Do Players' Beliefs or Risk Attitudes Determine The Equilibrium Selections in 2x2 Coordination Games?

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Do Players' Beliefs or Risk Attitudes Determine The Equilibrium Selections in 2x2 Coordination Games?

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ABSTRACT

This study focuses on the question whether it is risk aversion or the beliefs of players that explains the strategic choices in 2x2 coordination games. In a laboratory experiment, we elicit the risk attitudes by using lottery choices. Furthermore, using a quadratic scoring rule, subjects' beliefs about the choice of the opponent are elicited directly. Our data show that participants' behavior is not explained by risk attitude, but rather is explained as their best response to their stated first order beliefs.

1   Introduction

A CLASSICAL PROBLEM that a decision-maker in uncertain situations has to solve is the tradeoff between the uncertainty and the resulting outcome (Schmidt et al., 2003). As a solution approach, Harsanyi and Selten (1988) introduced two selection criteria in their theory: the risk dominance and the payoff dominance.

In terms of uncertainty, we know two different kinds (Knight, 1921): one, exogenous uncertainty or risk with given *a priori* probabilities for all possible states of the world, as lotteries are and two, endogenous uncertainty given by the lack of such probabilities (Heinemann et al., 2009).

As a typical example for uncertain situations, symmetric games with multiple equilibria, such as coordination games, represent the tradeoff in uncertain situations. The equilibrium behavior in coordination games requires knowledge about the other player's behavior, meaning that the outcome of the players' depends on their expectations about the other player's behavior. Under the assumption of collective rationality, Harsanyi and Selten (1988) present arguments for selecting the payoff dominant equilibrium in such situations. In their words: "They should trust each other to play U (payoff dominant strategy)" (Harsanyi and Selten, 1988). In contrast, Carlsson and Damme (1993) or Harsanyi (1995) attribute the greater weight to selecting the risk dominant equilibrium.

Focusing on the question of decision-making in situations in which the payoff depends on other players' decisions, in Heinemann et al. (2009), a method to measure strategic

uncertainty is proposed. For a class of one-shot coordination games, the strategic uncertainty is measured by eliciting certainty equivalents. This method works analogously to the measurement of risk attitudes in lotteries: in coordination games, subjects had to choose between a sure payoff and an uncertain option (the payoff depends on the number of other players making the same choice). For different sure payoffs, the subjects' switching point is interpreted as the certainty equivalent for strategic uncertainty in coordination games.

Coordination games and the behavior of players in these games were center of attention in recent studies (see, e. g. van Huyck et al. (1990), Cooper et al. (1992), Heinemann et al. (2004), Cabrales et al. (2007), or Heinemann et al. (2009)). Summarizing these and other studies, no common consensus is reached on the question of equilibrium selection in coordination games (see e.g. Keser et al. (1998) or Keser and Vogt (2000)).

With respect to research addressing the question of equilibrium selection, the required knowledge about other players' behavior was added to the discussion. For eliciting players' expectations, or beliefs, the literature basically provides two procedures: direct or indirect elicitation. In Manski (2004), different methods for belief elicitation were presented and in different studies one can find arguments for using one or the other.

To study the question of equilibrium selection in coordination games, we combine a method of eliciting risk attitudes and aspects of strategic uncertainty. In this study, we relate risk and uncertainty by comparing lottery choices with the strategic behavior of players in a 2x2 coordination game and players' expectations about the behavior of other players. The used lottery choices and the coordination game are framed as similarly as possible.

For our study, we designed a laboratory experiment focusing on the following three key questions:

1. Is the risk attitude a good prediction for subjects' behavior in coordination games?
2. Do players predict their opponents' behavior?
3. Do they choose the best response to their stated beliefs?

We can show that players' risk attitudes do not predict the behavior in the coordination game, which can be explained by players' first order beliefs. Moreover, the majority of players play their best response to their stated first order beliefs.

In Section 2, we present the game design, theoretical predictions, and our research hypotheses. Section 3 explains the experimental design we used, Section 4 describes the results, and Section 5 concludes.

2 Game Design, Theoretical Predictions, and Hypotheses

2.1 Coordination Game

Because we were interested in the players' decisions, we wanted a game that was easy to understand. So we presented a symmetric 2x2 normal form coordination game with two pure strategy Nash equilibria: a payoff dominant (A,A) and a risk dominant (B,B), following the two selection criteria introduced by Harsanyi and Selten (1988). This game also has one

mixed strategy Nash equilibrium, where each player chooses A with probability 0.65. The game used in our experiment is presented in Table 1.

		Column Player	
		A	B
Row Player	A	(200,200)	(0,120)
	B	(120,0)	(150,150)

Table 1: Game design

If we interpret the given payoffs as von Neumann-Morgenstern utilities rather than as monetary payoffs, we can use the measure of risk dominance introduced by Selten (1995). Selten (1995) and Schmidt et al. (2003) pointed out that this is not a measure of risk preferences, but it can be interpreted as measuring the relative riskiness between the equilibria.

In our game the level of risk dominance of (A,A) is $R = Log(0.533)$, so R is negative, indicating that (B,B) is risk dominant. This result points out that the mixed strategy equilibrium is not risk dominant.

If we assume a utility function given as $u(x) = x^{\alpha}$, one can conclude that the higher the risk aversion of a participant, the higher the attractiveness of the risk-dominant strategy.

2.2 Lottery choices

In order to discuss the relation between risk attitude and strategic decision in the game, we had to identify each player's risk attitude. For this purpose, we used lottery choices. The players were asked to compare lotteries with the same payoff-structure as in the game. The lotteries we used are presented in Table 2.

No. of pair	Lottery A	Lottery B
	[p,150; 1-p,120]	[1-p,200;p,0]
1	[.1,150;.9,120]	[.9,200;.1,0]
2	[.2,150;.8,120]	[.8,200;.2,0]
3	[.3,150;.7,120]	[.7,200;.3,0]
4	[.4,150;.6,120]	[.6,200;.4,0]
5	[.5,150;.5,120]	[.5,200;.5,0]
6	[.6,150;.4,120]	[.4,200;.6,0]
7	[.7,150;.3,120]	[.3,200;.7,0]
8	[.8,150;.2,120]	[.2,200;.8,0]
9	[.9,150;.1,120]	[.1,200;.9,0]

Table 2: Lottery choices

For purposes of this study, the main focus was not the elicitation of certainty equivalents, but the identification of the strategy people use when transforming the 2x2 game into lottery choices. Therefore, we were interested in the point where participants switch from the risky option (Lottery B) to the less risky option (Lottery A) and how often they switch between the options. According to studies on risk preferences, such a design can help in identifying degrees of risk aversion (Holt and Laury, 2002). A risk neutral agent, for example,

would switch between No. 3 and 4. We see that the further down the switching point in Table 2, the higher the degree of an agent's risk aversion. Applying this procedure helped to identify that subjects use a threshold strategy when facing a game as presented in our paper (Heinemann et al., 2004).

2.3 Belief elicitation

Like many other studies (e. g. Nyarko and Schotter (2002), Gerber (2006) or Biel (2009)), we elicited the players' beliefs directly. In our sub-experiment 1, we elicited players' beliefs by asking what they predict as to which strategy their partner has chosen. Additionally, they had to indicate by a number between 0 (not confident at all) and 100 (fully confident) how confident they are with their answer. The players were rewarded according to a quadratic scoring rule adopted from Nyarko and Schotter (2002) and Gerber (2006). This quadratic scoring rule is based on the axiomatic characterization formulated by Selten (1998). This function is designed such that it is optimal for a risk neutral player to report her true belief. With respect to players' risk attitudes or the consequences of probability weighting, there is a probability that players misreport their true belief, which is pointed out by Sonnemans and Offerman (2001). In our experiment we used the following function:

If their partner chooses the predicted strategy, the payoff is

$$1 - \left(1 - \frac{p}{100}\right)^2 \ [in \ Euro],$$

and if their partner does not choose the predicted strategy, the payoff is

$$1 - \left(\frac{p}{100}\right)^2 \ [in \ Euro].$$

Obviously, reporting a first order belief of $p = 50$ guarantees a riskless payoff off 0.75 Euro.

2.4 Research Hypotheses

We designed our experiment to test the following hypotheses. Based on many other studies (e.g. Schmidt et al. (2003), Heinemann et al. (2006) or Goeree et al. (2003)), we assume that behavior in games is related to risk aversion. Therefore, the first hypothesis is formulated as follows:

> *H1:* *The players' risk attitudes determine the strategy selection in the 2x2 coordination game.*

Inspired by the literature about the influence of beliefs on the behavior (e.g. Nyarko and Schotter (2002) or Costa-Gomes and Weizsäcker (2008)), we elicit players' first order beliefs to test our second hypothesis. That is:

> *H2:* *The players' first order beliefs determine the strategy selection in the 2x2 coordination game.*

In order to test our second hypothesis, we study the question whether players choose the best response to their first order beliefs. The literature provides various examples of studies, which show on the one hand that a majority of players do choose the best response (e.g. Nyarko and Schotter (2002) or Biel (2009)), and on the other hand that players often fail to

best respond to their stated beliefs (e.g. Heinemann et al. (2006), Gerber (2006), or Costa-Gomes and Weizsäcker (2008)). According to these findings, our third hypothesis is formulated as:

> H3: The participants choose best response to their stated first order beliefs.

3 The Experiment

To answer the key questions and to test our hypotheses, we run the following experiment. This experiment was divided into two parts. In this section we give a detailed presentation of the design and procedure of each part.

The experiment was performed in the MaXLab, the experimental laboratory at the University of Magdeburg in August 2007. Participants were recruited using ORSEE software (Greiner, 2004) from a pool of mostly students from various faculties. We ran our experiment in six sessions with groups of six subjects each. For the computerized parts, we used a program implemented in z-tree (Fischbacher, 2007). All instructions were provided in German. A translation of the written instructions is shown in the appendix. For the first part of the experiment, the instruction sheets contained detailed information about the payoff mechanism, in particular a table showing the payoffs for different possible probabilities based on the payoff functions used in this part.

During the whole experiment, no communication was allowed among the participants and subjects did not get any information about their payoffs or the behavior of their partners. In total, participants could have earned a maximum of 5 Euro. The experiment provided a riskless payoff of 3.15 Euro.

3.1 Part 1 of the experiment

In our treatment, two players were randomly matched to play a symmetric 2x2 normal form coordination game, which is explained in Section 2. Each player was instructed to play as a column or as a row player. The players were asked simultaneously to choose one of the two possible options. The payoffs were revealed in Eurocent.

After making their own strategic decision, the players were asked to predict the action her partner had chosen. The players also had to indicate by a number between 0 (not confident at all) and 100 (fully confident) how confident they are with their answer. Given their first order beliefs, participants were rewarded according to the payoff-function as explained in Section 2.

The decision in the coordination game and the first order belief elicitation were computerized. The maximum payoff participants could earn in the first part of the experiment was 3 Euro. There was a riskless payoff off 1.95 Euro.

3.2 Part 2 of the experiment

To identify players' risk attitude we run the second part. For the lottery choices we used a questionnaire. The participants were shown a table of two lottery tickets on it, Lottery A $[G_{1A}, p\%; G_{2A}, (100-p)\%]$ and Lottery B $[G_{1B}, p\%; G_{2B}, (100-p)\%]$, as explained in

Section 2. For nine pairs of lotteries, they were asked which lottery they prefer or if they are indifferent between the two lotteries.

Contrary to the representation in Section 2.2, we changed the order of the probabilities *(p)* and the payoffs *(G)* in the lottery tickets. Thus, the participants were shown the payoffs at first, which should create a better understanding. The payoffs were revealed in Eurocent and the probabilities were given in percent.

At the end of the experiment, one of the decisions was realized. For each participant, this decision was determined by drawing one ball from a bingo cage containing 9 balls numbered from 1 to 9. According to the participants' preferences, the preferred lottery was played by drawing a ball from a bingo cage containing a specified number of red and blue balls, reflecting the probabilities of the lottery (the number of red balls equates to the probability of payoff one (G_1) and the number of blue balls equates to the probability of payoff two (G_2)). In the case of indifference, the toss of a coin determined which lottery was played.

In a third part, we collected data concerning higher order beliefs, which we did not report in this study. Neither the decisions in the third part nor the payoffs were directly related to the first two parts.

4   Results: Descriptive Statistics

As shown in previous sections, lottery choices and the coordination game follow a setup framed as similarly as possible. Participants choose between an alternative with a risky payoff and an alternative with a riskless payoff. Depending on the probability, they typically choose the risky option if the probability to get the high payoff is high and otherwise choose the other alternative. In the lottery choices, we observe the switching point from the risky lottery to the riskless lottery between the second and the fourth pair.

Our data shows that 58 percent of the participants chose the risky strategy A in the first part of our experiment. In Table 3 we provide the observations of the strategy selection and of the first order beliefs in Part 1 of the experiment. As one can see, 86 percent of our participants guess their partner would select the same strategy and 67 percent guess their partner would select the risky strategy A.

36 participants in total	Number of players (in %)
strategy A chosen	21 (58.33%)
strategy B chosen	15 (41.66%)
player guess their partner choose the same strategy	31 (86.11%)
player guess their partner choose the alternative strategy	5 (13.88%)
player guess A as their partners decision (first order belief)	24 (66.66%)
player guess B as their partners decision (first order belief)	12 (33.33%)

Table 3: strategy selections and first order beliefs in Part 1 of the experiment

The lottery choices of the participants are presented in Table 4. It is obvious that on average the participants show an equal risk attitude. The switch from the risky lottery to the safe lottery is in a probability interval, which includes the mixed strategy equilibrium of the game.

No. of pair	Lottery A [p,150; 1-p,120]	Lottery B [1-p,200;p,0]	No. of players, who choose A	No. of players, who choose B	indifferent
		Lottery choices – No. of players			
1	[.1,150;.9,120]	[.9,200;.1,0]	5	31	0
2	[.2,150;.8,120]	[.8,200;.2,0]	7	29	0
3	[.3,150;.7,120]	[.7,200;.3,0]	17	16	3
4	[.4,150;.6,120]	[.6,200;.4,0]	30	1	5
5	[.5,150;.5,120]	[.5,200;.5,0]	30	0	6
6	[.6,150;.4,120]	[.4,200;.6,0]	33	0	3
7	[.7,150;.3,120]	[.3,200;.7,0]	35	1	0
8	[.8,150;.2,120]	[.2,200;.8,0]	35	1	0
9	[.9,150;.1,120]	[.1,200;.9,0]	35	1	0

Table 4: lottery choices and switching point

In conclusion, the participants in this study show equal risk attitudes. As assumed, the players used a threshold strategy, indicating for high probabilities ($p \geq .8$) of getting the maximum payoff, they chose the risky lottery, and for probabilities below a threshold ($.6 < p < .8$), they switch to the less risky lottery.

In our experiment, the majority of the players was risk averse and only switched one time.

To test our first two hypotheses, we compare the medians of the elicited first order beliefs (to get the maximum payoff) and the medians of the switching points in the lottery choices of the participants sorted by their strategy selections in the coordination game.

As you can see in Table 5, the switching points of the resulting groups do not differ significantly. In contrast, the first order beliefs differ significantly (Wilcoxon-Test, 1%-level). We did not, however, find any evidence that the risk attitudes determine the strategy selections (H1 rejected) in the game. As shown before, the first order beliefs of the strategy B players are significantly lower than in the other group. With respect to these results, we summarize that the first order beliefs determine the strategy selection (H2 not rejected) in the game.

	No. of Player	First order belief (to get the max. payoff)	Lottery choice (switching point)
		Strategy selection – first order beliefs vs. switching points	
strategy A (payoff-dominant)	21	.8	.7
strategy B (risk-dominant)	15	.3	.75

Table 5: Strategy selection, first order beliefs, and switching points in Part 1 of the experiment

Considering these results, the following analysis focuses on the question whether the participants chose the best response to their stated first order beliefs. For this test we assumed that the maximal error rate in the first order beliefs is $\leq .25$. We found that the majority of players choose the best response to their first order beliefs (One-sided Binomial Test, 5%-level) and therefore we do not reject H3.

5   Conclusion

Our starting point for this study was the question whether the risk attitudes or the first order beliefs of players determine the strategy selections in symmetric 2x2 coordination games. Guided by three key questions, we designed a laboratory experiment to collect data including the strategy selections, the estimation of the players' risk attitudes, and the direct elicitation of the players' first order beliefs.

Using lottery choices to identify the players' risk attitudes, we found that participants in our experiment used a threshold strategy and that the average player was risk averse. To relate the players' risk attitudes to the uncertainty in the coordination game, we compare the risk attitudes and the strategic decisions. As an answer to our first key question, we did not find evidence for a determining influence of the risk attitudes on the players' decisions.

As a second result, it is shown, that players predict their opponents' behavior in the game we used. Moreover, in contrast to our first result, the expectations of the players, elicited by their first order beliefs, seem to be a much better predictor for the behavior of subjects in coordination games such as the one used in this study.

According to the finding above, we found lastly, that the majority of the participants in our experiment choose the best response to their stated first order beliefs.

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Appendix: Written instructions

Welcome to our today's experiment! Below, you can find the description of the experiment and then you are asked to make a series of decisions. Please read the following information very carefully. If you have any questions, please ask before you start the experiment. Please note that during the whole experiment, communication with the other participants is not allowed. Thank you!

The Experiment

The experiment consists of two parts. You get separate instructions for each part of the experiment. First, each instruction contains the description of this part of the experiment, second, we explain the payoff-mechanism for the respective part and then you are asked to make your decision.

The first part of the experiment is computerized and for the second part you will get a questionnaire. You receive a subscriber number by drawing a ball from a bingo cage containing numbered balls. This number applies to all parts of the experiment. Please indicate the number in the upper right box on your decision sheet. Please also write a pseudonym in this field. At the beginning of each part you get the instructions for this part of the experiment. Please read the complete instructions at first and ask any questions you may have. After that, please make your decision. The information about your total payoff is shown to you at the end of the whole experiment.

Part 1

In this part you will be randomly matched with a partner.

Part 2

In this part you are asked to compare lotteries.

Part 1 - Instructions

The following Game is played one time. You will be told, whether you play as the "row player" or as the "column player". Your randomly matched partner plays the other role. The table shows the game you play:

		Column Player	
		A	**B**
Row Player	**A**	(200,200)	(0,120)
	B	(120,0)	(150,150)

You have to decide between the two possible options, strategy A or strategy B. Your payoff depends on your decision as well as on the strategy selection of your partner. There are four possible strategy combinations (A,A), (A,B), (B,A) and (B,B). In the table above, you can find the corresponding payoffs. The first number in a field represents the payoff of the row player and the second number represents the payoff of the column player. The payoffs are revealed in Eurocent.

In addition you are asked to predict your partner's strategy. Please indicate by a number P between 0 (not confident at all) and 100 (fully confident) how confident you are with your answer.

Payoff mechanism

Your payoff depends on the resulting strategy combination. Additionally you get a payoff according the following function (for the two possible alternatives):

Alternative 1: If your partner chooses the predicted strategy, your payoff is:

$$1-(1-\frac{p}{100})^2 \qquad \text{p = level of confidence}$$

Examples for the resulting payoff for different levels p, if your prediction is correct:	
p = 0 → O Euro	p = 60 → 0,84 Euro
p = 10 → 0,19 Euro	p = 70 → 0,91 Euro
p = 20 → 0,36 Euro	p = 80 → 0,96 Euro
p = 30 → 0,51 Euro	p = 90 → 0,99 Euro
p = 40 → 0,64 Euro	p = 100 → 1 Euro
p = 50 → 0,75 Euro	

Alternative 2: If your partner does not choose the predicted strategy, your payoff is:

$$1-(\frac{p}{100})^2 \qquad \text{p = level of confidence}$$

Examples for the resulting payoff for different levels p, if your prediction is not correct:	
p = 0 → 1 Euro	p = 60 → 0,64 Euro
p = 10 → 0,99 Euro	p = 70 → 0,51 Euro
p = 20 → 0,96 Euro	p = 80 → 0,36 Euro
p = 30 → 0,91 Euro	p = 90 → 0,19 Euro
p = 40 → 0,84 Euro	p = 100 → 0 Euro
p = 50 → 0,75 Euro	

Decision

Please make your decision using the computer.

Part 2 - Instructions

In this sub-experiment, you are asked which lottery you prefer for nine pairs of lotteries. The lotteries are all of the following type:

	lottery A		lottery B	
probability	p%	(100-p)%	p%	(100-p)%
payoff	G_{1A}	G_{2A}	G_{1B}	G_{2B}

For each lottery, p denotes the probability to win the amount of money G_{1A} or G_{1B} and (100-p) denotes the probability to win the amount of money G_{2A} or G_{2B}.

For example:

	lottery A		lottery B	
probability	10%	90%	90%	10%
payoff	800	600	1000	0

In this example: if you prefer the lottery A, then you win 800 Eurocent with probability 10% and 600 Eurocent with probability 90%. If you prefer lottery B, then you win 1000 Eurocent with probability 90% and 0 Eurocent with probability 10%.

Please use the following questionnaire to indicate your decision, whether you prefer lottery A or B in the table. If you are indifferent between the two lotteries, please check the box on the form.

Payoff mechanism

At the end of the experiment, one of the decisions will be realized. This decision will be determined by drawing one ball from a bingo cage containing nine balls numbered from 1 to 9. According to your preferences, the preferred lottery will be played by drawing a ball from a bingo cage containing a specified number of red and blue balls, reflecting the probabilities of the lottery (the number of red balls equates to the probability off the payoff one (G_1) and the number of blue balls equates to the probability of the payoff two (G_2)). In the case of indifference, the toss of a coin determines which lottery is played (heads for lottery A, tails for lottery B).

Decision-table

No. of pair	lottery A		lottery B	A	B	indifferent
1	[150,(10%);120,(90%)]		[200,(90%);0,(10%)]			
2	[150,(20%);120,(80%)]		[200,(80%);0,(20%)]			
3	[150,(30%);120,(70%)]		[200,(70%);0,(30%)]			
4	[150,(40%);120,(60%)]		[200,(60%);0,(40%)]			
5	[150,(50%);120,(50%)]		[200,(50%);0,(50%)]			
6	[150,(60%);120,(40%)]		[200,(40%);0,(60%)]			
7	[150,(70%);120,(30%)]		[200,(30%);0,(70%)]			
8	[150,(80%);120,(20%)]		[200,(20%);0,(80%)]			
9	[150,(90%);120,(10%)]		[200,(10%);0,(90%)]			