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On asset prices and leverage requirements - an experimental analysis

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Abstract

The present study contributes to the ongoing debate on possible costs and benefis of leverage requirements. In particular, we run two series of electronic call auctions with heterogeneous agents in the laboratory where we change the leverage bounds as a treatment variable. Over the two treatments, participants in our experiment realise about forty percent of the possible gains from trade. We show, in accordance the theory, leverage bounds do affect the efficiency of the market and the price of the asset.

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1. Introduction

Describing the roots of the last financial crisis, Geanakoplos (2011) claims that "collateral rates or leverage can be more important to economic activity and prices than interest rates, and more important to manage." This perspective is shared by policy-makers during the last few years as, e.g., the EU capital requirements regulation (CRR, No 575/2013) pays a special interest to the legal requirements to the leverage bounds. In details, the Basel Committee on Banking Supervision (BCBS) intends to set the binding requirement to the leverage ratio on January 1, 2018.

The evident impact of leverage on the financial stability was reflected by theoretical models focusing on the role of leverage at the asset level (see Fostel and Geanakoplos, 2008; Gârleanu and Pedersen, 2011). Further, Geanakoplos and Zame (2014) and Geanakoplos (2010) recently proposed models endogenising leverage within a general equilibrium framework. Theoretically, the welfare impact of leverage requirements is ambiguous: lower leverage requirements make it possible for buyers to hold more assets but create more competition, thereby driving up the prices.

The closest study to our is the seminal paper of Cipriani, Fostel, and Houser (2012) who are testing two border cases of market design: No-Leverage Economy and Leverage Economy. In our experimental setup, we will analyse more subtle institutional changes in the leverage requirements at the market where the asset price is sensitive to our exogenously imposed collateral (leverage) requirements. Moreover, we would like to implement a more realistic experimental markets instead of eliciting the supply and demand by the strategy method for different prices employed by Cipriani, Fostel, and Houser (2012).

The trading institution we consider in our analysis is the standard continuous double auction. Analysing the Bayesian Nash equilibria of the call auction we show that leverage increases the asset price. This is also the central hypothesis tested in our experiment.

2. The model

2.1. **The call auction.** We formalise a typical call auction as follows. There is a single period lived asset with random terminal payoff x. The trading environment includes n risk neutral traders, who can be buyers or sellers. Buyers have a higher valuation of the asset, $x+k$, while sellers have a lower valuation, $x-k$.[2] In order to keep the model simple, we assume that all buyers have the same premium k and all sellers have a discount of the same size. There are n_B buyers and n_S sellers in the model; $n_B + n_S = n$.

Each trader can enter ℓ limit orders for ℓ units of the asset into the call auction. The order book is closed, i.e., traders cannot observe the orders placed by other traders.

The orders are collected in the order book, and after a specified time the market is cleared. The clearing price range corresponds to the interval of prices for which trading volume is maximised and no buy order with a higher limit price and no sell order with a lower limit price is left unexecuted. Given the clearing price range, the transaction price is determined by a pricing rule $\kappa \in [0,1]$. Let p_u and p_l denote the upper and lower bounds of the price range. The transaction price implied by pricing rule κ is then $(1-\kappa)p_l + \kappa p_u$. Satterthwaite and Williams (1989) show that for $\kappa = 1$ sellers have no incentive to act strategically. Demanding a price higher than their true valuation will just reduce the probability of having their order executed, but will not affect the price they receive. Buyers, however, might misrepresent their valuation to affect the price they have to pay. Conversely, for $\kappa = 0$ buyers will have no incentive to misrepresent while sellers will demand more than their true valuations. Following many real world call auction algorithms[3], we employ the following pricing rule: $\kappa = 0$ when there are more sellers than buyers, $\kappa = 1/2$ if the number of buyers and sellers is equal and $\kappa = 1$, otherwise.

[2]This difference in valuation $2k$ represents individual portfolio considerations or tax brackets.

[3]For example EURONEXT and Xetra, as the quotations in the introduction demonstrate.

If there is excess demand or supply for a given transaction price, traders on the more populated market side with limit prices above the transaction price have their orders fulfilled, while traders whose limit prices equal the transaction price split the remaining shares equally between themselves. Other possible rationing methods are random execution or time priority. For risk neutral traders the proportionate allocation of assets and random execution is equivalent. In the experiment reported below, we use time priority, which is often employed in real asset markets, like NASDAQ CROSS, Euronext and Xetra, to encourage early order placement.

Before we describe the equilibrium of the model, we want to introduce the notion of allocational efficiency that will be important for evaluating the equilibrium and the experimental results. Our model exhibits strong incentives to trade due to the difference in valuation, k. Allocational efficiency requires that this difference in valuation is realised, i.e., that those traders who value the asset most buy and those who value the asset least sell. Since all the traders can trade ℓ assets at most, the maximum number of efficiency improving trades is $\underline{n} = \min\{n_B, n_S\}\ell$. Efficiency in our model corresponds to the utility surplus that is achieved through trade.

Definition 1 (Allocational efficiency)**.** We say that the outcome of a call auction is allocational efficient when the maximum amount of $\underline{n}$ assets are traded from sellers to buyers; the maximal corresponding utility surplus is $2k\underline{n}\ell$.

In the analysis of the experimental data, we distinguish absolute allocational efficiency (AAE) as the realised gains from trade relative to the maximum gains from trade and relative allocational efficiency (RAE) as the realised gains from trade relative to the gains from trade realised in the most efficient Bayesian Nash equilibrium.

3. Experimental design

There is a single asset traded in our experimental stock market that pays different dividends depending on the state of nature. In the state U, the asset

Table 1. Dividends that the asset pays to traders of type A and B conditional on the realised state: U, or D. The probability of each state is given in parentheses.

State:	U (50%)	D (50%)
Type A	250	550
Type B	150	450

pays 500 ECU, and in the state D, it pays 200 ECU. States U and D both occurred with probability 50%. The payoff to the traders also depends on their type. Type A traders have a premium of $k = 50$ ECU, type B traders a discount $k = 50$ ECU. In each auction, there are 3 traders of type A and 3 of B-traders. The dividend payments of the asset conditional on the states of nature and trader types are displayed in Table 1. In the economy, the agents can mutually trade the assets.

3.1. **Collateral requirements.** We consider two treatments in our experiment. In accordance with Geanakoplos and Zame (2014) we introduce another exogenous parameter $\alpha \in [0, 250]$ that specifies the size of the security promise that can be made using an asset as collateral. The case of $\alpha = 0$ corresponds, in fact, the NL-economy of Cipriani, Fostel, and Houser (2012). Since we do not endowe the participants with cash in our experiment, it makes no sense to study the situation of $\alpha = 0$ since clearly no trade is possible in this case. Instead, in our two treatments, we analyse in our study we have $\alpha \in \{100, 250\}$. The case $\alpha = 250$ corresponds to to the situation where the whole dividend in the state D, i.e. 250 ECU can be used as a collateral. In the intermediate treatment $\alpha = 100$ only some part of the dividend of the asset can be used as a collateral.

To ensure that differences across treatments are not attributable to different realisations of the states of nature, the random draw was done just for the 100-treatment and replicated for the 250-treatment afterwards (as, e.g., in Dominitz and Hung, 2009).

3.2. **The call auction mechanism.** At the beginning of each auction, every trader is endowed with three assets. The subjects can generate profit from trading, i.e., by selling the asset at a price higher than the realised dividend or by buying the asset for a price lower than the realised dividend. Each trader first decides whether to place a limit buy or limit sell order and then specifies the limit price. A trader can enter only three orders per auction. Limit prices are restricted to integers between 0 and 500. When entering their orders, the traders are unaware of the other traders' orders. Once all traders have submitted their orders to the order book, the market is cleared. If there are several identical orders and not all of them can be executed, those orders that are entered earliest are given priority.

After each auction the state of nature is revealed and every trader sees all orders, the auction price, the numbers of shares traded and her own period profit and accumulated profits on her trading screens. The final payoff the participants receive is the sum of all period profits converted into Euros at the rate of 1 Euro = 1000 ECU.

3.3. **Experimental procedures.** The experiment was run at the lab of Vienna Center for Experimental Economics in May 2017. The call auction experiment was implemented using the experimental software z-tree (Fischbacher, 2007). Subjects were students of mathematics or economics at the University of Vienna. They were recruited using ORSEE (Greiner, 2004). Around 30 subjects were invited to any of our four sessions. Having read the instructions, the participants did complete four test auctions against prespecified computer orders to get familiar with the trading situation. After these test auctions the subjects did answer 12 questions to assess their understanding of the trading environment. To guarantee that only subjects with intimate knowledge of the market environment participate in the experiment, only the 24 subjects who answered all questions with the fewest mistakes participated in the analysed

Table 2. $c \in \{2, 3, 3.3, 3.8, 4, 4.3, 4.5, 4.8, 5, 5.2, 5.5, 6, 6.5, 7, 8\}$

LEFT	RIGHT	Decision
with 50% Chance 10 Euro and with 50% Chance 0 Euro	c Euro with certainty	LEFT ☐ ☐ RIGHT

part of the experiment; the remaining subjects will receive a fixed fee of 10 Euros and were asked to leave.[4]

Then, we elicited the risk attitudes of the remaining 24 participants. In this part, each subject was shown 15 binary choices, one pair at a time. Each binary choice takes the form as in Table 2. The left hand choice is always a lottery with 50% of chance to win 10 Euro and zero otherwise. The right hand choice is a certainty payment, ranging from 2 Euro to 8 Euro. Subjects are asked to choose, for each pair, between the "LEFT' alternative and the "RIGHT" alternative.

After subjects made choices for all 15 binary choices, they have seen a table with the complete list of choices, in the sequence of c increasing, as in Table 11. They are then given a chance to change their choices. For experimental payment, one of the 15 binary choices is randomly chosen for each subject. If the subject chooses "LEFT", a random draw decides his payment. If the subject chooses "RIGHT", he is paid c Euro. Subjects were not informed of their payments until the end of the experiment.

After eliciting the risk attitudes the 24 participants in the particular Sessions 1-4 will be grouped into 4 markets. Each market will last for 14 periods or auctions so that our sample consists of 256 auctions of altogether 16 markets of which always 8 relied on each of our two treatments.[5] Thus, we have eight independent observations for both treatments.

[4]This introductory part of each session, where participants read the instructions, took part in four test auctions and answered the questions, lasted for about 50 minutes.

[5]The participants were not informed in advance how many auctions will be played.

3.4. **Equilibrium prediction.** Let us describe the efficient equilibria for the three treatments α described above which are defined by asset price p_α and asset holdings of participants of type A and B such that asset market clears and that agents maximise their payoff subject to the budget constraint.

There are many other equilibria in our economy. For example, there exists symmetric Bayesian Nash equilibrium where A-agents are only willing to pay 0 and B-agents demand a price above 400. This is an equilibrium where no trade takes places in all the three treatments. The multiplicity of Nash equilibria is not surprising here at all. In contrast, it is a common property of games where the possible gains can only be realised by mutual actions of a group of players (here: by a pair of agents of type A and B). In a situation where only bilateral trade can possibly be profitable, the concept of Nash equilibrium that considers exclusively the profitability of unilateral deviations is too weak. In the rest of the paper we will discuss the efficient equilibria only. In fact, to get the efficient equilibria, it is enough to consider the mutual deviations of all the two-agents coalitions as, e.g., in Bernheim, Peleg, and Whinston (1987) in our set-up.

The equilibrium price in the 100-treatment is $p_{100} = 300$ assuming risk-neutral traders B. In 100-treatment, cash of agents A is the scarce commodity. In result, every agent A puts 1 buy order with the limit price as high as possible. (The maximum amount available to agent A is 400 ECU, she can borrow 300 ECU against her 3 assets and 100 against the buy order). The agents B are submitting all the sell orders they can (i.e. 9). Considering the expected value for B-agents (300 ECU), we see that any agent has an incentive to undercut any sell order higher than 300 ECU. Thus, the identical sell orders of 300 ECU are the only stable constellation at the market. Consequently, all the three A-agents are buying one asset each for $p_{100} = 300$.

The equilibrium price in the 250-treatment is $p_{250} \in [300, 400]$. Any price from this interval can establish in the equilibrium, the lower bound describes the expected value of the asset of agent B, the upper bound describes the expected value of the asset of agent A. This equilibrium is allocationally efficient in the sense that all 9 assets from B-agents are purchased by A-agents.

Table 3. Trades w.r.t. types

	$A \to A$	$A \to B$	$B \to A$	$B \to B$	Σ
Number of trades	139	159	340	176	814
	17.1%	19.5%	41.8%	21.6%	100.0%
Number of trades	208	153	535	154	1050
	19.8%	14.6%	51.0%	14.7%	100.0%

In comparison to many studies of Geanakloplos and co-authors, the price of the asset increases only weakly with leverage in our setup; $p = 300$ belongs to the set of equilibrium prices for both treatments. This fact follows from the linearity of our model. We find this feature of our model advantageous. Considering our hypothesis that price increases with leverage we are testing "the worst case scenario" in our paper.

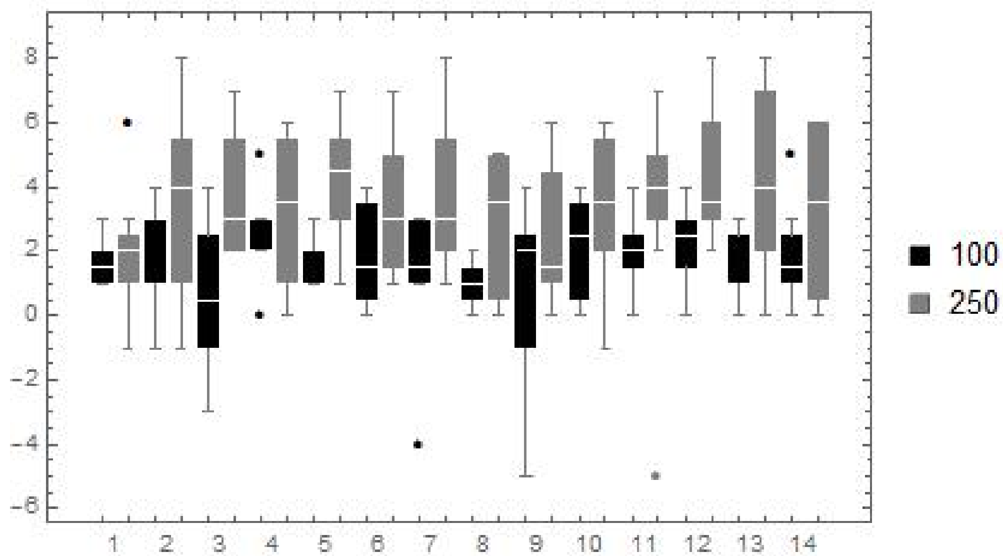
4. Experimental Results

Table 3 presents all the realised trades. In the efficient equilibrium with risk-neutral traders in treatment 100 we have three trades from agents B to A at any market, i.e. alltogether $3 \times 14 \times 8 = 336$ efficient trades. In comparison to that, in our experimental sample, just 340-159=181 shares were transfered from B traders to A traders. Simirarly, comparing the equilibrium benchmark for the treatment 250, where we have $9 \times 14 \times 8 = 1008$ efficient trades, we observe 535-153=382 shares transfered (netto) from B to A.

The experiment that is closest to ours is the experiment conducted by Pouget (2007) because he also models the call auction as a strategic game. He observes average gains from trade of around 30% of the full extraction level. In this perspective, despite of deviations from equilibrium strategies, our experimental call auction performs reasonably well.

Result 1. (Allocational efficiency) Overall. the allocational efficiency of the call auction is above 40%.

Figure 1. Efficient trades



In Figure 1 we can see that the efficiency of the 250-market is above the efficiency of 100-market in almost all of the trading periods. Considering the 8 independent observations (8 markets) we have for both treatments, the difference in efficiency is, not surprisingly, highly significant. The non-parametric Wilcoxon-Mann-Whitney test rejects the hypothesis the two samples were selected from populations having the same distribution ($p = 0.0045$).

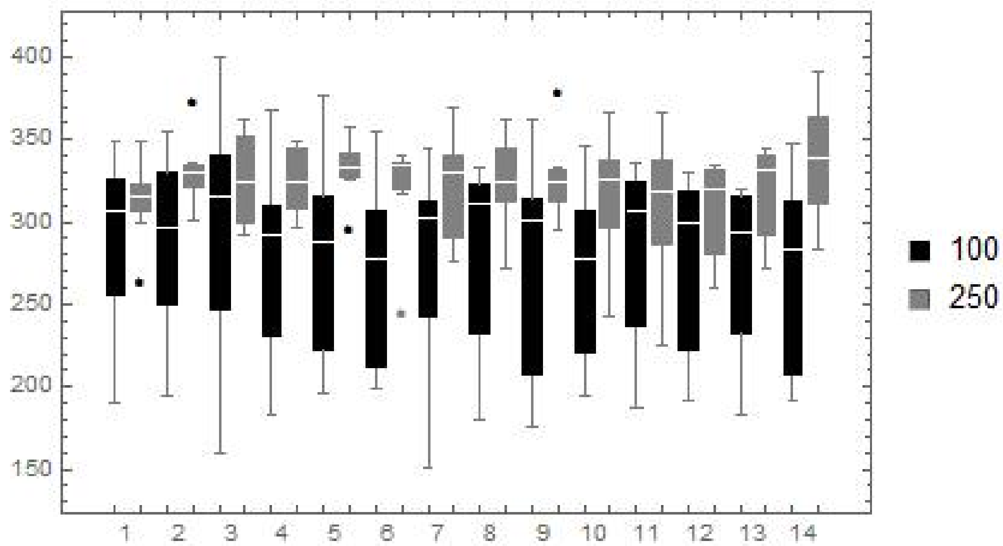
Of course, much more interesting is the influence of different leverage bounds to the asset price, since here the difference in the equilibrium prediction is much more subtle. The main statistical results are summed up in the table below.

Table 4. Summary of Trades

Treatment	Mean	# Trades	Std. Deviation
100	256.26	814	80.805
250	320.46	1050	59.447

Comparing Tables 7 and 8 in the Appendix we can see that in 6 out of 8 markets a higher leverage bound leads to a higher price, only in market 3 we

Figure 2. Prices



see the opposite and in market 4 the average prices are almost identical. Considering the time trend we can see at Figure 2 that the price in 250-treatment is systematically above the price in 100-treatment.

Employing the non-parametric Wilcoxon-Mann-Whitney test for our 8 independent observations, the difference in prices is only weakly significant ($p = 0.066$).

Result 2. (Price and leverage bounds) Higher leverage bounds cause higher asset prices in accordance the theoretical prediction.

5. Discussion and Conclusions

In the presented paper we analyse the question originally raised in the experimental context by Cipriani, Fostel, and Houser (2012), namely in which magnitude the leverage requirements affect the asset price. In comparison to Cipriani, Fostel, and Houser (2012), who study just two border cases of market design: No-Leverage Economy and Leverage Economy, we compare two different levels of leverage requirements. Moreover, instead of eliciting the supply and demand by the strategy method for different prices, we test the question in "hot" experimental markets.

In our experimental setup of a double auction, we show that even moderate institutional changes in leverage requirements affects substantiallly the market efficiency and the asset price. From this perspective, our paper confirms the theoretical finding that the asset price is sensitive to exogenously imposed collateral (leverage) requirements.

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6. Appendix*

Table 5. Treatment 100, efficient trades

Market	1	2	3	4	5	6	7	8
1	2	2	1	2	1	1	1	3
2	4	3	3	1	1	1	-1	1
3	0	2	1	0	4	-3	-2	3
4	3	3	2	2	0	5	2	2
5	3	2	2	1	1	2	2	1
6	3	2	1	1	0	4	4	0
7	3	3	2	1	3	1	-4	1
8	1	2	1	2	0	0	1	1
9	3	2	-1	2	4	-5	-1	2
10	3	2	3	1	0	4	4	0
11	3	2	2	2	0	4	1	2
12	3	3	0	3	4	2	2	1
13	1	0	1	3	1	2	3	1
14	1	3	2	1	5	0	2	1
∅	2,36	2.21	1.43	1.57	1.71	1.29	1.00	1.36

Table 6. Treatment 250, efficient trades

Market	1	2	3	4	5	6	7	8
1	2	6	1	1	-1	2	3	2
2	6	5	-1	0	2	8	3	5
3	7	4	2	3	2	2	3	7
4	0	0	6	4	3	2	6	5
5	5	5	4	6	1	4	2	7
6	5	3	1	3	1	2	5	7
7	3	6	3	2	1	5	8	2
8	5	5	3	0	0	1	5	4
9	5	0	1	2	1	1	4	6
10	6	3	-1	6	1	3	4	5
11	5	4	-5	2	5	4	7	4
12	7	4	3	2	8	3	5	3
13	8	8	2	0	5	6	2	3
14	4	0	0	3	6	6	6	1
⌀	4,86	3,79	1,36	2,43	2,50	3,50	4,50	4,36

Table 7. Treatment 100, prices

Market	1	2	3	4	5	6	7	8
1	308.00	349.33	331.67	251.67	320.00	190.00	257.14	305.00
2	284.00	328.00	307.50	332.00	285.00	194.00	213.00	355.00
3	360.00	322.00	300.00	318.33	311.67	191.00	159.52	400.00
4	287.14	320.00	300.00	297.80	266.00	193.75	182.50	368.00
5	300.00	297.50	331.25	278.14	232.50	211.67	195.83	376.67
6	218.00	314.17	301.67	281.50	274.00	198.18	203.33	355.00
7	300.00	320.56	305.00	306.00	288.75	194.17	151.38	344.00
8	316.67	325.71	320.00	305.56	248.33	180.00	213.75	332.50
9	311.67	304.82	316.67	296.15	225.00	187.50	176.00	361.67
10	272.00	302.50	283.33	311.64	230.00	194.29	210.00	346.33
11	308.00	326.20	325.00	306.75	253.33	220.00	187.27	336.25
12	306.00	321.00	293.33	329.38	233.75	192.00	207.69	318.33
13	320.00	318.70	276.67	312.14	266.88	197.27	183.33	310.83
14	325.00	271.00	295.00	300.71	212.22	191.25	201.76	347.50
$\not\varnothing$	297.45	314.87	306.10	302.32	254.94	194.48	189.37	342.46

Table 8. Treatment 250, prices

Market	1	2	3	4	5	6	7	8
1	348.33	313.21	263.33	318.56	300.00	313.75	324.20	322.50
2	325.89	332.71	300.36	335.13	316.25	333.89	324.00	371.88
3	341.80	296.22	362.27	305.13	292.00	351.67	301.00	354.55
4	337.25	296.67	302.47	345.13	312.00	346.67	311.70	348.28
5	331.33	357.78	333.75	294.60	326.67	342.14	341.33	326.09
6	333.89	333.64	244.62	334.67	316.75	338.75	340.75	321.08
7	335.45	369.09	302.67	275.50	276.20	345.00	326.25	332.79
8	349.22	362.14	271.75	319.30	303.00	341.67	321.73	325.55
9	319.00	378.33	332.44	295.57	309.00	328.00	314.86	330.86
10	340.67	366.36	295.10	242.50	297.50	333.86	331.50	319.43
11	311.29	366.25	225.00	275.00	294.88	336.00	326.77	341.17
12	322.14	317.50	263.67	259.50	296.88	334.88	330.73	334.85
13	331.10	343.90	272.36	285.00	299.17	339.11	330.70	343.22
14	350.67	391.67	284.08	376.67	290.00	337.50	329.67	339.31
$\not\emptyset$	333.74	345.21	285.85	302.83	303.55	337.59	324.79	334.52

Table 9. Treatment 100, volumes

Market	1	2	3	4	5	6	7	8
1	5	3	3	6	3	8	7	5
2	5	5	4	5	2	10	10	4
3	4	5	2	6	6	10	21	3
4	7	9	2	10	5	16	16	3
5	4	8	4	14	4	6	24	3
6	5	6	3	6	5	11	24	2
7	5	9	3	12	8	12	29	5
8	6	7	2	9	6	8	8	4
9	3	11	3	13	8	8	10	3
10	5	8	3	14	7	7	9	3
11	3	15	2	8	9	5	11	4
12	3	12	3	13	8	5	13	3
13	3	10	3	7	8	11	6	6
14	2	7	4	7	9	8	17	2
Σ	60	115	41	130	88	125	205	50

TABLE 10. Treatment 250, volumes

	1	2	3	4	5	6	7	8
1	3	14	15	9	2	4	5	6
2	9	7	14	8	8	9	5	8
3	10	9	11	8	5	6	10	11
4	8	3	15	8	5	6	10	18
5	15	9	16	10	9	7	6	23
6	9	11	13	6	8	4	8	25
7	11	11	15	6	5	7	12	24
8	9	7	12	10	3	6	11	20
9	5	6	9	7	5	8	7	21
10	9	11	10	8	4	7	6	7
11	7	8	21	8	8	7	13	12
12	14	4	15	6	8	8	11	13
13	10	10	11	4	6	9	10	9
14	9	6	12	3	8	8	9	16
Σ	128	116	189	101	84	96	123	213

LEFT	RIGHT	Decision
with 50% Chance 10 Euro with 50% Chance 0 Euro	2 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	3 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	3.3 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	3.8 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	4 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	4.3 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	4.5 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	4.8 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	5 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	5.2 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	5.5 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	6 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	6.5 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	7 Euro with certainty	LEFT☐ ☐ RIGHT
with 50% Chance 10 Euro with 50% Chance 0 Euro	8 Euro with certainty	LEFT☐ ☐ RIGHT

Table 11. The complete table of 15 binary choices (risk elicitation).