, 15\%, \dots, 85\%, 90\%, 95\%, 100\%]$ . The exact probability for a buyback price in the range  $[8, 108]$  is therefore not known, that is, neither you nor the experimenter knows the probability with which each of the two ranges can be drawn. The randomly determined buyback price is the same for all assets in this period. Thus, at the end of the period the assets you hold will be bought back from the experimenter at this buyback price, which will be determined as described above.

Short overview of the payment:

1. In the front of the laboratory you see three numbered urns.
2. Urn 1 is filled with 20 yellow or white balls. Neither you nor the experimenter know the exact composition of balls in this urn.
3. Before the beginning of the trading period all participants of this experiment vote which color stands for a buyback price in the range between 8 and 108 Taler. The other color then stands for a buyback price in the range between 108 and 208 Taler. The decision is made by majority vote. If the same number of participants votes for white than for yellow, the computer randomly

*selects the color which stands for a buyback price in the range between 8 and 108 Taler with equal probability.*

- 4. Then, participant in cubicle number 1 will be asked to draw a ball from Urn 1.*
- 5. If the ball drawn from the participant is of color with the majority of votes, the buyback price is in the range between 8 and 108 Taler; otherwise in the range between 108 and 208 Taler.*
- 6. To determine the exact buyback price, the same participants will draw a ball from Urn 2 or Urn 3.*
- 7. Urn 2 is filled with 21 balls. The balls are labeled with buyback prices in the range from 8 to 108. Neither you nor the experimenter know the exact composition of balls in this urn.*
- 8. Urn 3 is also filled with 21 balls. The balls are labeled with buyback prices in the range from 108 to 208. Neither you nor the experimenter know the exact composition of balls in this urn.*
- 9. Depending on the drawn color from the first urn the participant will draw a ball from the urn with the relevant range and thereby determine the exact buyback price.*

## B Screenshots of the experimental tasks

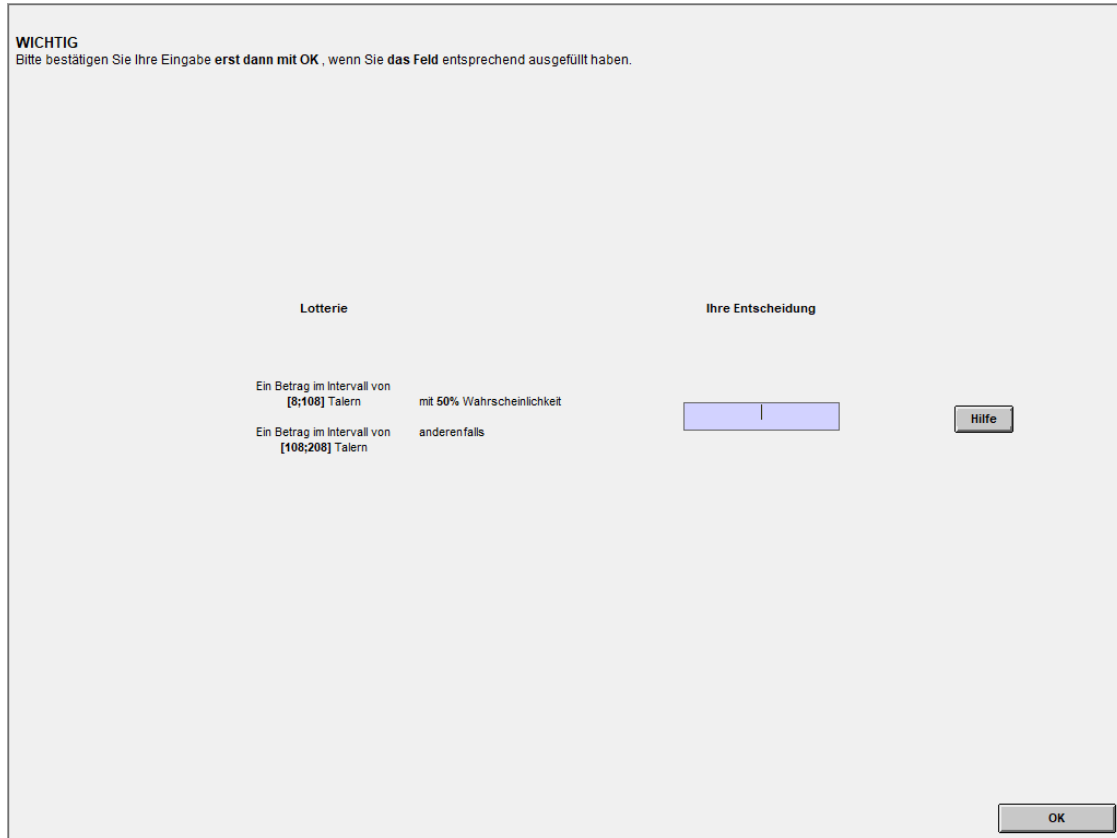


Figure B1: Screenshot of the Investment Task in Treatment 10.

Periode 1 von 4

Die Urne besteht aus **20 weißen und gelben** Bällen.  
 Die Mehrheit der Marktteilnehmer/-innen hat die Farbe **Weiß** gewählt.  
 Wird zufällig ein **weißer Ball** gezogen, so wird jede Aktie um einen zufälligen Preis **zwischen 0 und 100 Taler** zurückgekauft.  
 Wird zufällig ein **gelber Ball** gezogen, so wird jede Aktie um einen zufälligen Preis **zwischen 100 und 200 Taler** zurückgekauft.

Bisher keine Transaktionen

Kaufgebote	Verkaufgebote	Gebotsabgabe
Preis	Preis	Taler: 800.00 Aktien: 5 Letzter Preis: Kein Handel
<input type="button" value="Stornieren"/> <input type="button" value="Verkauf"/>	<input type="button" value="Stornieren"/> <input type="button" value="Kauf"/>	Preis <input type="text"/> <input type="button" value="Kaufgebot"/> <input type="button" value="Verkaufsgebot"/>

Figure B2: Screenshot of the Trading Screen in Treatment 10.

## C Additional figures and tables

Table C1: **Subject demographics across treatments.** This table depicts the averages of demographic variables for each treatment. The last column shows  $p$ -values for differences between treatments from Kruskal-Wallis tests.

Treatment	RISK	IO	IOP	IP	$p$ -value
Age	23.49	23.03	23.26	22.88	0.56
Female (in %)	46.25	51.25	45.00	43.75	0.79
Study semester	5.84	5.75	6.28	5.45	0.46
Risk aversion (general)	5.05	4.59	5.14	5.08	0.38
Risk aversion (financial)	4.10	3.89	4.36	4.25	0.53
CRT score (correct out of 4)	1.84	1.71	1.84	2.14	0.16
Financial literacy score (correct out of 3)	2.54	2.46	2.46	2.35	0.23
$N$	80	80	80	80	

Table C2: **Market medians of subjects' certainty equivalents and mean market prices across treatments and Wilcoxon signed-rank tests.** This figure shows the mean of subjects' median certainty equivalents (CEs, left two columns) and mean market prices (right two columns) for each treatment at the market-level. The columns labeled ' $p$ -value' each show the corresponding  $p$ -values and ' $Z$ ' shows corresponding  $Z$ -values from two-sided Wilcoxon signed-rank tests against the expected value of 108. \*, \*\*, and \*\*\* represent the respective 10%, 5%, and 1% significance levels. The sample size  $N$  for each test is 10.

Treatment	CE	$Z$	$p$ -value	Market price	$Z$	$p$ -value
RISK	107.90	1.380	0.1677	126.92	1.172	0.2411
IP	104.50	-0.565	0.5723	123.95	0.764	0.4446
IO	115.95**	2.202	0.0277	146.98**	1.988	0.0469
IOP	105.85	-1.231	0.2183	108.84	0.051	0.9594

Table C3: **Summary statistics of completed transactions across treatments.** This table depicts the summary statistics of the number of completed transactions across all treatments. There is no significant difference across treatments with  $p = 0.7147$  (Kruskal-Wallis test).

Treatment	RISK	IO	IOP	IP
Median	24.5	22.5	25.5	17.5
Mean	26.6	27.1	26.1	22.9
Standard Deviation	10.52	13.74	9.28	11.77
$N$	10	10	10	10

Figure C1: **Number of active traders (in the sense of posting sell/buy offers) for each market across treatments.** This graph depicts the number of traders posting sell and/or buy offers in the market, separated by treatments. There is no significant difference in the number of active traders across treatments with  $p = 0.2734$  (Kruskal-Wallis test).

### Number of Completed Transactions per Treatment and Market

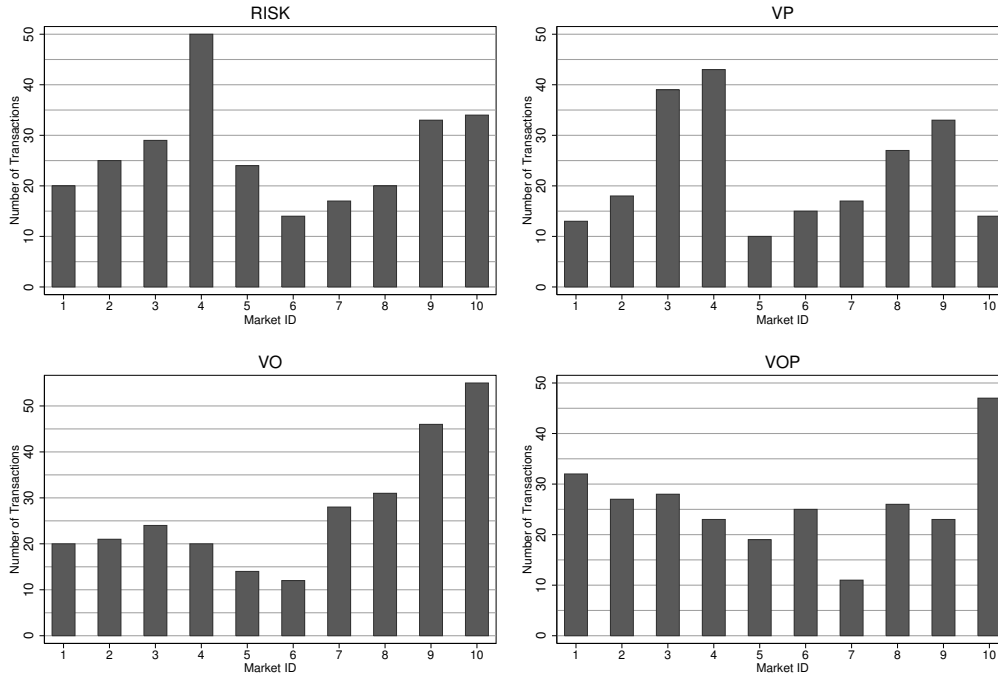


Figure C2: **Number of completed transactions for each market across treatments.** This graph depicts the number of actual completed transactions per market for each treatment separately.

### Number of Active Traders per Treatment and Market

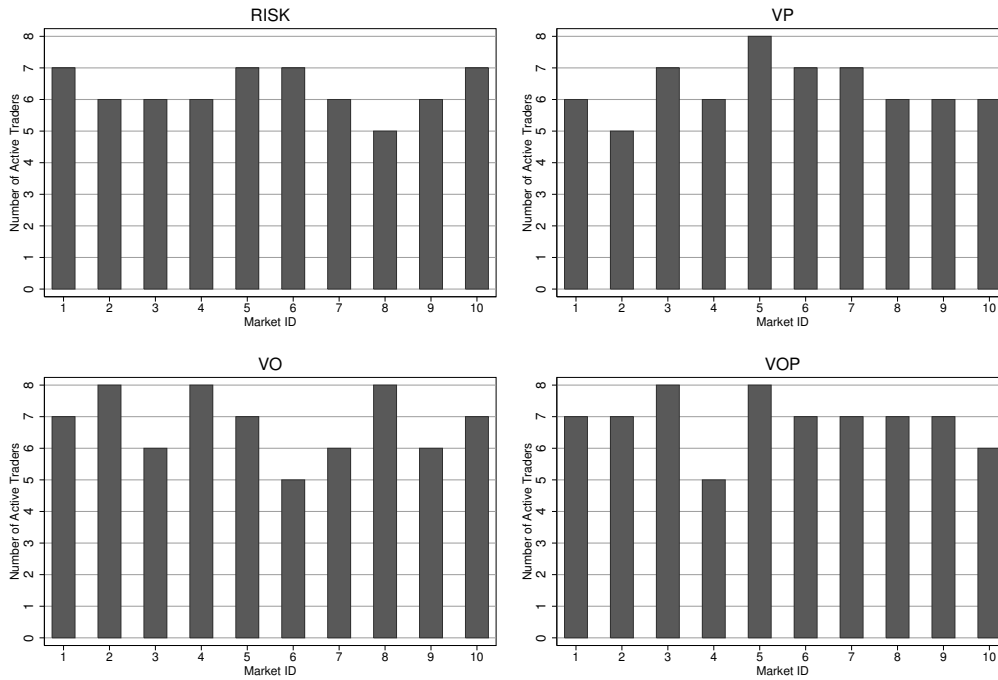
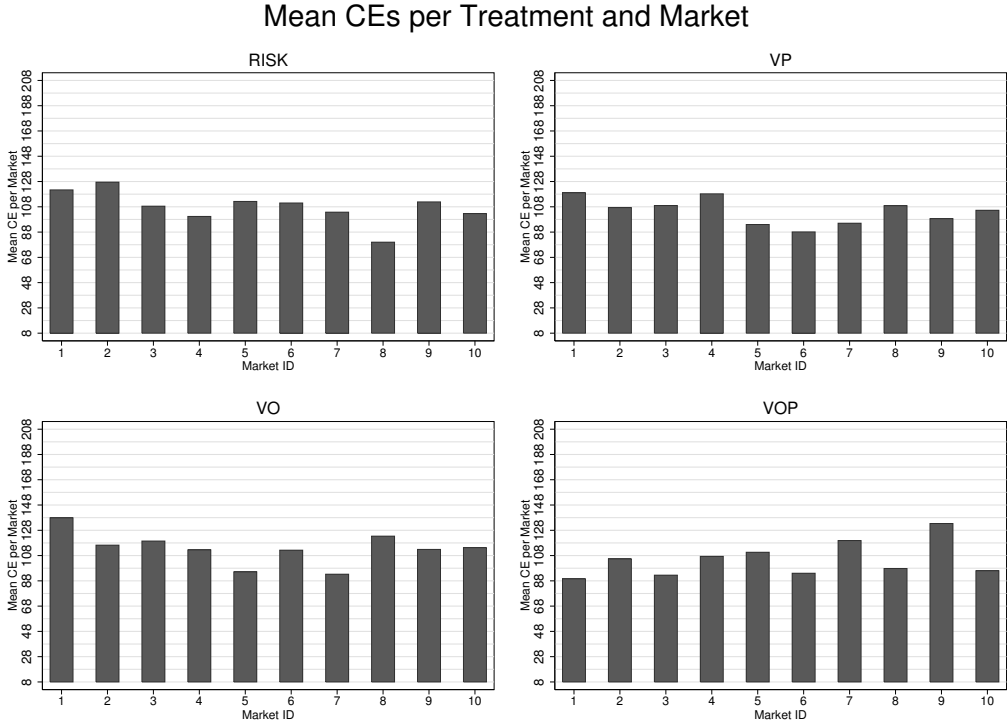




Figure C3: Mean certainty equivalents for each market across treatments. This graph depicts the mean certainty equivalents per market for each market separately.



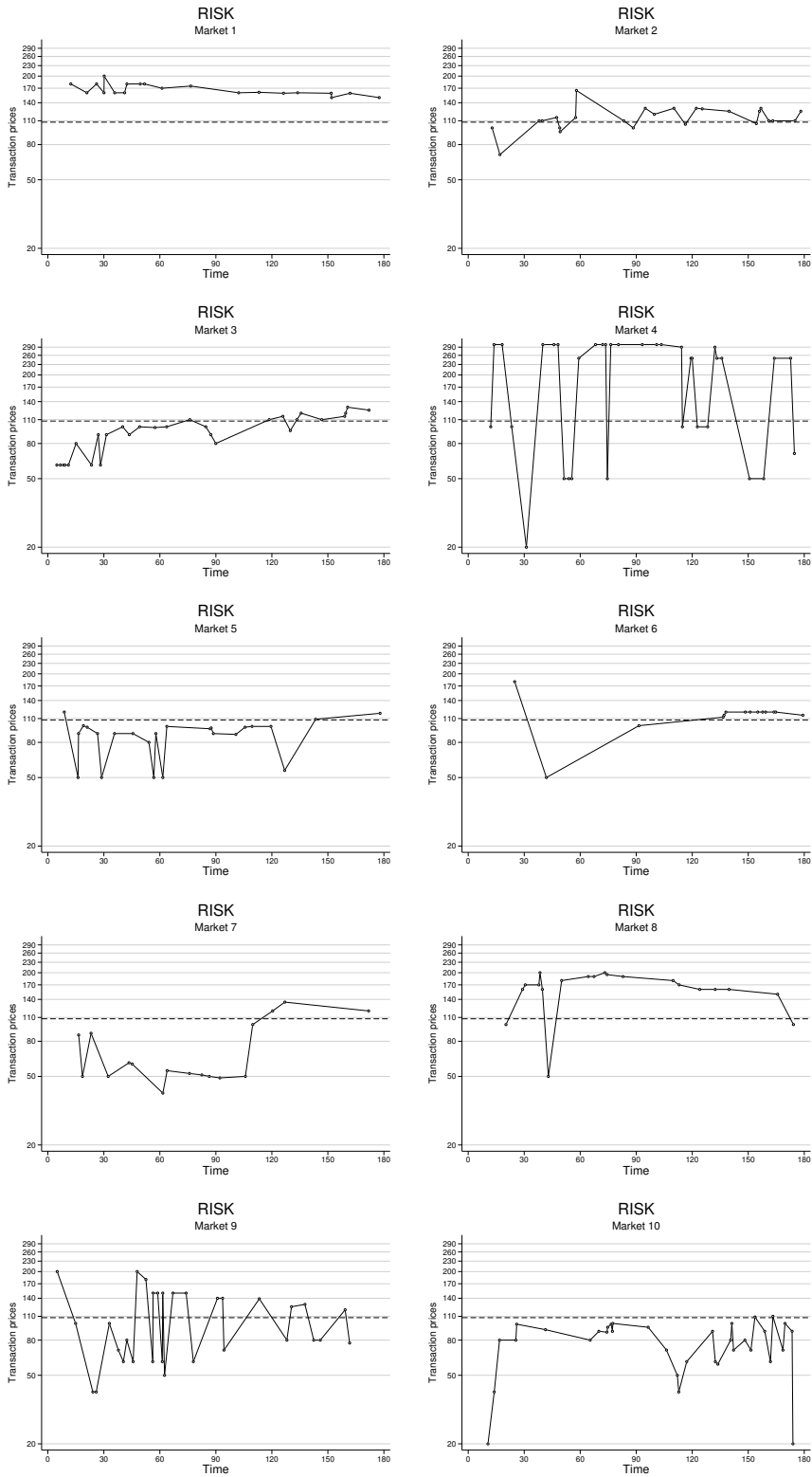


Figure C4: **Individual transaction prices for each market of Treatment RISK.** The dashed line represents the expected value of 108.

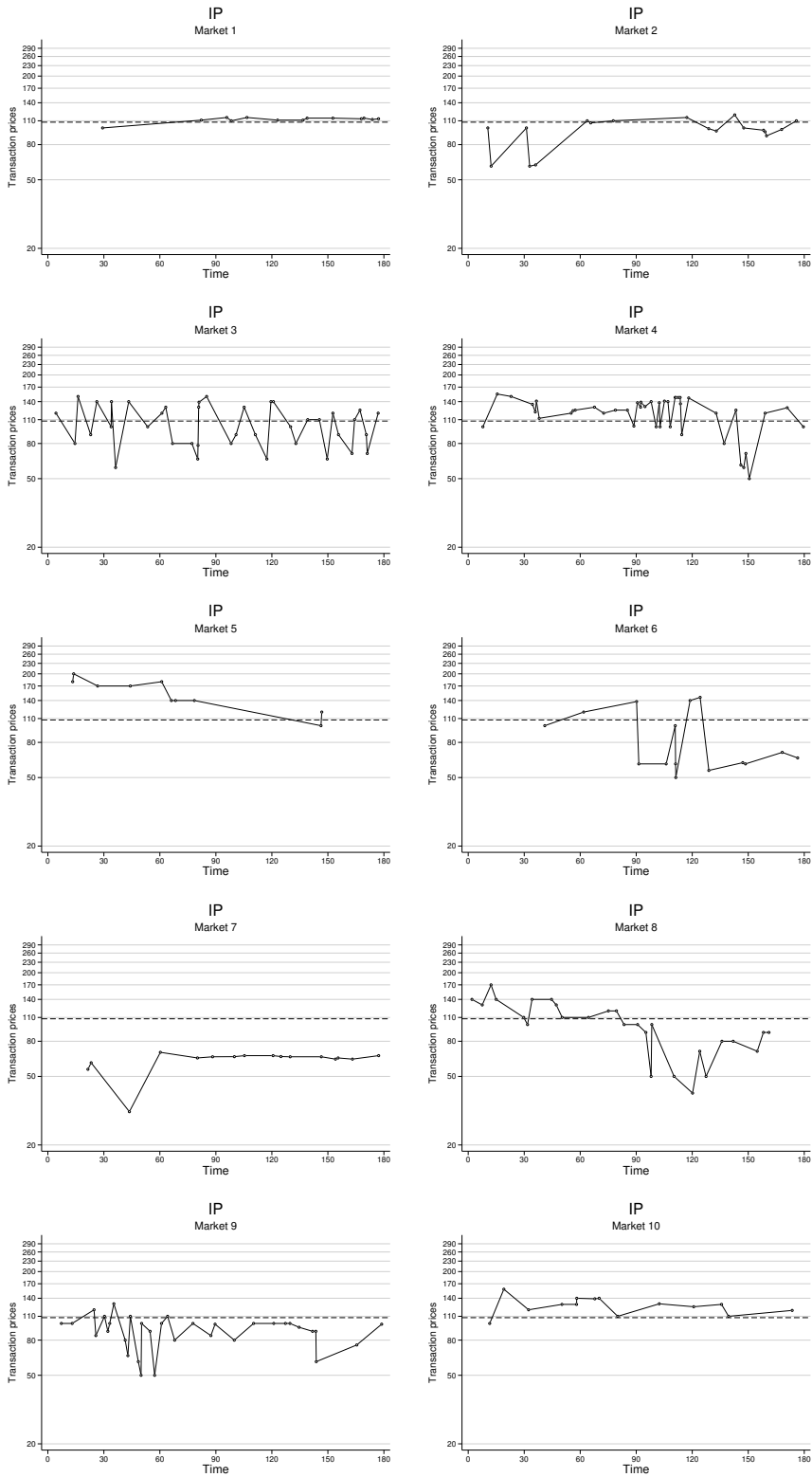


Figure C5: **Individual transaction prices for each market of Treatment IP.** The dashed line represents the expected value of 108.

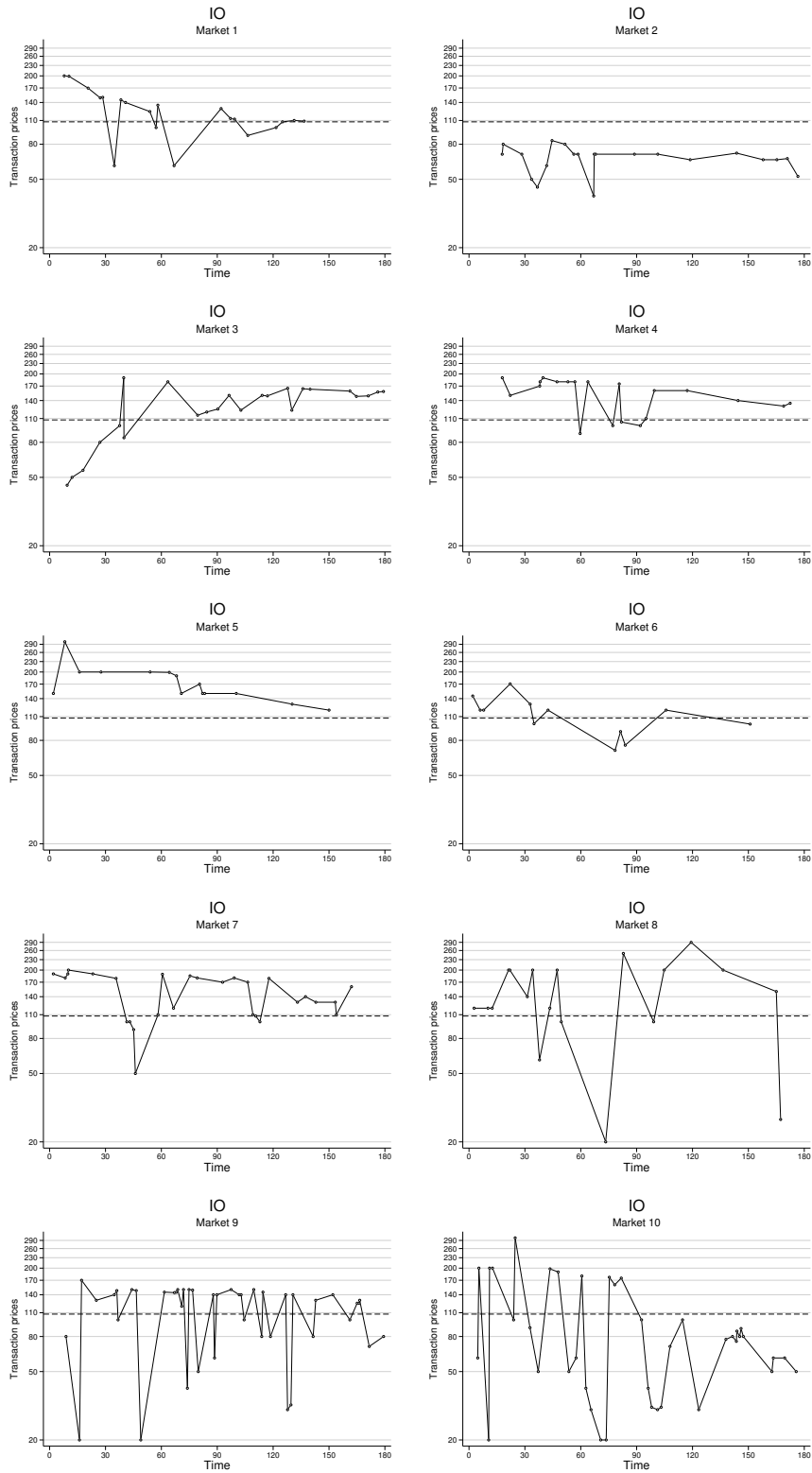


Figure C6: **Individual transaction prices for each market of Treatment IO.** The dashed line represents the expected value of 108.

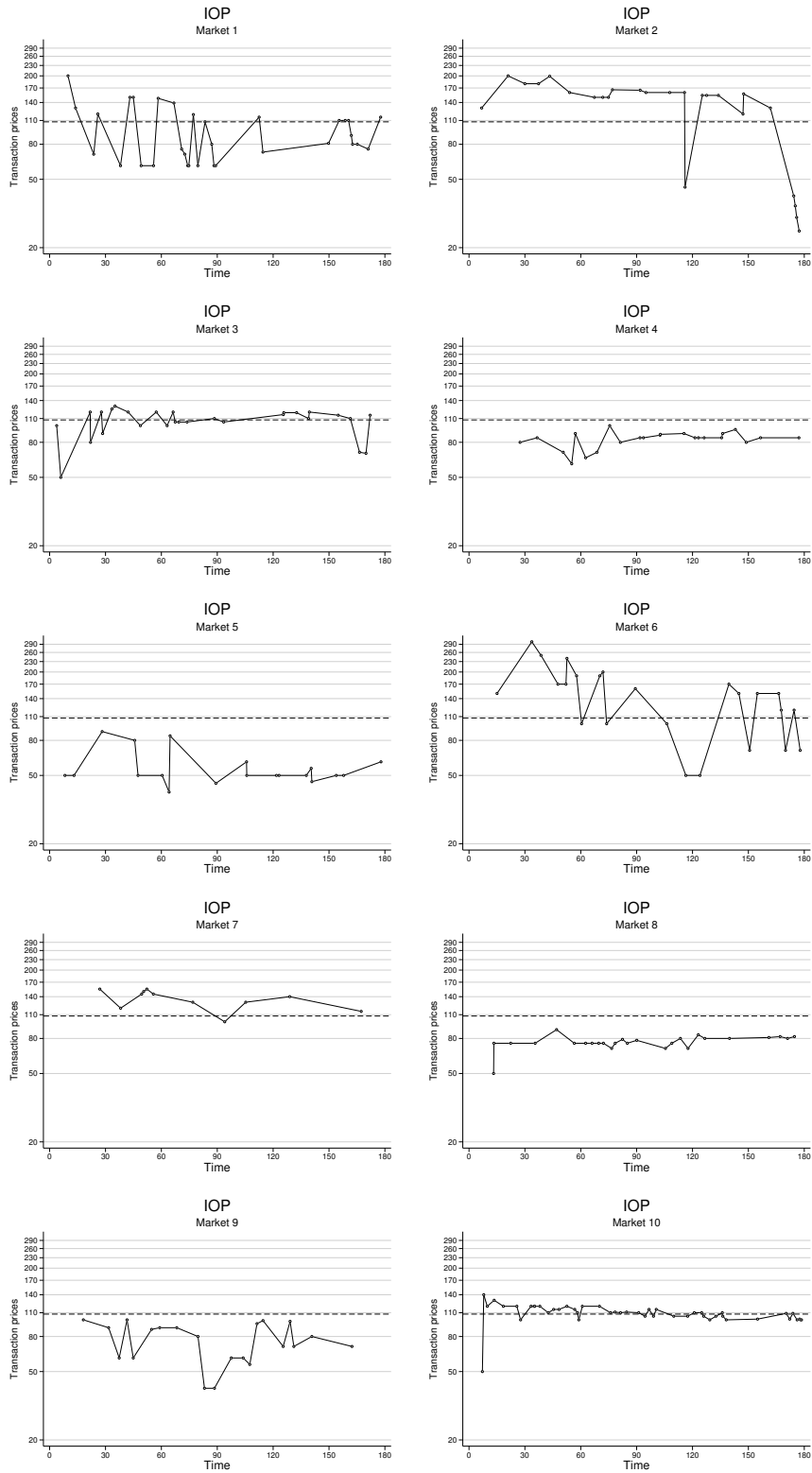


Figure C7: **Individual transaction prices for each market of Treatment IOP.** The dashed line represents the expected value of 108.

**University of Innsbruck - Working Papers in Economics and Statistics**  
**Recent Papers** can be accessed on the following webpage:

<https://www.uibk.ac.at/eeecon/wopec/>

- 2019-06 **Christoph Huber, Julia Rose:** Individual attitudes and market dynamics towards imprecision
- 2019-05 **Felix Holzmeister, Jürgen Huber, Michael Kirchler, Florian Lindner, Utz Weitzel, Stefan Zeisberger:** What Drives Risk Perception? A Global Survey with Financial Professionals and Lay People
- 2019-04 **David M. McEvoy, Tobias Haller, Esther Blanco:** The Role of Non-Binding Pledges in Social Dilemmas with Mitigation and Adaptation
- 2019-03 **Katharina Momsen, Markus Ohndorf:** When do people exploit moral wiggle room? An experimental analysis in a market setup
- 2019-02 **Rudolf Kerschbamer, Daniel Neururer, Matthias Sutter:** Credence goods markets and the informational value of new media: A natural field experiment
- 2019-01 **Martin Geiger, Eric Mayer, Johann Scharler:** Inequality and the Business Cycle: Evidence from U.S. survey data
- 2018-18 **Matthias Sutter, Jürgen Huber, Michael Kirchler, Matthias Stefan, Markus Walzl:** Where to look for the morals in markets?
- 2018-17 **Rene Schwaiger, Michael Kirchler, Florian Lindner, Utz Weitzel:** Determinants of investor expectations and satisfaction. A study with financial professionals
- 2018-16 **Andreas Groll, Julien Hambuckers, Thomas Kneib, Nikolaus Umlauf:** LASSO-Type Penalization in the Framework of Generalized Additive Models for Location, Scale and Shape
- 2018-15 **Christoph Huber, Jürgen Huber:** Scale matters: Risk perception, return expectations, and investment propensity under different scalings
- 2018-14 **Thorsten Simon, Georg J. Mayr, Nikolaus Umlauf, Achim Zeileis:** Lightning prediction using model output statistics
- 2018-13 **Martin Geiger, Johann Scharler:** How do consumers interpret the macroeconomic effects of oil price fluctuations? Evidence from U.S. survey data
- 2018-12 **Martin Geiger, Johann Scharler:** How do people interpret macroeconomic shocks? Evidence from U.S. survey data

- 2018-11 **Sebastian J. Dietz, Philipp Kneringer, Georg J. Mayr, Achim Zeileis:** Low visibility forecasts for different flight planning horizons using tree-based boosting models
- 2018-10 **Michael Pfaffermayr:** Trade creation and trade diversion of regional trade agreements revisited: A constrained panel pseudo-maximum likelihood approach
- 2018-09 **Achim Zeileis, Christoph Leitner, Kurt Hornik:** Probabilistic forecasts for the 2018 FIFA World Cup based on the bookmaker consensus model
- 2018-08 **Lisa Schlosser, Torsten Hothorn, Reto Stauffer, Achim Zeileis:** Distributional regression forests for probabilistic precipitation forecasting in complex terrain
- 2018-07 **Michael Kirchler, Florian Lindner, Utz Weitzel:** Delegated decision making and social competition in the finance industry
- 2018-06 **Manuel Gebetsberger, Reto Stauffer, Georg J. Mayr, Achim Zeileis:** Skewed logistic distribution for statistical temperature post-processing in mountainous areas
- 2018-05 **Reto Stauffer, Georg J. Mayr, Jakob W. Messner, Achim Zeileis:** Hourly probabilistic snow forecasts over complex terrain: A hybrid ensemble postprocessing approach
- 2018-04 **Utz Weitzel, Christoph Huber, Florian Lindner, Jürgen Huber, Julia Rose, Michael Kirchler:** Bubbles and financial professionals
- 2018-03 **Carolin Strobl, Julia Kopf, Raphael Hartmann, Achim Zeileis:** Anchor point selection: An approach for anchoring without anchor items
- 2018-02 **Michael Greinecker, Christopher Kah:** Pairwise stable matching in large economies
- 2018-01 **Max Breitenlechner, Johann Scharler:** How does monetary policy influence bank lending? Evidence from the market for banks' wholesale funding

University of Innsbruck

Working Papers in Economics and Statistics

2019-06

Christoph Huber, Julia Rose

Individual attitudes and market dynamics towards imprecision

**Abstract**

In real world financial markets, dividend processes as well as fundamental values are governed by imprecision; neither the objective probabilities of returns nor the actual amounts of possible returns are known for certain. With a novel experimental approach, we analyze the impact of risk, imprecision in probabilities (ambiguity), imprecision in outcomes, and a combination of the latter two in an individual decision task and in a market environment. In contrast to the previous literature, we do not find any significant imprecision premia for imprecise probabilities. However, we do find significant and persistent imprecision-in-outcomes seeking in the individual task as well as the market setting. Looking deeper into the combination of individual attitudes and market behavior, we find that these patterns survive despite a high level of heterogeneity in individual's beliefs about outcomes.

ISSN 1993-4378 (Print)

ISSN 1993-6885 (Online)