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Measuring Strategic Uncertainty in Coordination Games

Frank Heinemann*
Rosemarie Nagel**
Peter Ockenfels***

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*Frank Heinemann, Ludwig-Maximilians-Universität München, frank.heinemann@lrz.uni-muenchen.de
**Rosemarie Nagel, Universitat Pompeu Fabra, Barcelona, Spain, rosemarie.nagel@econ.upf.es
***Peter Ockenfels, Goethe-Universität Frankfurt am Main, Germany, peter@ockenfels.com

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Speaker: Prof. Konrad Stahl, Ph.D. · Department of Economics · University of Mannheim · D-68131 Mannheim,
Phone: +49(0621)1812786 · Fax: +49(0621)1812785

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Measuring Strategic Uncertainty in Coordination Games*

By Frank Heinemann,[a] Rosemarie Nagel,[b] and Peter Ockenfels[c]

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Abstract

This paper explores three aspects of strategic uncertainty: its relation to risk, predictability of behavior and subjective beliefs of players. In a laboratory experiment we measure subjects' certainty equivalents for three coordination games and one lottery. Behavior in coordination games is related to risk aversion, experience seeking, gender, and age.

From the distribution of certainty equivalents among subjects we estimate probabilities for successful coordination in a wide range of games. For many games, success of coordination is predictable with a reasonable error rate. The best response to observed behavior is close to the global-game solution.

Comparing choices in coordination games with revealed risk aversion, we estimate subjective probabilities for successful coordination. In games with a low coordination requirement, most subjects underestimate the probability of success. In games with a high coordination requirement, most subjects overestimate this probability. Estimated error rates of quantal response equilibria can be used as measure of strategic uncertainty in coordination games.

JEL classification: C 72, C 91, D 81, D 84

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[a] Ludwig-Maximilians-Universität München, Germany, frank.heinemann@lrz.uni-muenchen.de
[b] Universitat Pompeu Fabra, Barcelona, Spain, rosemarie.nagel@econ.upf.es
[c] Goethe-Universität Frankfurt am Main, Germany, peter@ockenfels.com

1. Introduction

Coordination games with strategic complementarities typically have multiple equilibria. Multiplicity of equilibria is associated with strategic uncertainty to which we cannot assign probabilities by pure deductive reasoning. Strategic uncertainty has often been described as a situation of Knightian (endogenous) uncertainty as opposed to risky situations that are characterized by given probabilities. In this paper we present an experiment designed to measure individual attitudes towards strategic uncertainty and compare them with risk aversion and other personal characteristics.

Since Knight (1921), the literature distinguishes two kinds of uncertainty. Risk (or exogenous uncertainty) is characterized by the existence of given (not necessarily known) probabilities for all possible states of the world. A lottery is the prototype of a risky situation. Endogenous uncertainty arises in situations, where the outcome depends on social interaction. Imagine a situation, where an investment pays off, if and only if a sufficient number of agents takes the same action. If nobody invests, then the investment of a single agent fails. Not investing is an equilibrium. If everybody invests, then the investment is profitable. Investing is another equilibrium and it is the efficient strategy profile. In this situation, neoclassical theory cannot predict behavior, nor assign probabilities, because both outcomes are consistent with optimizing behavior and rational expectations. Efficiency considerations are relevant for normative statements, but one cannot rely on them having any descriptive power.

Experiments on coordination games, however, show clear patterns of behavior. Van Huyck, Battaglio and Beil (1990, 1991) show that subjects coordinate rather quickly on an equilibrium that depends on group size, coordination requirement and experience. A high degree of efficiency can be achieved in pair wise matchings, but not in situations that require the coordination of all members in a group of seven or more players. Berninghaus and Erhart (2001) show that disaggregate information enhances efficiency. Heinemann, Nagel and Ockenfels (2002) compare coordination games with public and private information and find no significant difference in predictability of aggregate behavior, even though the private information game has a unique equilibrium, while the public information game has multiple equilibria. Subjects coordinate on equilibria that are fairly predictable and vary (depending on the payoff function) from the payoff-dominant to the risk-dominant equilibrium. Public information does enhance efficiency. Comparative statics with respect to parameters of the payoff function follow the risk-dominant equilibrium. Schmidt et al. (2003) use different coordination games, in which they vary either risk dominance or the level of payoff dominance, holding the other constant. They show that changes in risk dominance affect behavior, while changes in the level of payoff dominance do not.

Risk dominance and other theoretical refinement concepts are characterized by assumptions on players' beliefs about other players' behavior. While some concepts are rather ad hoc, risk dominance has an axiomatic justification, laid out in Harsanyi and Selten (1988). Related to this, the theory of global games, developed by Carlsson and van Damme (1993) and advanced by Morris and Shin (2000), assumes that players behave as if they have private information about payoffs. In the limit, when the variance of private information vanishes, the global game is characterized by the belief that the proportion of players, who contribute to a coordination game has a uniform distribution in [0,1]. In binary-action games with two players the global-game solution coincides with risk dominance. In other games both concepts give similar predictions. Risk dominance has a firm axiomatic foundation, the global-game solution is easier to calculate.

Morris and Shin (2002) propose that strategic uncertainty can be measured in a game, where private beliefs about the payoff function are combined with private values. We designed an experiment that compares behavor in coordination games with lottery choices. In laboratory experiments, subjects typically behave risk averse. The degree of risk aversion is private information, and it affects the private value (utility) of a monetary payment. The relation between uncertainty about players' risk aversion and the global-game approach has been explored by Hellwig (2002).

In our experiment, we compare lottery choices with choices to engage in coordination games. Thereby, we measure risk aversion and attitudes towards strategic uncertainty. The experiment extracts security equivalents for a lottery to win 15 Euro with probability 2/3 and thresholds to participate in a coordination game, where a subject gets 15 Euro, provided that a fraction k of the other players does also join the coordination game. Observed thresholds may be interpreted as security equivalents for the respective coordination game. Thereby, we have comparable measures for both kinds of uncertainty. The experiment combines these games with an extended questionnaire containing Zuckerman's Sensation Seeking Scale V (SSS-V) that psychologists use to characterize personalities.[1]

Naturally, thresholds fall with rising coordination requirement k. Subjects prefer lower safe payoffs, because they realize that it is less likely to achieve a higher degree of coordination. For most subjects, the security equivalent of the lottery is in between the thresholds for coordination games with $k = 1/3$ and $k = 2/3$. These subjects view actions that require one third of the other players to join as less risky than the lottery, which in turn appears less risky than an action that requires 2/3 of the others to join.

Security equivalents of coordination games and the lottery are positively correlated. Subjects, who avoid risk, do also avoid strategic uncertainty. The amount that a subject is willing to risk for participating in a coordination game rises with falling risk aversion and is positively related to experience seeking and age. Males tend to have higher security equivalents than females.

The distribution of certainty equivalents is sensitive to the subject pool. Running the experiment at three places with tractable differences between subject pools, we find significant differences in behavior. A possible explanation is that homogeneity of a group increases the expected success of coordination. But, even across the three groups, many coordination games with multiple equilibria have a predictable outcome. For one half of the games covered by our experiment, success or failure can be predicted with an error rate below

[1] For details, see Zuckerman (1994).

five per cent for all three data sets. The probability that a randomly selected player chooses the uncertain action can be approximated by a logistic distribution.

The best response of a risk neutral player to observed behavior is close to the global-game solution. Using lottery choices as measures of individual risk aversion, we estimate utility functions and compare expected utilities of various refinement strategies. For most subjects, the global-game solution calculated under risk neutrality leads to a higher expected utility than any other considered strategy. From this, we conclude that the global-game solution can be recommended to agents who are engaged in a one-shot coordination game.

Using the measures of individual risk aversion, we estimate subjective probabilities for successful coordination. In games that require 1/3 of the other players to get a reward, most subjects underestimate success probabilities. In games that require 2/3 of the others or all group members, most subjects overestimate success probabilities. Simulations indicate that subjects have probabilistic beliefs about success or failure of coordination rather than beliefs about the behavior of other players.

We estimate three models of behavior in coordination games that differ in their treatment of expectations: subjective beliefs are modeled (i) by a logistic distribution for the probability of success that depends on payoffs and on the coordination requirement, (ii) by a logistic distribution for the probability of other players choosing the uncertain action, and (iii) by quantal response equilibria. Maximum likelihood estimates indicate that subjects underestimate the effect of the safe payoff on the probability for successful coordination. Models (i) and (ii) have similar log-likelihoods, so that neither can be rejected in favor of the other. Quantal response equilibria achieve a lower likelihood.

The response precision of quantal response equilibria may be used as a measure of strategic uncertainty. In most coordination games the estimated parameter λ is lower than in lottery decisions, which indicates that strategic uncertainty adds to diversity of beliefs and behavior. Strategic uncertainty is low in situations that require few subjects to coordinate at low opportunity costs and in situations, where coordination is difficult and costly. In intermediate situations, the degree of uncertainty is higher. Situations with high strategic uncertainty (estimated from data within a subject pool) are about the same situations at which random draws from different subject pools produce different success probabilities.

To our knowledge, this is the first study that tries to measure subjective probabilities in situations of strategic uncertainty. Goree, Holt and Palfrey (2002) do also combine individual decisions for lotteries with games and show that the inclusion of risk aversion in a quantal response equilibrium can explain systematic deviations of subjects' behavior from Nash equilibrium in matching pennies games.

In Section 2, we define the type of coordination games covered by our experiment. Section 3 describes the experimental design. Section 4 presents results and explores predictability and optimality of behavior in coordination games. In Section 5, we estimate subjective beliefs and compare them to objective probabilities. Section 6 describes quantitative models of behavior and Section 7 concludes.

2. Coordination Game

We are interested in the following coordination game: N players simultaneously decide whether to contribute an amount Z to a public good or to an investment that is installed if the total revenue is at least $Z\,K,$ where $1 < K \leq N.$ Contribution yields a return greater than $Z,$ if and only if at least K players contribute. Games of this structure are also used to model network goods, currency and liquidity crises, and bubbles.

Players' choices are strategic complements, and the game has two equilibria in pure strategies for any nonnegative Z below the value of the public good. If every body else contributes, the best response is to contribute as well and receive the high payoff. If nobody else decides to invest, then it is a best response to stay out and save the costs.

Suppose that contributions are 5 Euro, the return is 15 Euro to each contributor, and the good is installed, if at least 7 out of 10 players contribute. How many contributions may we expect in this situation and how likely is it that the good is installed and positive externalities unfold?

Suppose, contributions are 14 Euro and all 10 players must contribute. Here, the payoff to coordination is low and the hurdle is high. May we dare to hope for coordination on the efficient equilibrium in such a situation?

Our experiment is designed to answer these questions and assign measures of strategic uncertainty and probabilities for efficient outcomes to this kind of coordination games. In addition, we analyze how behavior in coordination games is related to risk aversion and other personal characteristics.

3. Design of the Experiment

Sessions were run at a PC pool in the economics department at the University of Frankfurt and in the LEEX at Universitat Pompeu Fabra, Barcelona, from May until July 2003. In Frankfurt we announced the experiment by e-mail to all students with an e-mail account at the department of business and economics and via leaflets and posters at various places in the university. In order to participate, students replied by e-mail. In Barcelona students were notified via posters within the university and signed up on a list at the door of the laboratory. In both places, most of the participants were business and economics undergraduates. The procedure during the sessions was kept the same throughout all sessions at both places, besides the languages (German and Spanish, respectively). All sessions were computerized, using a program done with z-tree (Fischbacher, 1999). Students were seated in a random order at PCs. Instructions (see Appendix A) were then read aloud and questions were answered in private. Throughout the sessions students were not allowed to communicate and could not see others' screens.

Subjects were randomly assigned to groups of size N, where N was 4, 7 or 10 in different sessions. There were at least two groups in each session, and subjects did not know who the other members of their group were. Before starting the experiment, subjects had to answer a few questions concerning their understanding of the rules.

In the experiment, subjects face 4 x 10 independent decision situations. In each situation they are asked to decide between two alternatives, A and B. One block of 10 decision situations involves lottery choices and 3 blocks of 10 situations each involve coordination games. Option A always gives a secure payoff that ranges from € 1.50 to € 15.00 in steps of € 1.50 within each block. The payoff for a B-choice is either zero or € 15 in each situation.

In the lottery setup the payoff for B depends on the result of throwing a die (simulated by the computer): if the result of the die is 1 or 2, the payoff is zero and if the result of the die is 3, 4, 5 or 6, the payoff is € 15. Figure 1 shows a sample screen of the lottery setup.

Sample Screen

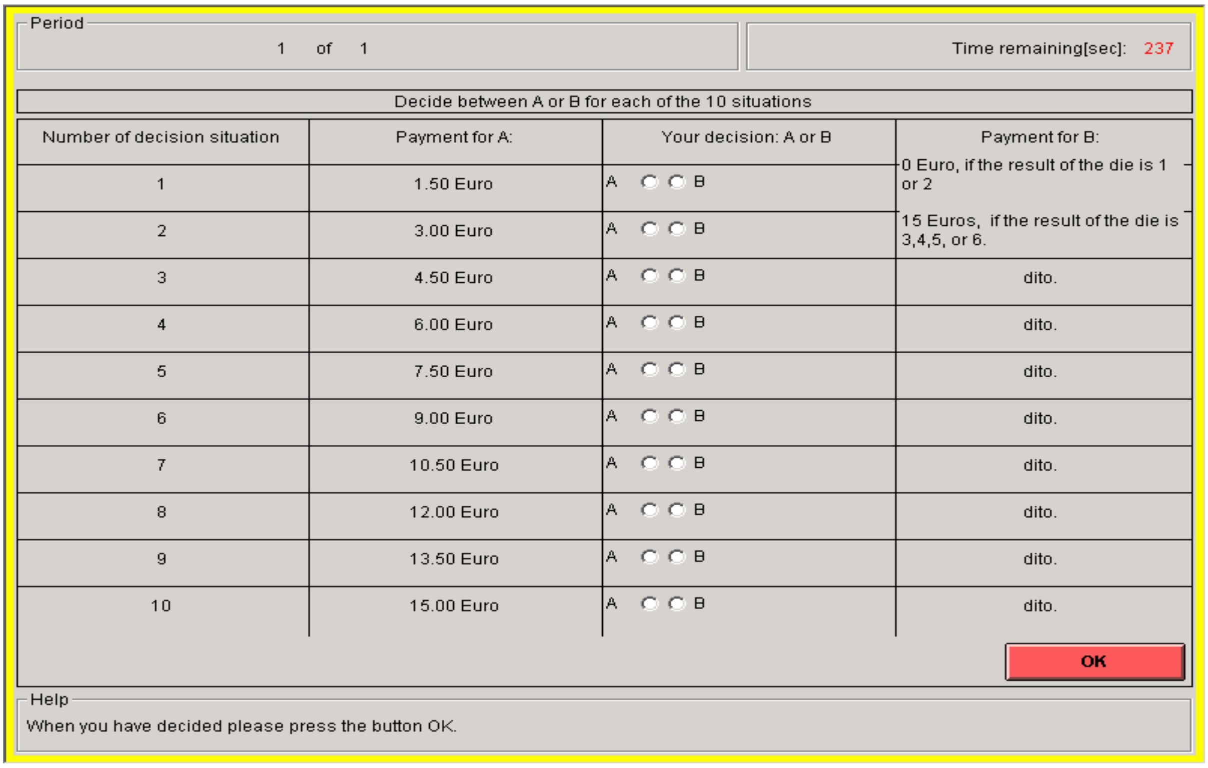

Figure 1.

Coordination-game choices are as similar as possible: here, the payoff for option B is € 15, provided that at least *K* out of *N* members of the subject's group (including her- or himself) choose B in this situation, and otherwise 0 Euro, where *K* varied across sessions and setups, but is kept constant throughout the ten situations of a setup. In the coordination-game setup, the last column on the screen shows the text "Payment for B: 0 Euro if less than *K* members of your group choose B. 15 Euros if at least *K* members of your group choose B." Parameter *K* is replaced by the appropriate number.

Finally, the computer randomly selects one of these 40 situations and payoffs are calculated according to the rules of this situation. In addition, we paid each subject a show-up fee of € 5.

The four setups were given one after another without feedback. After completing all four setups, subjects were informed about the selected situation, on the result of the die or how many members of their group had chosen B in this situation, and what they earned.

Afterwards, each player had to answer a questionnaire asking for personal data, questions concerning the experiment, questions about attitudes towards various kinds of risk, and the

Zuckerman Sensation Seeking Scale V (SSS-V). The duration of the experiment was 40 to 60 minutes with an average payoff of € 16.68 per subject.

In each session, we used one particular group size N and three different coordination requirements K. Combinations of N and K were chosen in such a way that each subject was faced with situations that required one third, two third or all of the *other* group members to take the same position in order to be successful with option B. Thus, $k = (K - 1) / (N - 1)$ equals 1/3 , 2/3 or 1 in the three coordination setups of each session. Table 1 shows the parameter combinations used in the experiment.

Parameters used in the experiment

	$k = 1/3$	$k = 2/3$	$k = 1$
$N = 4$	$K = 2$	$K = 3$	$K = 4$
$N = 7$	$K = 3$	$K = 5$	$K = 7$
$N = 10$	$K = 4$	$K = 7$	$K = 10$

Table 1.

As subjects did not receive any feedback until they had completed all forty decisions, the order of the four decision blocks should not matter too much. To minimize systematic order effects on the data, we changed the order between sessions with otherwise equal parameters. Table 2 gives an overview of the sessions and applied parameters. In total we ran 10 sessions with 174 participants. Each session had a different treatment.

Overview of sessions

treatment	Group size N	Order of blocks (L = lottery, numbers = K)	location	Number of subjects
4A	4	L – 4 – 3 – 2	Frankfurt	20
4B	4	L – 2 – 3 – 4	Frankfurt	16
4C	4	4 – 3 – 2 – L	Frankfurt	12
4D	4	2 – 3 – 4 – L	Frankfurt	16
7A	7	L – 7 – 5 – 3	Frankfurt	21
7B	7	L – 3 – 5 – 7	Barcelona	14
7C	7	7 – 5 – 3 – L	Frankfurt	21
7D	7	3 – 5 – 7 – L	Barcelona	14
10C	10	10 – 7 – 4 – L	Frankfurt	20
10D	10	4 – 7 – 10 – L	Frankfurt	20
			Total number of subjects:	174

Table 2.

4. Results

4.1. Individual Choices

Lottery and coordination-game choices are as similar as possible: subjects decide between a safe payoff for A and a risky or uncertain payoff associated with B. In all set-ups, subjects typically choose the safe payoff when it is high, and opt for B when the alternative safe payoff is low. Thereby, we have approximate measures of certainty equivalents for the lottery up to an interval of € 1.50 and comparable thresholds for coordination games that may be interpreted as certainty equivalents for the coordination games. Data are displayed in Appendix B.

In Frankfurt, 131 out of 146 subjects chose threshold strategies in all four set-ups (including persons, who chose the same action in all ten situations of a set-up). In Barcelona, threshold strategies were chosen by 27 from 28 subjects. Some subjects (7 in Frankfurt and 4 in Barcelona) chose the lottery in all ten situations, even when the alternative safe payoff was 15. This is inconsistent with utility maximization. Some statistical analyses will only consider data from subjects, who used threshold strategies in all four set-ups and choose a safe payoff of 15, when the alternative was a lottery yielding 15 with probability 2/3. Table 3 gives a summary statistic of the number of B-choices by these subjects. Note that for a threshold strategy, the highest safe payment, at which B is chosen, equals the number of B-choices times € 1.50. Appendix C contains the data from all threshold players.

Heinemann, Scivos and Stein (2004) have done a follow-up experiment that combines our treatments 4C, 7C, or 10C (whith payoffs scaled down by 0.4) with some other games. Subjects were 86 participants of a meeting for particular intelligent people[2] in Köln. 84 of these subjects played threshold strategies throughout and chose a safe payoff of 15, when the alternative was the lottery. We include these data in Table 3.

Average number of B-choices (standard deviation)

Group size Location	Number of subjects	Lottery	Coordination games k = 1/3	 k = 2/3	 k = 1
N = 4 Frankfurt	56	**5.04** (1.73)	**6.18** (2.01)	**4.41** (2.16)	**3.25** (2.57)
N = 7 Frankfurt	35	**4.97** (1.95)	**5.74** (2.41)	**4.11** (2.18)	**2.91** (2.17)
N = 10 Frankfurt	33	**5.03** (1.76)	**6.24** (2.26)	**4.36** (2.50)	**2.67** (2.57)
N = 7 Barcelona	23	**6,09** (2,09)	**7,39** (2,57)	**6,61** (2,93)	**5,78** (3,67)
$N = 4$ Köln	27	**5.41** (1.25)	**7.63** (1.64)	**5.52** (2.29)	**3.81** (2.82)
$N = 7$ Köln	28	**5.64** (2.23)	**8.04** (1.62)	**6.50** (2.62)	**5.04** (3.35)
$N = 10$ Köln	29	**5.66** (1.47)	**7.31** (1.97)	**5.62** (2.13)	**3.93** (2.46)

Table 3. Data from subjects with threshold strategies and less than 10 B-choices in the lottery set-up.

[2] Members of MENSA in Germany and interested visitors.

The number of B-choices decreases with increasing coordination requirement k, while the dispersion of thresholds (standard deviation) tends to increase in k. Group size N has no significant effect. In Frankfurt, the number of B-choices in the lottery set-up is in between the numbers for $k = 1/3$ and $k = 2/3$. In Barcelona and Köln the average number of B-choices in the coordination game with $k = 2/3$ is higher than in the lottery set-up.

The order of decision blocks affects behavior: especially D-sessions that start with the lowest coordination requirement and have the lottery at last produce significantly higher thresholds in the game with $k = 1/3$ and in the lottery.

In Barcelona and Köln thresholds are significantly higher than in Frankfurt and their variance increases with k. The session in Köln is not entirely comparable though, because it was done in paper form and combined our treatments with four other types of games. But, there are differences in the subject pool as well. 65 per cent of the participants in Köln are members of MENSA. Membership requires an IQ above 130. Some knew each other from previous meetings. With respect to profession and age, subjects in Köln are more diverse than student populations. With respect to origin and nationality, student population in Frankfurt is more diverse than subject pools in Köln and Barcelona. Students in Barcelona have more experience with experiments. Our results indicate that differences between subject pools may have non-negligible effects on behavior in coordination games.

Sessions in Barcelona and Köln do also show higher numbers of B-choices in the lottery set-up than sessions in Frankfurt. This indicates that risk aversion differs among these groups. For the session in Köln, lower risk aversion can be explained by the down-scaled payoff and combination with other games that also contributed to subjects' earnings. In Barcelona, most subjects behave as risk lovers. This may be an effect of the small sample.[3]

We cannot join data from different subject pools. Some of the further analyses consider only data from Frankfurt and Köln, because the sample from Barcelona is too small. Table 4 presents results from linear regressions with the number of B-choices in coordination set-ups as explained variable. Here, we also use age and gender and the four subscales of Zuckerman's SSS-V as explaining variables. The session in Köln did not include the Zuckerman Test.

[3] In Barcelona, one of the two sessions had 10 out of 14 subjects choosing the lottery, when the alternative safe payoff was higher than the expected value of the lottery. Three subjects chose B in all situations of the experiment. This session may be an outlier. We could not find any control-mistakes, and we do not want to "clean" the sample. Therefore, we keep these data in.

Linear regressions on the number of B-choices in coordination set-ups

	Coefficients (t-values) of regression with data from			
Explaining Variables	Frankfurt	Barcelona	Köln	all locations
constant	2.79 ** (2.32)	1.73 (0.41)	5.38 *** (6.24)	0.60 (0.94)
Dummy: 1=Barcelona				1.85 *** (5.46)
Dummy: 1=Köln				0.99 *** (4.52)
Group size N	- 0.06 (- 1.30)		- 0.07 (- 1.14)	- 0.06 (- 1.51)
Coordination requirement k	- 4.56 *** (- 12.10)	- 2.52 ** (- 2.40)	- 5.05 *** (- 9.60)	- 0.93 ** (- 2.67)
Number of B-choices in lottery	0.55 *** (8.58)	1.18 *** (6.34)	0.38 *** (4.47)	0.57 *** (10.47)
Age	0.04 (1.05)	0.11 (0.69)	0.07 *** (4.03)	0.07 *** (3.93)
Gender (0=female, 1=male)	0.57 ** (2.28)	0.52 (0.63)	0.37 (1.21)	0.40 * (1.99)
Disinhibition	- 0.05 (- 0.84)	0.36 * (2.16)		
Boredom suspectability	- 0.09 (- 1.60)	- 0.70 * (- 2.28)		
Thrill and adventure seeking	0.04 (0.80)	- 0.25 (- 1.46)		
Experience seeking	0.23 *** (3.99)	- 0.11 (- 0.65)		
R^2 (adjusted R^2)	0,44 (0,43)	0.50 (0.44)	0.35 (0.34)	0.24 (0.24)
Number of subjects	121	22	84	231

Table 4. Significance levels: * 5%, ** 2.5%, *** 1%.

Table 4 confirms that the number of B-choices in coordination games is significantly affected by the coordination requirement k. The effect of the coordination requirement arises, because most subjects lower their threshold when k increases (see Table 5 below). Surprisingly, group size N has a negative impact. However, it is not significant.

The number of B-choices in the lottery set-up is a measure of risk aversion. The higher this number, the lower is a subject's revealed risk aversion. Regression results indicate that risk averse subjects choose B less often in coordination games. It is highly significant in all three samples. Males tend to choose the uncertain action more frequently than females, although gender is significant only in Frankfurt. There is little age variation among subjects in Frankfurt and Barcelona. Participants of the MENSA meeting in Köln are more diverse in respect of age. Here, age is significant. Older subjects opt more often for coordination.[4] In Frankfurt, the "Experience Seeking"-subscale of the Zuckerman test is highly significant. Subjects who appear to be experience seekers opt more often for coordination.

The positive correlation of thresholds for coordination games with lottery thresholds tells us that both situations are treated in a similar way. Risk aversion matters in situations of strategic uncertainty. Subjects behave as if they have probabilistic beliefs about success or failure of coordination in any of our coordination games. This justifies assuming probabilistic beliefs in modeling strategic uncertainty, even though there is no exogenous random process in these situations.

Thresholds tell us, how risky a subject views a situation to be. The more risky a situation is perceived, the lower is the security equivalent. We suggest using the relative order of security equivalents as a measure of strategic uncertainty. The lower the security equivalent of a game is, the more risk seems to be associated with it. This allows ranking and comparing situations of strategic uncertainty with situations of exogenously given probabilities. Table 5 shows how subjects changed their thresholds between the four decision blocks.

Pair wise comparison of thresholds

Number of subjects, who choose	in games with $k = 1/3$ than in lottery	in games with $k = 2/3$ than in lottery	in games with $k = 1$ than in lottery	in games with $k = 2/3$ than for $k = 1/3$	in games with $k = 1$ than for $k = 2/3$	in games with $k = 1$ than for $k = 1/3$
a lower threshold	20	68	100	105	94	115
the same threshold	39	40	16	24	33	12
a higher threshold	72	23	15	2	4	4

Table 5. Data from subjects with threshold strategies in Frankfurt.

In 76 per cent of all cases, subjects lowered their thresholds with increasing in k. In only 2 per cent thresholds are increasing in k. Thus, subjects view a situation as more risky, when the coordination requirement rises.

In the coordination game with $k = 1/3$, 72 subjects (55 per cent) chose a higher threshold than in the lottery. They view this coordination game as less risky than the lottery. 20 subjects (15 per cent) reveal an opposite view. In the coordination game with $k = 2/3$, the proportions are turned around: more than half of all subjects view the coordination game with $k = 2/3$ as more risky than the lottery, while 18 per cent have an opposite view. 76 per cent view the

[4] We did not ask subjects to state their personal income that may be related to age among the subjects in Köln.

coordination game with $k = 1$ as more risky than the lottery, but still 11 per cent take the other side.

Subjects in Barcelona seemed to have a different perception of strategic uncertainty. Here, half of all subjects did not change their threshold in response to an increase in k. Nine subjects chose a higher threshold in the coordination game with $k = 2/3$ than in the lottery, while only seven subjects behaved reverse (the other eleven subjects chose the same threshold in both decision blocks).

In Köln, 59 out of 85 subjects lowered their thresholds for rising coordination requirements both times. 41 subjects chose a higher threshold in the game with $k = 2/3$ than in the lottery set-up, and 33 subjects chose lower thresholds in the game with $k = 2/3$ than in the lottery. The median subject chooses the same threshold in this coordination game and in the lottery.

From these results we conclude that most people view a coordination game that requires one third of others to join as less risky than a lottery with a winning probability of 2/3, while a game that requires all members of a group is viewed as being more risky.

4.2. Aggregate Outcomes

Next, we analyze the distribution of individual thresholds and its implications for the probability of successful coordination. Figures 2 and 3 show the proportion of subjects, who chose B conditional on the alternative safe payoff, denoted by X. Figure 2 rests on data from all subjects in Frankfurt who played threshold strategies. Figure 3 rests on the data from Köln. Aggregate behavior of subjects, who did not always play threshold strategies, cannot be distinguished from random behavior.

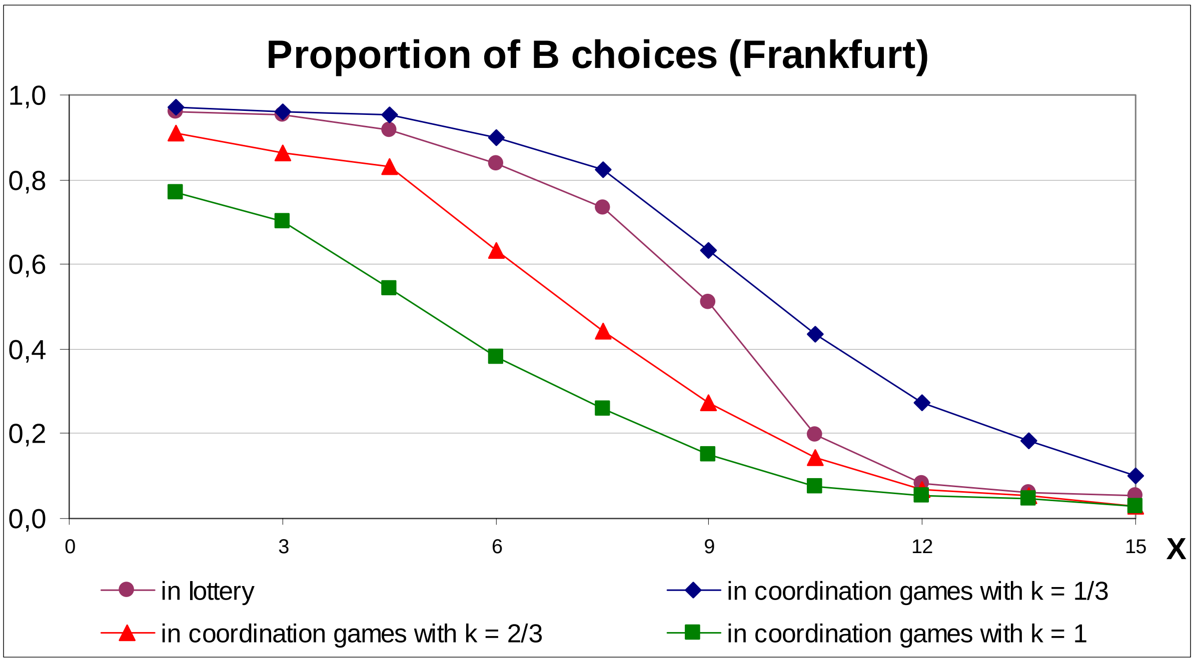

Figure 2. Data from 131 subjects in Frankfurt who played threshold strategies.

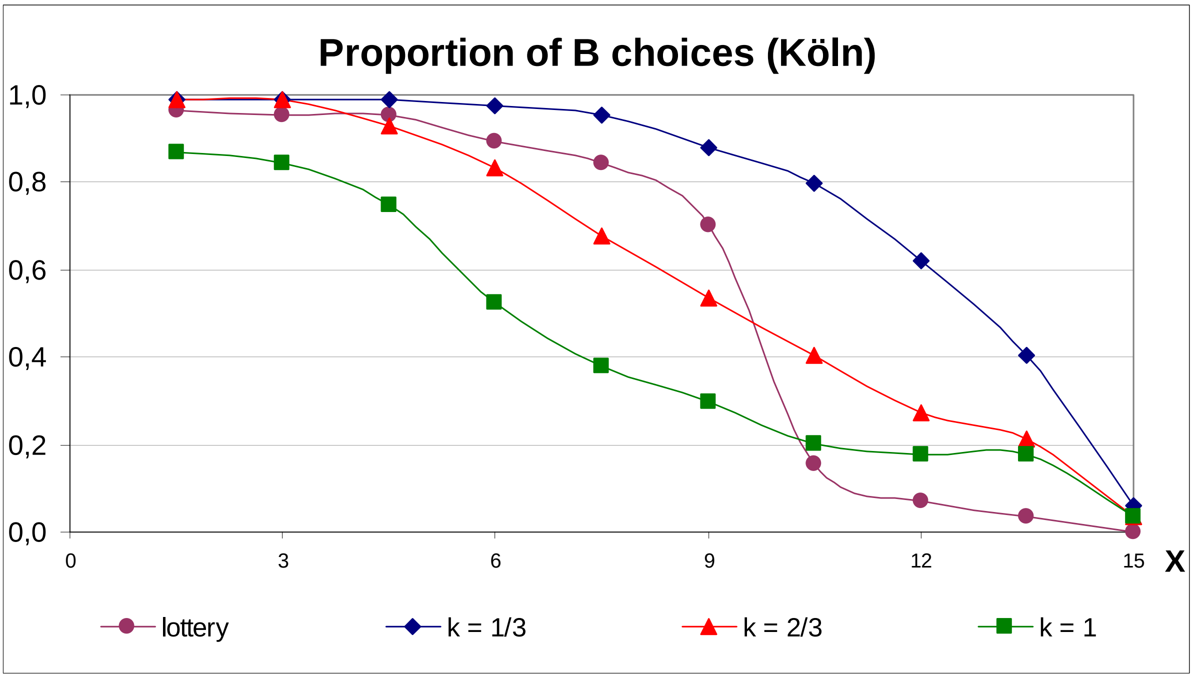

Figure 3. Data from 85 subjects in Köln who played threshold strategies.

In the lottery setup, the proportion of B choices sharply declines between X=7.50 and X=10.50. Recall that the expected payoff of the lottery is € 10.00. The distributions for coordination games are flatter. Uncertainty about the probability of getting a reward for B adds to individual differences in the evaluation of this uncertainty, i.e. risk aversion. The difference in slopes of distribution functions is most pronounced in the sample from Köln.

In Frankfurt, 29 per cent of participants are approximately risk neutral. 47 per cent prefer 9 Euro to the lottery, which reveals a non-negligible risk aversion. 24 per cent appear to be risk lovers. In Barcelona 37 per cent are risk averse, and 48 per cent are risk loving, in Köln 30 per cent are risk averse and 15 per cent risk loving. Stochastic dominance between the four curves in Figure 2 is another expression for the relative order of risk that most subjects associate with the four types of games.

In a coordination game, there are N randomly selected subjects who decide simultaneously between A and B. If each subject chooses B with probability p, than the probability for getting at least K subjects choosing B is 1–Bin(K–1, N, p), where Bin is the cumulative binomial distribution. Replacing p by the observed proportion of B-choices, we derive objective probabilities for successful coordination of randomly drawn subjects. These probabilities are given in Table 6. For these calculations, we use data from all subjects, including non-threshold players.

Probabilities for successful coordination

N	*K*	*k*	*X*=1.50	3.00	4.50	6.00	7.50	9.00	10.50	12.00	13.50	15.00
							Frankfurt					
4	2	1/3	1.00	1.00	1.00	0.99	0.98	0.86	0.59	0.29	0.16	0.06
7	3	1/3	1.00	1.00	1.00	1.00	0.98	0.92	0.64	0.27	0.10	0.10
10	4	1/3	1.00	1.00	1.00	1.00	1.00	0.94	0.73	0.49	0.22	0.12
4	3	2/3	0.92	0.92	0.88	0.66	0.27	0.06	0.01	0.01	0.00	0.00
7	5	2/3	0.90	0.68	0.73	0.36	0.13	0.04	0.00	0.00	0.00	0.00
10	7	2/3	0.95	0.95	0.88	0.22	0.04	0.00	0.00	0.00	0.00	0.00
4	4	1	0.37	0.27	0.14	0.04	0.01	0.00	0.00	0.00	0.00	0.00
7	7	1	0.09	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	10	1	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
							Barcelona					
7	3	1/3	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.87	0.87	0.32
7	5	2/3	0.99	0.99	0.97	0.89	0.83	0.52	0.29	0.29	0.29	0.01
7	7	1	0.45	0.25	0.18	0.18	0.07	0.02	0.01	0.01	0.01	0.00
							Köln					
4	2	1/3	1.00	1.00	1.00	1.00	1.00	0.98	0.97	0.83	0.45	0.01
7	3	1/3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.94	0.83	0.07
10	4	1/3	1.00	1.00	1.00	1.00	1.00	1.00	0.99	0.92	0.35	0.00
4	3	2/3	0.99	0.99	0.94	0.85	0.55	0.17	0.13	0.07	0.02	0.00
7	5	2/3	1.00	1.00	0.99	0.89	0.68	0.52	0.23	0.13	0.09	0.00
10	7	2/3	1.00	1.00	1.00	0.97	0.65	0.30	0.03	0.00	0.00	0.00
4	4	1	0.38	0.38	0.26	0.03	0.01	0.00	0.00	0.00	0.00	0.00
7	7	1	0.45	0.34	0.13	0.03	0.00	0.00	0.00	0.00	0.00	0.00
10	10	1	0.24	0.16	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 6. Probability for getting at least *K* B-choices from *N* subjects, who are randomly selected from the respective subject pools (including non-threshold players).

While the proportion of B-choices is almost independent from the group size, probabilities for successful coordination depend on *N*. However, the major influence comes from the hurdle *k*. It is stunning that for most games success or failure can be predicted (in sample) with an error of less than five per cent. Even across different subject pools, 43 per cent of all games are predictable with an error rate below 0.05. So, even if we do not know the subject pool from which players are drawn, we can predict the outcome in half of all coordination games.

Coordination games with k=1/3 are successful with a probability of at least 0.95, whenever the alternative safe payoff is 7.50 or lower. Games that require coordination of all group members are successful with a probability of at most 0.07, when the alternative safe payoff is 7.50 or higher. These results give an impression of some circumstances under which one may expect coordination or coordination failure. For some games, however, the subject pool has extreme effects on the probability of successful coordination. Consider, for example, the game with N = 7, k = 2/3 and X = 7.50. In Frankfurt, the probability for successful coordination is only 0.13, while it is 0.83 in Barcelona, and 0.68 in Köln.

As a first step to an empirical theory on behavior under strategic uncertainty, we suggest to describe the probability that a person chooses B, when the alternative is a safe payoff X Euro and success of B requires a fraction k of other people to yield a payoff of 15 Euro, by a logistic function

$$p = 1 - \frac{1}{1 + \exp(a - bX - ck)}.$$

We emphasize the absolute payoffs, because we expect behavior to be affected when payoffs are scaled up.[5] Table 7 presents parameter estimates based on the decisions of threshold-players in all three locations.

Estimated logit model

	$\hat{a}$	$\hat{b}$	$\hat{c}$
Estimates from Frankfurt data	5.69	0.45	3.55
Estimates from Barcelona data	4.13	0.27	1.26
Estimates from Köln data	8.19	0.42	5.29

Table 7.

The estimated probability of a randomly selected subject choosing B is now given by

$$\hat{p} = 1 - \frac{1}{1 + \exp(\hat{a} - \hat{b}X - \hat{c}k)}$$

and, accordingly, the estimated probability of successful coordination in a given game is

prob(success) = 1 – Bin (K–1, N, $\hat{p}$).

The obtained fit between estimated and objective probabilities is high (see Figure 4) and the estimates allows out of sample tests. We can reject the parameters estimated in Frankfurt by the data from Köln and vice versa. Nevertheless, in 60 per cent of all games, the estimates from Frankfurt deviate by less than 5 per cent from objective probabilities of success in Köln.

[5] Holt and Laury (2002) show that risk aversion rises with higher payoffs. Given our results on the close relationship between risk aversion and thresholds in coordination games, we expect these thresholds to fall when payoffs are scaled up.

To be more precise, in 21 out of 30 situations, in which success probabilities in Köln are above 0.95, estimates from Frankfurt data predict a success probability above 0.95. In turn, in 33 out of 39 cases, where Frankfurt data predict a success probability below 0.05, the objective probability in Köln is below 0.05. Whenever estimated success probabilities are between 0.05 and 0.95, they deviate from objective probabilities in Köln by more than 5 per cent. Similar results are obtained, when estimates from Köln are compared to data in Frankfurt.

We conclude that observations of behavior in coordination games are useful to detect the extreme cases, in which successful coordination is very likely or very unlikely. But, they do not give reliable estimates of success probabilities for intermediate cases. This raises the question, how a player should behave who happens to participate in a coordination game.

Proportion of B-choices in Frankfurt and estimated probabilities $\hat{p}$

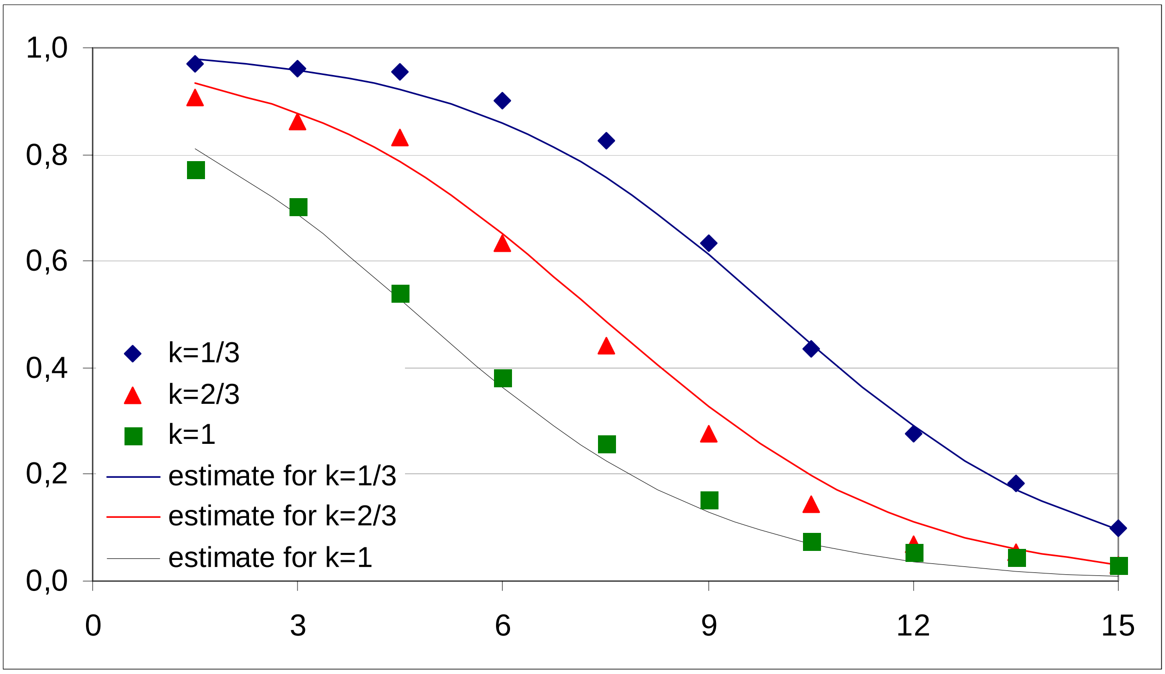

Figure 4.

4.3. Best response strategies

For a participant, opting for B pays off, if at least K–1 other group members decide for B. Thus, from a player's point of view, the probability to be successful with opting for B at an alternative safe payoff X is given by 1–Bin(K–2, N–1, p), where p is again the probability that a randomly selected subject chooses B in this situation. The best response of a player is to choose B if and only if

$$(1 - \text{Bin}(K-2, N-1, p))\, U(15) > U(X),$$

where U is the player's utility function. In Table 8, we compare the recommended numbers of B-choices with two theoretical concepts: the global-game solution and the risk-dominant equilibrium. We give the results for three different utility functions with (i) risk neutrality, (ii) constant absolute risk aversion (CARA), and (iii) constant relative risk aversion (CRRA).

The CARA utility function is given by

$$U(x) = \frac{1-\exp(-\alpha\, x)}{\alpha},$$

where a is the Arrow-Pratt measure of absolute risk aversion. The CRRA utility function is

$$U(x) = \frac{x^{1-r}}{1-r}$$

with relative risk aversion r. In the calculations, x is replaced by the payoffs from the experiment. Applied parameter values $\alpha = 0.092$ and $r = 1{,}035$ are such that a player with any of these utility functions is indifferent between the lottery and a safe payoff of € 7.50.

The global-game solution is the best response of a player who believes that the proportion of other players who choose B has a uniform distribution in [0,1]. Such a player should switch from B to A at a threshold Z^*, given by the solution to

$$\left(1-\frac{K-1}{N}\right)U(15) = U(Z^*).$$

The risk-dominant equilibrium is the best response of a player who believes that other players believe that the probability of success has a uniform distribution in [0,1]. The associated threshold Z^* is given by the solution to

$$(1 - \mathrm{Bin}(K-2, N-1, 1-Z^*/15))\; U(15) = U(Z^*).$$

The risk-dominant equilibrium is always close to the global-game solution. Parameters of the experiment have been chosen to yield a notable difference between the two equilibium refinements.

Apparently, the global-game solution gives a good recommendation for behavior of a risk neutral player in Frankfurt. In Barcelona and Köln, a risk neutral player should choose a higher threshold, but the global-game solution is still a good guide. Risk aversion lowers the optimal number of B-choices. However, with increasing risk aversion the optimal number of B-choices falls less than predicted by global-game solution or risk dominance. In Frankfurt, a risk-averse player can achieve a higher expected payoff by choosing a threshold that is in between the global-game solution calculated for risk-neutrality and the global-game solution based on the player's own utility function. In Barcelona and Köln, even a risk-averse player should choose a higher threshold than predicted by the global-game solution based on risk neutrality.[6]

[6] This in line with previous observations by Heinemann, Nagel and Ockenfels (2003) and Cabrales, Nagel and Armenter (2003), who detect systematic deviations of behavior from the global-game solution towards the payoff-dominant equilibrium.

Optimal and theoretical number of B-choices

	k = 1/3			k = 2/3			k = 1		
	N=4	N=7	N=10	N=4	N=7	N=10	N=4	N=7	N=10
(i) Best response of a risk neutral player									
in Frankfurt	7	7	7	4	4	3	2	1	0
in Barcelona		9			6			2	
in Köln	8	9	8	5	6	5	3	2	1
Equlibrium refinements assuming risk neutrality									
Global-game solution	7	7	6–7	4–5	4	3–4	2	1	0–1
Risk-dominant equilibrium	6	6	6	4–5	4	4	3	2	1
(ii) Best response of a player with CARA, α = 0.092									
in Frankfurt	6	6	7	4	3	3	2	0	0
in Barcelona		8			5			1	
in Köln	8	8	8	5	5	5	2	2	1
Equlibrium refinements assuming CARA, α = 0.092									
Global-game solution	5	5	5	3	2	2	1	0	0
Risk-dominant equilibrium	5	4	4	3	2	2	1	1	1
(iii) Best response of a player with CRRA, r = 0.1,035									
in Frankfurt	7	6	7	4	3	3	2	0	0
in Barcelona		8			5			1	
in Köln	8	8	8	5	5	5	2	2	1
Equlibrium refinements assuming CRRA, r = 1.035									
Global-game solution	6	5	5	3	2	2	1	0	0
Risk-dominant equilibrium	5	4	4	3	2	2	1	1	0

Table 8.

If a risk avers subject in Köln would have known the data from Frankfurt, she would have been better off following the predictions derived from Frankfurt data than following the global game solution. The reverse is not true: the best response in Frankfurt is closer the global-game solution than to the best response in Köln. Whether risk aversion is described by CARA or CRRA has no big effects, neither on best responses nor on equilibrium refinements. This is also true, when results are calculated for the degrees of risk aversion that are associated with other thresholds in the lottery set-up. Comparing recommendations with actual behavior (see Table 3), it is obvious that in all three locations most subjects choose B too often in games that require coordination of all subjects (k=1).

When participating in a coordination game, players usually do not know success probabilities and, therefore, cannot predict best responses. Next, we analyze, which strategy we can recommend to an arbitrary participant in a coordination game. We consider the following strategies:

GGS(α) global-game solution: choose B if

$$\left(1-\frac{K-1}{N}\right)U_\alpha(15) > U_\alpha(Z)$$

and A if the reverse inequality holds. Choose B with probability ½ if both sides are equal,

RDE(α) risk-dominant equilibrium: choose B if

$$(1 - \mathrm{Bin}(K-2, N-1, 1-Z/15))\ U_\alpha(15) > U_\alpha(Z),$$

and A if the reverse inequality holds. Choose B with probability ½ if both sides are equal.

P2/3(α) best response to other players choosing B with probability 2/3: choose B if

$$(1 - \mathrm{Bin}(K-2, N-1, 2/3))\ U_\alpha(15) > U_\alpha(Z),$$

and A if the reverse inequality holds. Choose B with probability ½ if both sides are equal. We include this strategy, because it gives the best prediction in the experiment studied by Heinemann, Nagel and Ockenfels (2002).

LLE(α) limiting logit equilibrium, introduced by McKelvey and Palfrey (1995): for any non-negative λ, a quantal response equilibrium desribes the probability that a player chooses B by the solution to

$$p(\lambda) = \frac{1}{1-\exp(\lambda[U_\alpha(Z) - (1-\mathrm{Bin}(K-2, N-1, p(\lambda))U_\alpha(15)])}.$$

The limit of the continuous path of the solution correspondence $p(\lambda)$ for $\lambda \to \infty$ defines the limiting logit equilibrium. The associated threshold Z^* is given by

$$(1 - \mathrm{Bin}(K-2, N-1, 1/2))\ U_\alpha(15) = U_\alpha(Z^*).$$

It amounts to the best response of a player who beliefs that others choose B with probability ½.

α is the absolute risk aversion. We distinguish strategies based on a subject's own risk aversion, $\alpha = \alpha^i$, and strategies based on $\alpha = 0$, for which $U(x) = x$. Strategies based on risk neutrality are easier to calculate and do not require to know one's own risk aversion. However, neglecting risk aversion may lead to losses in expected utility.

The left columns in Table 9 compare, how many subjects could have improved their expected utility (given the absolute risk aversion α^i, associated with a threshold that is in the middle between the highest safe payment, at which the subject chooses the lottery and the lowest safe payment that is preferred to the lottery) by choosing any of the above strategies in comparison to their actual choices. For these comparisons we consider only subjects who played threshold strategies and did not choose the lottery, when the alternative safe payoff was 15. Success probabilities are calculated from actual choices of the reference group. A vast majority of subjects could have improved their expected utility by any of the considered refinement strategies.

For the right three columns in Table 9 we compare expected utilities from GGS(0) with expected utilities from other strategies. For most subjects in Frankfurt and Köln, GGS(0) leads to a higher expected payoff than any other strategy in pair-wise comparisons. In Barcelona, however, a majority of subjects would achieve higher expected payoffs by using P2/3(0) or P2/3(α^i).

Comparison of expected utilities from different strategies

	Percentage of subjects who would have achieved higher expected utility by using the refinement strategy instead of their actual choices			Percentage of subjects for whom GGS(0) leads to a higher expected utility than the respective other refinement strategy		
	Frankfurt	Barcelona	Köln	Frankfurt	Barcelona	Köln
GGS(0)	78%	65%	88%			
RDE(0)	77%	65%	85%	100%	100%	74%
P2/3(0)	66%	65%	81%	99%	43%	74%
LLE(0)	75%	65%	81%	94%	85%	95%
GGS(α^i)	77%	70%	86%	65%	61%	81%
RDE(α^i)	77%	65%	85%	94%	61%	71%
P2/3(α^i)	77%	70%	81%	91%	43%	65%
LLE(α^i)	73%	70%	81%	94%	63%	89%
Number of subjects	124	23	84	124	23	84

Table 9.

It is a striking and surprising result that GGS(0) does so well in all of these comparisons. Results do not change much, if we replace α^i by minimal or maximal risk aversion consistent with subjects' choices. For most subjects in Frankfurt and Köln, GGS(0) is also the best strategy when compared to all others simultaneously. The threshold associated with GGS(0) is simply given by

$$Z^* = 15 \cdot \left(1 - \frac{K-1}{N}\right) .$$

This strategy is easy to calculate and does not even require knowing one's own risk aversion.

5. Subjective Probabilities

To find precise measures of individual attitudes towards strategic uncertainty, we estimate subjective beliefs by comparing choices in coordination games with those in the lottery set-up.

For example, consider a subject who chooses the lottery (B), when the payoff for A is smaller or equal than 6 Euro, but chooses B in a coordination setup, when the safe alternative is smaller or equal to 9 Euro. This subject seems to believe that successful coordination in situations where A pays 7.50 or 9 Euro has a higher probability than 2/3. If this person expects others to follow threshold strategies (in the questionnaire 83.6% of all subjects answered yes to the question, whether they expected other subjects to play threshold strategies), she should attribute even higher probabilities to successful coordination on B in situations, where the payoff to A is smaller than 7.50. On the other hand, if this subject chooses B in a coordination game, only when the payoff to A is smaller or equal to 4.50, she reveals that she attributes a probability below 2/3 to a successful coordination on B, whenever the payoff to A is 6 Euro or higher.

More precise measures of subjective beliefs can be obtained by assuming a particular utility function. Here, we use the CARA utility function, but we checked that the CRRA utility function yields about the same results.

Let X be a subject's certainty equivalent of the lottery and Z her threshold in a coordination game. Then,

$$U(X) = 2/3\ U(15) + 1/3\ U(0) \quad \text{and} \quad U(Z) = q\ U(15) + (1-q)\ U(0),$$

where q is the subjective probability for successful coordination on B, when the alternative safe payoff from A is Z. Assuming CARA, this is equivalent to

$$\exp(-\alpha X) = 1 - 2/3\ (1 - \exp(-15\,\alpha)) \quad \text{and} \quad \exp(-\alpha Z) = 1 - q\ (1 - \exp(-15\,\alpha)).$$

The first equation gives us an estimate for $\alpha(X)$ that we use in the second equation to estimate the subjective probability for successful coordination in the situation, where A gives a certain payoff of Z, $q(X, Z)$.

In our experiment, we measure certainty equivalents up to an interval of 1.50. Consider a subject, who chooses the lottery (B), when the payoff for A is smaller or equal to X Euro, but chooses B in a coordination setup, when the safe alternative is smaller or equal to Z Euro.

At Z, this subject chooses B and prefers the coordination game to the safe payoff Z. Thereby, she reveals a subjective probability that is at least $q(X+1.50, Z)$. If this exceeds the objective probability of success in the coordination game with alternative safe payoff of *Z*, then we say that this subject overestimates the probability for successful coordination.

At *Z*+1, the subject chooses A and prefers the safe payoff *Z*+1 over the coordination game. Here, she reveals a subjective probability that is at most $q(X, Z+1.50)$. If this is lower than the objective probability of success in the coordination game with alternative safe payoff of *Z*+1.50, then we say that this subject underestimates the probability for successful coordination.

Subjects, for whom neither of the two conditions above holds, are said to have subjective probabilities that are approximately equal to the objective ones. Table 10 presents these comparisons and shows that most subjects overestimate the probability of success in games with a high coordination requirement, but underestimate success in games with a low hurdle.

Estimated number of subjects, who over- or underestimate the probability of successful coordination

Game	k = 1/3			k = 2/3			k = 1		
	N=4	N=7	N=10	N=4	N=7	N=10	N=4	N=7	N=10
Subjects who overestimate success probability	$\underbrace{12 \quad 6 \quad 10}_{23\%}$			$\underbrace{23 \quad 19 \quad 18}_{48\%}$			$\underbrace{36 \quad 26 \quad 25}_{70\%}$		
Subjective probability approximately equal to objective	$\underbrace{18 \quad 13 \quad 6}_{31\%}$			$\underbrace{17 \quad 4 \quad 11}_{26\%}$			$\underbrace{7 \quad 6 \quad 7}_{16\%}$		
Subjects who underestimate success probability	$\underbrace{26 \quad 14 \quad 16}_{46\%}$			$\underbrace{16 \quad 12 \quad 5}_{26\%}$			$\underbrace{13 \quad 3 \quad 2}_{14\%}$		

Table 10.

Most subjects underestimate the probability of successful coordination, when they need only one third of the other players to be successful, while most subjects overestimate the probability of successful coordination in games with k = 2/3 or k = 1. The proportion of subjects who overestimate probabilities to win in the coordination game tends to rise in k and N, while the proportion of subjects, who underestimate success probabilities tends to fall in k and N.

What are the subjective probabilities associated with the situations at which subjects switch from B to A? To get a precise measure for each subject, we calculate $q(X, Z)$ based on the assumption that the true thresholds X and Z are the highest value of the safe payment, at which a subject chooses B. This overestimates risk aversion, but has no systematic effect on estimated subjective probabilities q. Table 11 presents average subjective probabilities for success in the coordination game with hurdle k, when the alternative safe payoff is Z. Numbers in round brackets are standard deviations, numbers in squared brackets give the number of subjects, who chose this threshold and revealed a finite degree of risk aversion. Again, these estimates do not change substantially, if we apply other utility functions.

Subjective probabilities for successful coordination

	Estimated q-values: Mean	(standard deviation)	[number of subjects*]						
Safe payoff Z		$k = 1/3$			$k = 2/3$			$k = 1$	
0.00	n.a.	(-)	[0]	0	(0)	[4]	0	(0)	[22]
1.50	0.67	(-)	[1]	0.40	(0.16)	[6]	0.20	(0.14)	[9]
3.00	0.67	(-)	[1]	0.43	(0.17)	[4]	0.35	(0.11)	[21]
4.50	0.62	(0.17)	[7]	0.46	(0.14)	[25]	0.45	(0.12)	[20]
6.00	0.61	(0.17)	[9]	0.57	(0.14)	[24]	0.51	(0.08)	[15]
7.50	0.66	(0.12)	[25]	0,60	(0.08)	[21]	0.56	(0.13)	[14]
9.00	0.75	(0.09)	[26]	0.67	(0.07)	[17]	0.71	(0.08)	[9]
10.50	0.76	(0.08)	[21]	0.71	(0.09)	[10]	0.73	(0.05)	[3]
12.00	0.81	(0.06)	[12]	0.91	(0.03)	[2]	0.89	(-)	[1]
13.50	0.90	(0.09)	[11]	0.80	(0.13)	[3]	0.87	(0.07)	[2]
15.00	1	(0)	[7]	1	(0)	[3]	1	(0)	[3]
Total*			[120]			[119]			[119]

Table 11. Data from Frankfurt sessions. * These numbers are smaller than the number of subjects who chose threshold strategies, because q can not be calculated, when the subject chooses thresholds of zero or 15 in lottery *and* coordination game.

At first sight it might surprise that subjective probabilities are increasing in Z. It must be emphasized that these are beliefs of different subjects, who actually switched at the respective safe payment. Since 83.6% of all subjects expected others to follow threshold strategies, subjective probabilities of any single subject should be decreasing in Z. E.g., a subject that switches at 10.50 and has an estimated subjective probability for success of 0.75 should have higher subjective probabilities for success in situations with lower safe payments and lower subjective probabilities in situations with higher safe payments.

It is an open question, whether subjective beliefs are formed over the outcome of the order statistic (here: success or failure of coordination on B), or over individual choices. Our experiment provides some answers to this question.

If player i attributes subjective probability π_i to another randomly selected subject choosing B then her subjective probability for success with action B is q_i = 1–Bin(K–2, N–1, π_i). This function is invertible, so that we can estimate the subjective probability for another player choosing B by the value π_i that solves the equation for the estimated q_i.

For each subject we get estimated subjective probabilities at three different levels of k and Z. For a single subject, π_i and q_i should decrease with rising k and Z. For more than 70 per cent of subjects, estimated values of q_i at the respective threshold are decreasing in k, in Frankfurt there were only 3 cases with a reverse order. But, estimated values for π_i are increasing in k for two third of all subjects. This hints at estimated subjective beliefs being inconsistent with beliefs about individual behavior. At the same time, however, subjects reduce their threshold with rising coordination requirement. The lower threshold might compensate the higher hurdle in its effect on beliefs.

Simulations show that subjective beliefs about individual behavior that respond to k and X in the right direction must have variances that do not exceed the variance of the measured distribution of B-choices. The hypothesis that subjects have beliefs about individual actions is consistent with observations only if subject's confidence in their estimates is as high as our confidence in predictions that we can derive from the results of the experiment. It is hard to imagine that subjects have that much trust in the optimality of their decisions. This may be viewed as weak evidence against the hypothesis that subjects form beliefs about individual behavior. The question of how subjective beliefs can be modeled appropriately is analyzed more rigorously in the next section.

6. Quantitative Models of Behavior in Coordination Games

Drawing on our previous results, we estimate three models of behavior in coordination games. We assume that players have probabilistic beliefs about success of coordination that depend on the potential payoff and on the coordination requirement. The average player responds by maximizing expected utility. A probabilistic choice function accounts for differences in utility functions and subjective beliefs and for mistakes. Parameters of the models are estimated by maximizing the likelihood of observed choices. In this, we follow recent papers by Holt and Laury (2002) who use a similar approach to calibrate an average hybrid utility function that accounts for decreasing relative risk aversion and Kübler and Weizsäcker (2004) who measure depth of reasoning in cascade games.

Players are assumed to maximize expected utility, where the average utility function is estimated by observations from the lottery set-up. Again, we apply the CARA utility function after checking that CRRA leads to a similar fit of data. Individual differences in behavior are modeled by a probabilistic choice function. Two such functions are commonly used. Mc Kelvey and Palfrey (1995) apply a logistic choice function

$$\text{Prob(chosing B)} = \frac{\exp(\lambda U_B)}{\exp(\lambda U_B) + \exp(\lambda U_A)} \quad .$$

Luce (1959) introduces an exponential function

$$\text{Prob(chosing B)} = \frac{U_B^{1/\mu}}{U_A^{1/\mu} + U_B^{1/\mu}} \ .$$

Parameters of these choice functions allow variation between pure random decisions ($\lambda = 0$ or $\mu = \infty$) and full rationality ($\lambda = \infty$ or $\mu = 0$). The logistic choice function gives a slightly better fit, so we present results only for this function.

$$U_A = \frac{1 - \exp(-\alpha X)}{\alpha}$$

is the utility from choosing A in a situation with a safe payoff is X, and

$$U_B = q \frac{1 - \exp(-\alpha \cdot 15)}{\alpha}$$

is the expected utility from choosing B in this situation. In lottery decisions q = 2/3. In coordination games, q is the subjective probabilities for success. The three models differ in their assumptions regarding q.

In coordination games individual differences in behavior are expected to be larger than in lottery decisions. Reason is that different attitudes towards strategic uncertainty and subjective beliefs increase the variance of choices when risk aversion and true errors remain fixed. Therefore, we allow different response precisions (λ_L and λ_C) for lottery choices and coordination-games. This implies that parameters α and λ_L are independent from the model of subjective beliefs in the coordination games. They are estimated with the data of lottery choices only. The resulting α defines the utility function used to estimate models of behavior in coordination games.

Model 1 assumes that players respond to expectations about success of action B that are formed with a logit model

$$q = \frac{1}{1 + \exp(a - bX - ck - dN)} .$$

Model 2 assumes that players use a logit model for expectations about a randomly selected subject's choice. This is the same functional form that we have used to analyze aggregate behavior. Subjective probability for another agent choosing B is given by

$$p = \frac{1}{1 + \exp(a - bX - ck - dN)} ,$$

and subjective probability for success of action B is

$$q = 1 - \text{Bin}\,(K - 2, N - 1, p).$$

The third model is the quantal response equilibrium, introduced by McKelvey and Palfrey (1995). Here, response precisions are the only free parameters and are allowed to depend on the situation.

$$p = \frac{\exp(\lambda_C(X,k,N)U_B)}{\exp(\lambda_C(X,k,N)U_B) + \exp(\lambda_C(X,k,N)U_A)} ,$$

and

$$q = 1 - \text{Bin}\,(K - 2, N - 1, p).$$

There may be up to three equilibria associated with some λ_C. To derive a unique solution, McKelvey and Palfrey (1995) suggest a tracing procedure that selects the equilibrium that is connected to the equilibrium given by $\lambda_C = 0$ and $p = 1/2$.

The likelihood function maximizes the probability that a random draw of actions produces the results that we observed in the experiment. For these estimates, we use data from all subjects who apply threshold strategies in all four set-ups and choose A when the safe payoff is 15 and the alternative is the lottery. Results of these estimates are given in Tables 12 and 13.

Maximum-likelihood estimates of Models 1 and 2

	ARA	λ_L	Log-likelihood (lottery)	*a*	*b*	*c*	*d*	λ_C	Log-likelihood (coord. game)
Model 1									
Frankfurt	0.0652	1.117	46.14	5.617	0.284	4.352	0.037	0.421	189.80
Barcelona	0.0048	0.589	14.08						
Köln	0.0280	0.955	34.61						
Model 2									
Frankfurt	0.0652	1.117	46.14	0.887	0.226	-1.382	-0.006	0.378	194.23
Barcelona	0.0048	0.589	14.08						
Köln	0.0280	0.955	34.61						

Table 12.

Maximum likelihood estimates of risk aversion in Frankfurt and Köln are in the range that has been observed in other experiments with comparable monetary payoffs. Among our subjects in Barcelona, risk aversion is not significantly different from zero. As expected, response precisions are higher in lottery decisions than in coordination games.

Both models lead to similar log-likelihoods. Thus, we cannot reject one of these models in favor of the other. Parameters *c* in model 2 and *d* in both models are not significantly different from zero. The ML-estimates of Model 2 show negative coefficients associated with the hurdle ($c<0$). This is contra-intuitive, but in line with the observations reported at the end of the previous section that estimated subjective probabilities for other players choosing B seem to rise with increasing coordination requirement. Comparing coefficients *a*, *b*, and *c* of Model 2 with those from the logit estimation reported in Table 7, we see that subjective beliefs react less sensitive to variations in the safe payoff (coefficient *b*) than estimated objective probabilities. These results indicate that people underestimate the effects that payoffs and coordination requirement have on decisions of other subjects. If we compare the estimates of

Model 1 to the estimated logit model in Table 7, we see that subjective beliefs about success with B have a similar distribution as the objective probability that a randomly selected subject chooses B. Subjects behave as if they believe that the probability of success with B is equal to the probability of a single subject choosing B. We think that subjects do not fully account for the strong effects that the binomial distribution has on the probability of success or failure. This would also explain why observed choices are not affected by group size *N*.

In coordination games, the response precision is lower than in lottery decisions. This can be explained by strategic uncertainty. Suppose that subjects would know the objective success probabilities in coordination games. Then, coordination games would be like lotteries and we would expect the same error rate. Strategic uncertainty prevents subjects from knowing these probabilities and adds to the unknown risk. Because of strategic uncertainty, subjects differ in their probability assignments. This leads to a larger variance of individual decisions than in risky situations with known probabilities. The difference is due to strategic uncertainty and is measured by the difference in response precisions. For lotteries, the estimated response precision is close to 1 for data from Frankfurt and Köln. In situations of strategic uncertainty, estimated response precisions are lower than 0.5 in both models and locations. With the quantal response equilibrium we estimate separate response precisions for all situations. Table 13 reports the values of λ_C, for which the equilibrium selected by the tracing procedure maximizes the likelihood of observations. Estimated response precisions are always lower than for lottery decisions, except for a few situation, where all subjects happened to take the same decision, in which case the quantal response equilibrium is associated with an infinite λ_C. The summed log-likelihoods of these estimates are 230.68 for Frankfurt, 73.12 for Barcelona, and 220.07 for Köln.

Response precisions are relatively high in those situations, where we could also give reliable forecasts from comparing the outcomes of the experiment at three different places. In situations, for which we cannot predict the outcome, response precisions are low, often zero.

We suggest using the response precision of the quantal response equilibrium for measuring strategic uncertainty. Let us define the degree of strategic uncertainty by

$$\gamma = \exp(-\lambda_C) - \exp(-\lambda_L) .$$

This measure is normalized and related to a group's response precision of risky situations. If response precisions are the same in risky and uncertain situations, then $\gamma = 0$. Here, strategic uncertainty does not add anything to the diversity in players' behaviour. If $\lambda_C = 0$ and $\lambda_L = \infty$, then $\gamma = 1$. In this case, strategic uncertainty is the only source of differences in individual behaviour. In situations, where all players take the same action, $\lambda_C = \infty$ and $\gamma = -\exp(-\lambda_L)$. Here, players behave as if the situation is not even risky. Figure 5 displays the average (over *N*) of γ for data from Frankfurt.

Maximum-likelihood estimates of $\lambda_C(X,k,N)$ in quantal response equilibria

k	N	X=1.5	3	4.5	6	7.5	9	10.5	12	13.5	15
Frankfurt											
1/3	4	0.492	0.585	0.581	0.505	0.496	0.252	0	0	0.326	0.384
	7	0.344	0.346	0.418	0.389	0.296	0.212	0	0	0.291	0.306
	10	0.425	0.506	0.611	0.500	0.474	0.126	0	0	0.217	0.251
2/3	4	0.321	0.324	0.370	0	0.086	0.197	0.271	0.313	0.323	0.419
	7	0.294	0.254	0	0	0	0.113	0.270	∞	∞	∞
	10	0.337	0	0	0	0.105	0.169	0.174	0.238	0.257	0.286
1	4	0	0	0	0.068	0.175	0.264	0.279	0.308	0.320	0.344
	7	0	0	0	0.082	0.155	0.263	0.464	∞	∞	∞
	10	0	0	0.111	0.198	0.221	0.253	0.360	0.329	0.305	0.362
Barcelona											
1/3	7	0.238	0.269	0.308	0.275	0.267	0.276	0.203	0.058	0	0.150
2/3	7	0.239	0.269	0.238	0	0	0	0.015	0.012	0.010	0.132
1	7	0	0	0	0	0	0	0.009	0.023	0.020	0.131
Köln											
1/3	4	∞	∞	∞	0.485	0.595	0.412	0.482	0.370	0.259	0.298
	7	∞	∞	∞	∞	0.601	0.494	0.570	0.335	0	0.184
	10	0.309	0.356	0.416	0.496	0.475	0.503	0.309	0.207	0.185	∞
2/3	4	∞	∞	0.323	0.264	0	0.128	0.117	0.129	0.166	0.267
	7	∞	∞	0	0	0	0	0	0.038	0.048	0.210
	10	0.309	0.355	0	0	0	0	0.061	0.180	0.192	∞
1	4	0.287	0	0	0.050	0.110	0.160	0.164	0.204	0.185	0.266
	7	0	0	0	0	0.022	0.036	0.082	0.073	0.067	0.209
	10	0	0	0	0	0.095	0.144	0.237	0.212	0.192	∞

Table 13. [emphasized: situations in which the outcome is predictable with 95% independent from sample]

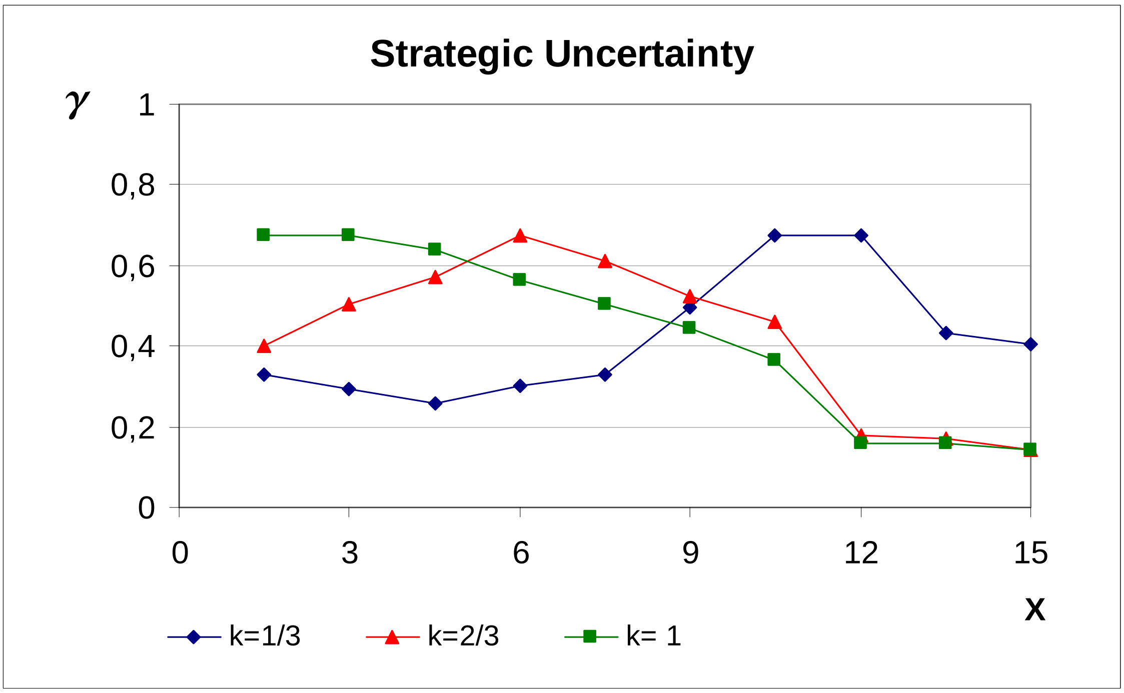

Figure 5.

Combining these results with those from Section 4.2, each situation of strategic uncertainty is characterized by an objective probability for successful coordination q and by a degree of strategic uncertainty γ. These measures are not entirely independent, but highlight different aspects of behavior in coordination games.

7. Conclusions

We have designed an experiment that allows to measure strategic uncertainty and to estimate subjective probabilities for successful coordination in a coordination game with multiple equilibria. The strategic uncertainty associated with the requirement to coordinate a certain number of group members is measured by the certainty equivalent, i.e. the certain payoff that a subject is willing to give up for the uncertain payoff from coordination. The lower the certainty equivalent of a coordination requirement is, the more risk seems to be associated with it.

The experiment shows that attitudes towards strategic uncertainty are closely related to risk aversion. Certainty equivalents for lotteries and coordination games are positively correlated. This indicates that risk aversion matters in situations of strategic uncertainty. Apparently, subjects treat situations of risk and situations with strategic uncertainty in a similar way. This allows to model subjective beliefs by probabilities. This result should already be valuable for theorists who commonly model subjective beliefs as probability distributions. Estimated subjective probabilities are sensitive to payoffs and to the coordination requirement, while the group size has no significant impact. However, subjective beliefs respond less sensitive to the coordination requirement than objective probabilities.

The outcome of a coordination game with multiple equilibria can be highly predictable, especially when the attitudes of a population towards risk and strategic uncertainty are known. The same knowledge allows recommendations for behavior and will thereby enhance efficiency in the process of achieving coordination. Without precise knowledge of the environment, the global-game solution can be recommended to agents who are engaged in coordination games. Note that this is an advice for a single agent. An advice given to the whole group should always try to move behavior towards the efficient equilibrium.

The quantal response equilibrium can be used to find separate measures of strategic uncertainty for each decision situation, while certainty equivalents measure subjective beliefs only at the marginal situation at which a subject switches actions. The drawback of quantal response equilibria is that they yield only an aggregate measure depending on the behavior of the whole group, while certainty equivalents measure individual attitudes towards strategic uncertainty.

The design of our experiment opens ways to measure strategic uncertainty in other games as well. A generic approach would ask subjects to decide between safe payoffs of various amounts or lotteries with various success probabilities on one side and participation in a strategic game on the other side. If a subject ever decides for the game, she must also state her decision in the strategic game. Her beliefs about the payoff from the strategic game can then be measured by the marginal payoff or lottery, at which she switches actions. This procedure can actually be applied to a wide variety of games. Analyzing strategic uncertainty helps forecasting behavior and giving advice to players.

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Appendix A: Instructions

Thank you for participating in this experiment, a project of economic investigation. Your earning depends on your decisions and the decisions of the other participants. From now on until the end of the experiment you are not allowed to communicate with each other. If you have some question raise your the hand and one of the instructors will answer the question in private. Please, do not ask aloud. Thank you very much.

The rules are equal for all the participants.

The experiment consists of 2 stages. The first stage consists of 40 situations. Each situation is independent of the other. In each situation you can decide between A and B. Your payment at the end depends on these decisions.

In the second stage we ask you to fill out a questionnaire.

Stage I

In this stage two groups are formed of 7 participants in each group. You don’t know who will be in your group.

This stage consists of 4x10 situations, which we explain below. In all situations you have to decide between A and B. At the end of the first stage 1 out of the 40 situations is chosen randomly. Your payment will be according to the situation picked. **Additionally you will get 5 Euros as a show-up fee.**

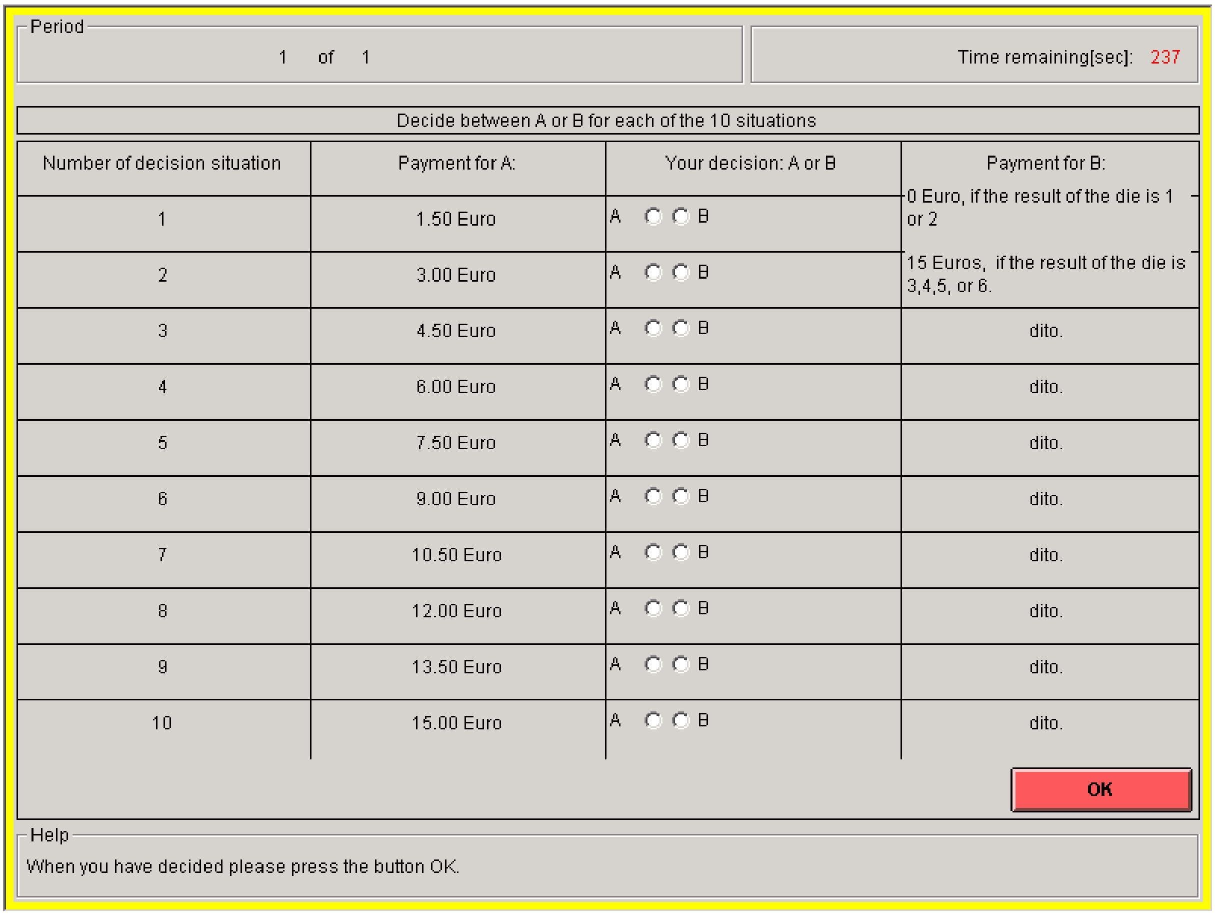
Situations of decisions 1 – 10:

If one of the situations 1-10 is picked at the end, you will be paid according in the following way (have also a look at the table below):

1. If you choose A, you receive a sure payment given in the second column. The payment which is actually chosen depends on the situation chosen randomly.

2. If you choose, you payment depends on the result of the throw of a die (thrown by the computer).

- If the result of the die is **1 or 2**, you receive 0 Euros.
- If the result of the die is **3, 4, 5, or 6**, you receive 15 Euros.



Period

1 of 1

Time remaining[sec]: 237

Decide between A or B for each of the 10 situations

Number of decision situation	Payment for A:	Your decision: A or B	Payment for B:
1	1.50 Euro	A B	0 Euro, if the result of the die is 1 or 2
2	3.00 Euro	A B	15 Euros, if the result of the die is 3,4,5, or 6.
3	4.50 Euro	A B	dito.
4	6.00 Euro	A B	dito.
5	7.50 Euro	A B	dito.
6	9.00 Euro	A B	dito.
7	10.50 Euro	A B	dito.
8	12.00 Euro	A B	dito.
9	13.50 Euro	A B	dito.
10	15.00 Euro	A B	dito.

OK

Help

When you have decided please press the button OK.

You have to choose between A and B for each situation and you can do it in any order. When you have decided you have to click the button ok. Until you have not pressed the button, you can change your decisions.

Situations of decisions 11 – 20:

If one of the situations 11-20 is picked at the end, you will be paid according in the following way (have also a look at the table below):

1. If you choose A, you receive a sure payment given in the second column. The payment which is actually chosen depends on the situation chosen randomly.

2. If you choose, you payment depends on how many members of your group (including yourself have chosen B:

- If at least 3 out of 7 members of your group have chosen B, you receive 15 Euros.
- If less than 3 members of your group have chosen B you receive 0 Euros.

Period

1 of 1

Time remaining[sec]: 93

Decide between A or B for each of the 10 situations.

Number of decision situation	Payment for A:	Your decision A or B:	Payment for B:
11	1.50 Euro	A ○ ○ B	0 Euro, if less than 3 members of your group choose B.
12	3.00 Euro	A ○ ○ B	15 Euros, if at least 3 members of your group choose B.
13	4.50 Euro	A ○ ○ B	dito.
14	6.00 Euro	A ○ ○ B	dito.
15	7.50 Euro	A ○ ○ B	dito.
16	9.00 Euro	A ○ ○ B	dito.
17	10.50 Euro	A ○ ○ B	dito.
18	12.00 Euro	A ○ ○ B	dito.
19	13.50 Euro	A ○ ○ B	dito.
20	15.00 Euro	A ○ ○ B	dito.

OK

Help

When you have decided please press the button OK.

You have to choose between A and B for each situation and you can do it in any order. When you have decided you have to click the button ok. Until you have not pressed the button, you can change your decisions.

Situations de decisions 21 – 30:

If one of the situations 21-30 is picked at the end, you will be paid according in the following way (have also a look at the table below):

1. If you choose A, you receive a sure payment given in the second column. The payment which is actually chosen depends on the situation chosen randomly.

2. If you choose, you payment depends on how many members of your group (including yourself have chosen B:

- If at least 5 out of 7 members of your group have chosen B, you receive 15 Euros.
- If less than 5 members of your group have chosen B you receive 0 Euros.

Period

1 of 1

Time remaining[sec]: 240

Decide between A or B for each of the 10 situations.

Number of decision situation	Payment for A:	Your decision: A or B	Payment for B:
21	1.50 Euro	A ○ ○ B	0 Euro, if less than 5 members of your group choose B.
22	3.00 Euro	A ○ ○ B	15 Euro, if at least 5 members of your group choose B.
23	4.50 Euro	A ○ ○ B	dito.
24	6.00 Euro	A ○ ○ B	dito.
25	7.50 Euro	A ○ ○ B	dito.
26	9.00 Euro	A ○ ○ B	dito.
27	10.50 Euro	A ○ ○ B	dito.
28	12.00 Euro	A ○ ○ B	dito.
29	13.50 Euro	A ○ ○ B	dito.
30	15.00 Euro	A ○ ○ B	dito.

OK

Help

When you have decided please press the button OK.

You have to choose between A and B for each situation and you can do it in any order. When you have decided you have to click the button ok. Until you have not pressed the button, you can change your decisions.

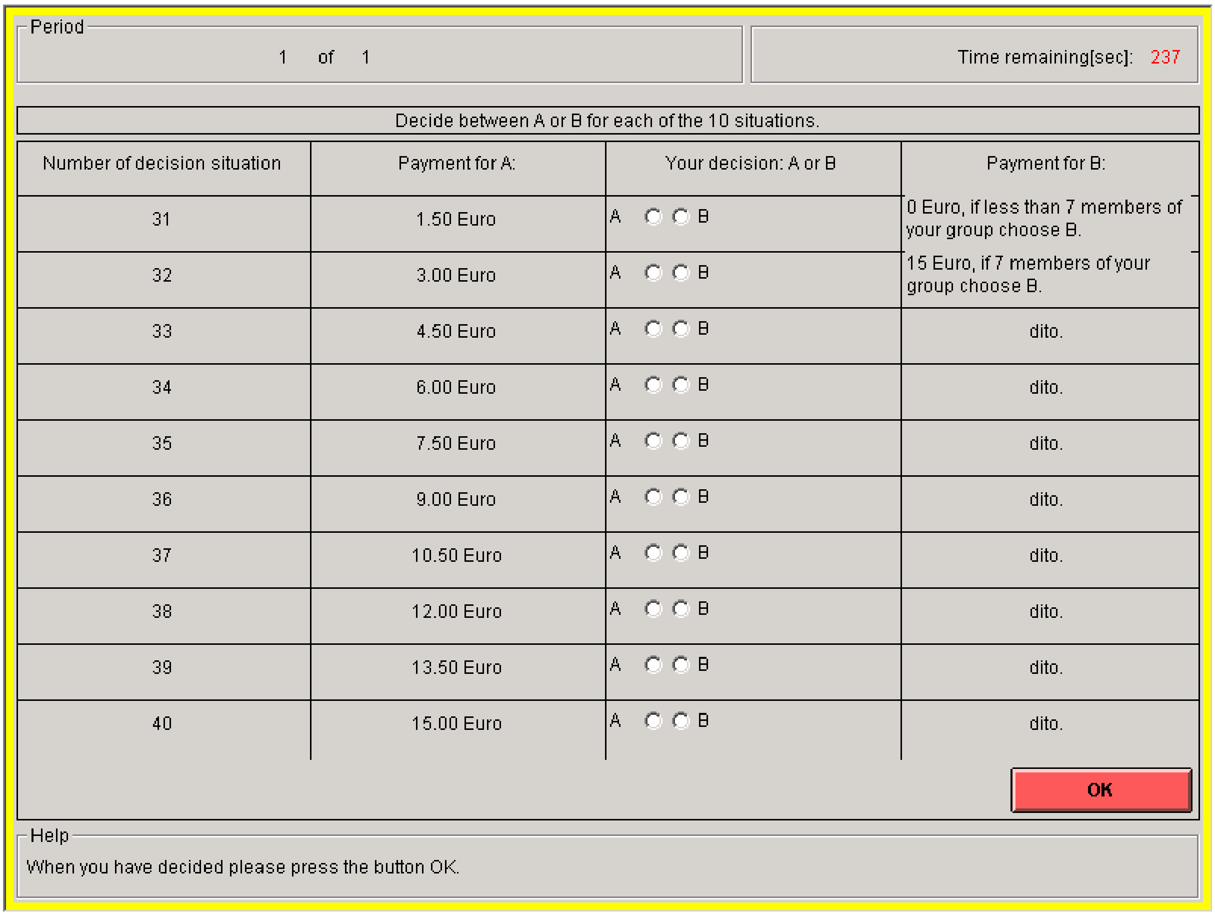
Situations de decisions 31 – 40:

If one of the situations 21-30 is picked at the end, you will be paid according in the following way (have also a look at the table below):

1. If you choose A, you receive a sure payment given in the second column. The payment which is actually chosen depends on the situation chosen randomly.

2. If you choose, you payment depends on how many members of your group (including yourself have chosen B:

- If at least 7 out of 7 members of your group have chosen B, you receive 15 Euros.
- If less than 7 members of your group have chosen B you receive 0 Euros.


Period

1 of 1

Time remaining[sec]: 237

Decide between A or B for each of the 10 situations.

Number of decision situation	Payment for A:	Your decision: A or B	Payment for B:
31	1.50 Euro	A B	0 Euro, if less than 7 members of your group choose B.
32	3.00 Euro	A B	15 Euro, if 7 members of your group choose B.
33	4.50 Euro	A B	dito.
34	6.00 Euro	A B	dito.
35	7.50 Euro	A B	dito.
36	9.00 Euro	A B	dito.
37	10.50 Euro	A B	dito.
38	12.00 Euro	A B	dito.
39	13.50 Euro	A B	dito.
40	15.00 Euro	A B	dito.

OK

Help

When you have decided please press the button OK.

You have to choose between A and B for each situation and you can do it in any order. When you have decided you have to click the button ok. Until you have not pressed the button, you can change your decisions.

When all participants made all 40 decisions and clicked the last OK-button, the computer randomly selects one of the situations 1 – 40. Your payment is determined by the rules of the selected situation.

On the screen you will then be informed about which of the 40 situations has been selected, how many members of your group have decided for A or B, respectively, in this situation, and how much money you will get.

Phase II

In the secon phase we ask you to fill in a questionnaire. The personal data will be treated confidential and are only used for research. To prove our spendings in case of investigation, we must ask you for your name and address. These data will be stored in separately from the others.

Once you complete the questionnaire, we pay you amount that you earned in phase I including the show-up fee of 5 Euro.

To make sure that everybody understands the rules of the game, we ask you some questions about the game. Phase I will start, when everybody gave the corect answers to these questions.

Appendix B: Data

The next table gives the number of B-choices in the four set-ups by threshold players from sessions in Frankfurt. For non-threshold players we give the sequence of decisions instead. In addition, the table presents each subject's gender and score in the experience seeking (ES) subscale of Zuckerman's SSS-V.

Subject number	Session	#B(Lottery)	#B(k=1/3)	#B(k=2/3)	#B(k=1)	gender	ES
1	4A	7	6	4	2	F	3
2		6	6	4	4	M	6
3		6	5	4	3	F	6
4		3	6	4	5	M	7
5		5	7	6	5	F	5
6		6	7	4	3	M	6
7		5	7	5	4	M	2
8		3	6	3	2	M	5
9		5	6	5	10	M	4
10		5	6	5	4	M	3
11		6	8	7	7	M	5
12		4	5	4	3	M	5
13		3	6	10	10	F	6
14		6	9	0	0	M	7
15		6	6	4	2	M	4
16		3	5	4	3	F	5
17		3	5	4	2	F	6
18		6	7	6	5	M	3
19		6	5	5	4	M	6
20		AAABBBAAAA	BBBBBBBBBB	AAAAAAAAAA	AAAAAAAAAA	M	9
21	4B	9	9	9	0	F	6
22		5	6	5	3	M	6
23		5	7	5	8	F	8
24		5	6	4	3	M	4
25		4	4	2	1	M	3
26		5	3	3	2	F	6
27		6	6	6	5	M	8
28		7	9	7	7	M	6
29		5	5	3	0	M	8
30		5	7	4	3	M	9
31		4	3	1	1	M	3
32		AABAABBABA	AABAABBAAB	ABAABAABAB	BABAAABABA	F	4
33		2	3	1	0	F	4
34		2	2	3	3	F	1
35		6	9	9	9	M	8
36		0	0	0	0	F	6
37	4C	BBBBBBBBBA	BBBBBBABAA	BBBBBBABBA	BBBBBBBAAA	M	2
38		6	5	3	1	M	8
39		4	5	3	2	F	5
40		7	8	6	5	M	7
41		5	8	6	4	M	3
42		5	5	3	2	M	5
43		6	9	6	4	F	6
44		BBBBBBAAAB	BBBAAAAAAB	BBBBAAAAAA	ABBBBBAAAA	F	7
45		8	7	4	0	F	6
46		6	6	4	3	M	8
47		5	9	7	6	F	8
48		4	5	4	3	F	5
49	4D	10	10	0	0	M	5
50		4	9	8	6	M	8

51		3	4	0	0	F	8
52		5	5	3	0	M	4
53		10	10	10	10	M	4
54		6	6	5	4	M	5
55		5	4	3	0	F	2
56		6	7	5	4	M	8
57		7	8	5	1	M	5
58		7	10	6	5	M	4
59		BBBAAAAAAA	ABAAAABAAA	ABBBBAAAAA	BBAAAAAAAA	F	5
60		0	10	0	0	M	5
61		6	5	5	0	M	9
62		6	7	6	5	M	6
63		10	4	4	4	M	6
64		7	7	5	4	M	2
65	7A	6	8	6	5	F	9
66		0	0	0	0	F	5
67		0	0	0	0	F	5
68		6	9	5	5	M	4
69		6	10	6	0	M	3
70		6	7	6	4	M	4
71		4	4	2	2	F	6
72		5	6	3	2	M	5
73		7	7	7	5	M	5
74		10	10	0	0	F	3
75		1	1	1	0	F	4
76		5	5	4	3	F	5
77		10	10	3	3	M	6
78		8	8	7	5	F	6
79		5	6	5	3	M	6
80		ABBABBBABB	BAABBBAAAA	AABBABBBAB	BAABABBBBA	M	1
81		6	5	5	3	M	4
82		5	7	6	5	F	5
83		6	8	6	3	M	7
84		5	7	6	6	F	8
85		5	6	5	4	M	7
86	7C	BBBABAABAA	BBBAABBBBB	AAAAAAAAAA	AAAAAAAAAA	F	8
87		7	4	3	2	F	6
88		6	8	7	7	M	6
89		6	6	6	6	M	7
90		BBAAABBBAA	AAABBAABAB	BABBAABBAA	BAAABABBAA	M	4
91		6	6	3	2	M	6
92		2	3	1	0	M	4
93		6	4	3	2	M	6
94		7	5	3	1	F	5
95		3	3	0	0	M	1
96		7	7	5	4	M	7
97		BAABABABAA	AABBAABABA	BABAABBABA	ABABABABBA	M	4
98		4	6	4	0	F	4
99		6	7	4	3	M	3
100		6	6	6	6	M	6
101		6	5	4	3	F	5
102		5	7	7	6	M	5
103		4	6	1	0	F	4
104		2	4	2	1	F	4
105		5	10	5	4	M	9
106		BBBBBBBBBA	AAAAAAAAAB	AAAAAAAAAB	AAAAAAAAAA	M	6
107	10C	5	5	3	2	M	9
108		4	6	5	4	F	3
109		2	9	1	1	F	8
110		5	5	4	4	M	5

111		6	5	0	0	F	6
112		AAAAABBBBB	BBBBBBBBBB	AAAAAAAAAA	AAAAAAAAAA	M	5
113		7	8	7	6	M	6
114		4	7	3	2	M	9
115		6	3	2	1	M	4
116		6	5	5	3	M	3
117		6	8	7	6	M	9
118		6	5	3	0	M	4
119		5	9	8	6	M	7
120		0	0	0	0	M	3
121		5	6	4	3	M	7
122		5	5	4	2	M	3
123		3	5	3	2	M	6
124		6	4	3	0	M	4
125		ABAAAAAAAA	ABAAAAAAAA	ABAAAAAAAA	ABBBBBBBBB	M	4
126		6	6	3	2	M	6
127	10D	7	5	3	1	M	6
128		3	3	3	2	F	3
129		AAAABBBBBB	AAABBBBBBB	BBBBBBBBBB	AAABBBBBBB	M	5
130		6	8	5	2	M	9
131		4	4	3	2	F	4
132		7	10	10	10	M	2
133		4	10	3	0	M	2
134		BBBBBBBBAB	BBBABBAAAB	AAAAAAAAAA	BBBBBBBBAA	M	3
135		6	7	6	5	M	8
136		BABABABABA	AAAAAAAAAA	BBBBBBBBBB	AAAAAAAAAA	F	6
137		3	6	4	0	F	4
138		4	5	4	2	F	8
139		6	7	5	3	F	7
140		7	8	7	5	M	9
141		10	10	0	0	M	3
142		8	9	9	9	M	6
143		5	6	4	3	F	8
144		6	10	10	0	M	8
145		7	7	3	0	M	3
146		10	10	5	6	M	7

The next table gives the number of B-choices in the four set-ups by threshold players from sessions in Barcelona. For non-threshold players we give the sequence of decisions instead. In addition, the table presents each subject's gender and score in the experience seeking (ES) subscale of Zuckerman's SSS-V.

Subject number	Session	#B(Lottery)	#B(k=1/3)	#B(k=2/3)	#B(k=1)	gender	ES
1	7B	ABBAAAAAAA	BBBBBBBBBB	BBBBBBBBBB	BBBBBBBBBB	F	6
2		9	6	4	5	F	10
3		9	10	10	10	F	9
4		7	9	9	7	M	10
5		5	7	5	4	M	6
6		5	9	9	9	M	7
7		5	5	5	5	F	3
8		6	7	6	6	M	6
9		6	7	5	4	M	4
10		5	6	3	1	F	8
11		3	6	5	0	F	6
12		6	7	6	5	M	6

13		3	0	0	0	F	8
14		4	3	2	1	M	5
1	7D	2	9	9	9	M	5
2		5	4	3	0	M	9
3		7	10	10	10	F	5
4		10	10	10	10	F	7
5		10	10	10	10	F	6
6		10	10	10	10	F	5
7		9	9	9	9	F	6
8		10	5	0	4	F	2
9		7	9	9	9	F	7
10		9	10	9	9	F	7
11		6	9	6	2	M	8
12		9	9	9	9	F	3
13		8	10	10	10	F	7
14		5	9	9	9	M	7