# Do Players' Beliefs or Risk attitudes determine the Equilibrium selections in 2x2 coordination Games

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## First Draft

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**ABSTRACT**

*This study focuses on the question whether risk aversion or beliefs of players explain 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 it best response to their stated first order beliefs. Higher order beliefs follow different patterns which are in most cases in contrast to Bayesian updating.*

**JEL-CLASSIFICATION:** D 81, C 91, C 72

**KEYWORDS:** coordination games, equilibrium selection, beliefs, belief updating

## 1 Introduction

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

In terms of uncertainty, we know two different kinds: exogenous uncertainty or risk with given a priori probabilities for all possible states of the world, as lotteries are and endogenous uncertainty given by the lack of such probabilities (Heinemann, Nagel et al. 2006).

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. Coordination games and the behavior of players in these games were center of attention in recent studies (see, e.g. van Huyck, Battalio et al. (1990), Cooper, DeJong et al. (1992), Heinemann, Nagel et al. (2004) or Cabrales, Nagel et al. (2007)). Summarizing these and other studies, there is no common consensus on the question of equilibrium selection in coordination games (Keser, Ehrhart 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. The assumption of infinite reasoning, as assumed in orthodox game theory is contrary to the findings in experiments on the depth in thinking (Colman 2003). A range of studies show that players operate on finite levels of strategic depth (e.g. Nagel (1995), Stahl and Wilson (1995), Costa-Gomes, Crawford et al. (2001) or Camerer, Ho et al. (2002)). Moreover, it is shown, that people tend to operate on only one or two levels (Colman (2003) or Camerer, Ho et al. (2002)).

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.

For our study, we designed a laboratory experiment focusing on the following four 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 best response to their stated beliefs?
4 Do they update their beliefs to build beliefs in higher order?

We can show that players' risk attitudes do not predict the behavior, which can be explained by players' beliefs. Moreover, the majority of players play best response to their stated first order beliefs. In our experiment participants operate on 4 steps of strategic depth on average. Most of our participants build higher order beliefs in a way, which is contrary to the concept of Bayesian updating.

# 2 Game Design and Theoretical Predictions

## 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, Shupp 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 $\mathrm{R} = \mathrm{Log}(0{,}533)$, so R is negative meaning that (B,B) is risk dominant. This result is not that surprising, but points out, that the mixed strategy equilibrium is not risk dominant.

If we assume an exponential utility function given as $\mathrm{u}(\mathrm{x}) = \mathrm{x}^{\propto}$ one can conclude that the higher the risk aversion of a participant is, the higher is 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 indentify 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 | [0.1,150;0.9,120] | [0.9,200;0.1,0] |
| 2 | [0.2,150;0.8,120] | [0.8,200;0.2,0] |
| 3 | [0.3,150;0.7,120] | [0.7,200;0.3,0] |
| 4 | [0.4,150;0.6,120] | [0.6,200;0.4,0] |
| 5 | [0.5,150;0.5,120] | [0.5,200;0.5,0] |
| 6 | [0.6,150;0.4,120] | [0.4,200;0.6,0] |
| 7 | [0.7,150;0.3,120] | [0.3,200;0.7,0] |
| 8 | [0.8,150;0.2,120] | [0.2,200;0.8,0] |
| 9 | [0.9,150;0.1,120] | [0.1,200;0.9,0] |

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 identifying degrees of risk aversion (Holt and Laury 2002). A risk neutral agent, for example, would switch between no. 3 and 4. The further down the switching point in table 2 is, 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, Nagel et al. 2004).

## 2.3 Belief elicitation

Like many other studies (e.g. Nyarko and Schotter (2002), Gerber (2006) or Biel (forthcoming)), we elicited the players' beliefs directly. In our sub-experiment 1 we elicited players' beliefs by asking what they think, 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

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

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.

In the second part of our study we were interested in the depth of strategic thinking of the players. Therefore, we do not ask what the players think, which action their partner has chosen. We ask for the relevance of thinking about this question and an appraisement of the level of confidence. In the context of beliefs, these questions focus on the same aspect. Thus, each partner's decision could only be relevant for their own, if they had been thinking about it. Using this design gave us the opportunity to reward the depth of thinking and correctness of the matched players' relevance prediction without paying too much attention on the question of correctness of the strategy prediction. Surely this would be an interesting point, but it would open an additional strategic field which would be difficult to isolate in the experimental analysis, especially given the structure of the payoff function.

With respect to former studies, we asked for a finite number of steps. Various studies show, that players use a limited number of steps of thinking (e.g. Camerer (2003) or Colman (2003)). Different studies (e.g. Camerer, Ho et al. (2002)) corroborate that human beings tend to operate at only one or two levels of strategic depth. We asked for eight steps, which should guarantee that all relevant steps were included. Our questions follow the scheme "It is relevant for me, that it is relevant for you, that it is relevant for me, that..., to think about which strategy you chose". In addition to the answer (yes or no) the player had to indicate by a number between 0 (not confident at all) and 100 (fully confident) how confident they are with their answer. Standard game theory assumes indefinitely reasoning with a level of confidence at 100. For answering these questions the players were rewarded according to the following quadratic scoring rule:

If the matched players' relevance prediction is correct, the payoff is

$$\frac{1}{7}\cdot\sum\left\{4\cdot\left[1-\left(1-\frac{p}{100}\right)^{2}\right]\right\}\ [in\ Euro]\text{, and}$$

if the matched players' relevance prediction is not correct, the payoff is

$$\frac{1}{7}\cdot\sum\left\{4\cdot\left[1-\left(\frac{p}{100}\right)^{2}-0{,}3\right]\right\}\ [in\ Euro].$$

With respect to players' loss aversion and the overweighting of losses (Kahneman and Tversky 1979) we designed the payoff function such that if the matched players' relevance predictions were not correct the negative payoffs were much smaller than the positive payoffs for correct guesses. Furthermore, we used an average function to make all steps of thinking relevant for the payoffs. Given this, reporting $p = 35$ on each step guarantees a riskless payoff off 2.31 Euro.

Connected to the question about the depth of thinking we were interested in the belief updating used by the participants. Probably the most common theoretical concept is the Bayesian updating, used by e.g. Kraemer, Nöth et al. (2006). The Bayesian belief updating follows the intuition that the deeper one may think, the degree of confidence cannot rise. In other words, a decision-maker is uncertain on two consecutive steps of thinking, so her degree of uncertainty is higher for the next step. The levels of certainty on these two steps determine the maximum level of certainty on the following step. In our experiment we consider any probability equal or smaller than the theoretical Bayesian probability as a result of Bayesian updating performed by the participants.

Following standard theory of rational choice, a decision-maker should report all eight steps as relevant with $p = 100$ as level of confidence.

## 2.4 Research Hypotheses

We designed our first sub-experiment to test the following hypotheses. Based on many other studies (e.g. Schmidt, Shupp et al. (2003), Heinemann, Nagel et al. (2006) or Goeree, Holt 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 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 best response (e.g. Nyarko and Schotter (2002) or Biel (forthcoming)) and on the other hand that players often fail to best respond to their stated beliefs (e.g. Heinemann, Nagel et al. (2006), Gerber (2006) or Costa-Gomes and Weizsäcker (2008)).

*H3: The participants choose best response to their stated first order beliefs!*

Various studies show, that human beings typically tend to operate on only one or two levels of strategic depth (e.g. Nagel (1995), Stahl and Wilson (1995), Costa-Gomes, Crawford et al. (2001), Camerer, Ho et al. (2002) or Colman (2003)). In the context of decisions under uncertainty, we study the question whether the depth of thinking influences the strategic decision in the game. To conclude and operationalize this question, we formulated our fourth hypothesis:

*H4: The depth of thinking of the participants influences the strategy selections in the game!*

Our second sub-experiment focuses on the question on depth of thinking. We were interested in the numbers of steps the players think and on the belief updating. As a reference model we used the Bayesian updating. Many studies pointed out that players do not behave as so called "perfect Bayesians". Moreover they often are not even close (e.g. Ouwersloot, Nijkamp et al. (1998) or Charness and Levin (2003). With respect to this finding, we formulated our fifth hypothesis:

*H5: The participants do not update their beliefs to form higher order beliefs according to the Bayes rule!*

## 3 The Experiment

To answer the key questions and to test our hypotheses, we ran the following experiment. This experiment was divided into 2 sub-experiments. In this section we give a detailed presentation of the design and procedure of each sub-experiment.

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. For each 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 the sub-experiments.

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 17 Euro. The experiment provided a riskless payoff of 12.57 Euro.

## 3.1 Sub-experiment 1

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 told, if she played as column or as 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 what they think, which 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 was computerized. For the following 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.

At the end of the whole 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 form 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 (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.

The maximum payoff participants could earn in sub-experiment 1 was 5 Euro. There was a riskless payoff off 3.15 Euro.

## 3.2 Sub-experiment 2

Before starting this sub-experiment, participants had to answer some questions. We used a questionnaire in order to check whether participants understood the meaning of the different steps of thinking. We also presented a computer screen to the participants, where they could try different probabilities to get a better understanding of the payoff-function as used here. After all participants gave the correct answers to the questions we started the second sub-experiment.

This experiment was based on the first sub-experiment. We ran the same coordination game but this time playing two rounds. Like in sub-experiment 1, participants were randomly matched. We used a matching-mechanism, which guaranteed that the players neither had interacted in a previous round nor that the matched partners were matched with the same other participant in a previous round and therefore guaranteeing independent observations.

As in the sub-experiment 1 the participants were asked to choose one of the two possible actions in the coordination game. This decision was equal to the step zero in terms of the depth of thinking we asked for. As pointed out in section 2 we asked for the relevance of thinking on eight steps. For that purpose we used a questionnaire with a table on it. On each of the eight steps the participants had to mark with a cross, it was relevant or not (yes or no) and analogously to the first sub-experiment they had to indicate by a number *p* how confident they are with their answer.

In each round of this sub-experiment the maximum payoff was 6 Euro and there also was a riskless payoff off 3.51 Euro.

# 4 Results: Descriptive Statistics

As shown in previous sections, lottery choices and the coordination game follow a setup framed as similar 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 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.

## 4.1 Strategy selection and risk

Our data shows that 58 percent of the participants chose the risky strategy A in our sub-experiment 1. In table 3 we present the strategy selections in the coordination game in the three rounds of our experiment. As one can see, the players select their strategies according to the mixed strategy equilibrium. The distribution of these strategy selections in the three rounds shows no significant difference.

**Strategy selection – No. of players**

| | sub-experiment 1 | sub-experiment 2 round 1 | sub-experiment 2 round 2 |
|---|---|---|---|
| strategy A (payoff-dominant) | 21 | 24 | 22 |
| strategy B (risk-dominant) | 15 | 12 | 14 |

Table 3: distribution of the strategy selections

During the experiment only six participants alternate in their strategy selections.

In table 4 we provide the observations of the strategy selection and of the first order beliefs in the sub-experiment 1. 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 4: strategy selections and first order beliefs in sub-experiment 1

The lottery choices of the participants are presented in table 5. 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.

**Lottery choices – No. of players**

| 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 |
|---|---|---|---|---|---|
| 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 5: lottery choices and switching point

In conclusion, the participants in this study show equal risk attitudes. As assumed, the players used a threshold strategy, meaning, for high probabilities $(p \geq 0.8)$ of getting the maximum payoff they chose the risky lottery and for probabilities below a threshold $(0.6 < p < 0.8)$ they switch to the less risky lottery. In our experiment the majority of the players were 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 6, 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.

**Strategy selection – first order beliefs vs. switching points**

| | No. of Player | First order belief (to get the max. payoff) | Lottery choice (switching point) |
|---|---|---|---|
| strategy A (payoff-dominant) | 21 | 0.8 | 0.7 |
| strategy B (risk-dominant) | 15 | 0.3 | 0.75 |

Table 6: Strategy selection, first order beliefs and switching points in sub-experiment 1

Considering these results, the following analysis focuses on the question whether the participants chose best response to their stated first order beliefs. For this test we assumed that the maximal error rate in the first order beliefs is $\leq 0.25$. We found that the majority of players choose best response to their first order beliefs (one-sided Binomial Test, 5%-level) and therefore we do not reject H3.

## 4.2 Higher order beliefs and Bayesian belief updating

The sub-experiment 2 was based on the coordination game we used in sub-experiment 1. In our experiment the average participant operated on four steps of strategic depth in both rounds of the sub-experiment 2. According to the strategy selections of the participants, we divided the subjects into two groups. Table 7 presents the medians of the depth of thinking of the participants classified in the two groups as explained before. In the first round, the 24 players who selected the risky strategy A operated on 5 steps of strategic depth, whereas the other 12 players operated on only 3 steps. It is noticeable that in the second round of this sub-experiment we did not find this difference and players in both groups operated on 4 steps.

**Strategy selection – depth of thinking (median)**

| | round 1 | round 2 |
|---|---|---|
| strategy A (payoff-dominant) | 5 | 4 |
| strategy B (risk-dominant) | 3 | 4 |

Table 7: strategy selection and median of the depth of thinking in sub-experiment 2

Thus we conclude, that in the second round the depth of thinking did not influence the strategy selection (Wilcoxon-Test, 5%-level) and H4 is rejected for round two. In the first round, the medians of the depth differ but do not do so significantly. (H4 not rejected for round one).

Our results show that forming higher order beliefs follows different patterns. The behavior of the sorted participants can be classified as seven different types (table 8) of belief building.

| | | |
|---|---|---|
| type 1 | - | participants report a constant probability over all relevant and/or irrelevant steps |
| type 2 | - | participants report constant probabilities which are different for relevant or irrelevant steps |
| type 3 | - | participants report decreasing probabilities in a case, that all steps are relevant |
| type 4 | - | participants report decreasing probabilities in a case, that the first step(s) are relevant and the later are irrelevant |
| type 5 | - | participants report decreasing probabilities for relevant steps and increasing probabilities for irrelevant steps |
| type 6 | - | participants report alternating probabilities for relevant steps and increasing probabilities for irrelevant steps |
| type 7 | - | participants report increasing probabilities for relevant steps and also increasing probabilities for irrelevant steps (with equal starting probability) |

Table 8: types of belief building

In table 9 we present the distribution of the participants over the seven types. The players are also divided into the two groups with respect to their strategy selections.

**Strategy selection – No. of players of the seven types (round 1)**

| | type 1 | type 2 | type 3 | type 4 | type 5 | type 6 | type 7 |
|---|---|---|---|---|---|---|---|
| strategy A | 3 | 1 | 3 | 6 | 9 | 1 | 1 |
| strategy B | 1 | 2 | 1 | 3 | 5 | 0 | 0 |

**Strategy selection – No. of players of the seven types (round 2)**

| | type 1 | type 2 | type 3 | type 4 | type 5 | type 6 | type 7 |
|---|---|---|---|---|---|---|---|
| strategy A | 2 | 2 | 3 | 3 | 11 | 1 | 0 |
| strategy B | 1 | 0 | 3 | 6 | 4 | 0 | 0 |

Table 9: No. of players of the possible types in the two rounds

To analyze the question of Bayesian belief updating we normalized the elicited beliefs by using the complementary probability. It follows that only the types 1, 3 and 5 are possibly Bayesian types.

In our experiment only four players in each round behave as so called Bayesians. One of these four follows the rational solution and reports the maximum probability $p = 1$ as level of confidence for all eight steps. The majority of the participants form beliefs according to various patterns (one-sided Binomial-Test, 5%-Level), which are in most cases in contrast to the concept of Bayesian belief updating (H5 not rejected).

## 5 Conclusion

Starting point of 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. Inspired by four 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.

Comparing the risk attitudes and the strategic decisions, we did not found evidence for a determining influence of the risk attitudes on the players' decisions. In contrast, the elicited 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. Moreover, the majority of the participants in our experiment choose the best response to their stated first order beliefs.

In a second experiment we focused on the question of the participants' belief updating to build higher order beliefs. In addition, we analyzed if there was any influence of the depth of thinking on the strategic decision. This experiment has been carried out in two rounds. On average, subjects reported four steps as relevant, which is equal to the depth of thinking. Whilst we found different depth of thinking depending on the strategy selection in the first round, we did not find differences in the second round.

To study the belief updating mechanism performed by the participants, we used the Bayesian updating as the reference model. Our results show, that only four subjects behave like a Bayesian player. In total, we observed seven different types of belief updating.

## References


Biel, P. R. (forthcoming). "Equilibrium Play and Best Response to (Stated) Beliefs in Constant Sum Games." Games and Economic Behavior.

Cabrales, A., R. Nagel, et al. (2007). "Equilibrium selection through incomplete information in coordination games: an experimental study." Experimental Economics **10**: 221-234.

Camerer, C. F. (2003). "Behavioural studies of strategic thinking in games." TRENDS in Cognitive Sciences **7**(5): 225-231.

Camerer, C. F., T.-H. Ho, et al. (2002). A Cognitive Hierarchy Theory of One-shot Games: Some Preliminary Results. CalTech working paper.

Carlsson, H. and E. v. Damme (1993). "Global Games and Equilibrium Selection." Econometrica **61**: 989-1018.

Charness, G. and D. Levin (2003). When Optimal Choices Feel Wrong: A Laboratory Study of Bayesian Updating, Complexity, and Affect. Economics Working Paper Series: No. 1164. Santa Barbara, University of California at Santa Barbara.

Colman, A. M. (2003). "Depth of strategic reasoning in games." TRENDS in Cognitive Sciences **7**(1): 2-4.

Cooper, R. W., D. V. DeJong, et al. (1992). "Forward induction in coordination games." Economics Letters **40**: 167-172.

Costa-Gomes, M., V. P. Crawford, et al. (2001). "Cognition and Behavior in Normal-Form Games: An Experimental Study." Econometrica **69**(5): 1193-1235.

Costa-Gomes, M. A. and G. Weizsäcker (2008). "Stated Beliefs and Play in Normal-Form Games." Review of Economic Studies **75**(3): 729-762.

Fischbacher, U. (2007). "z-Tree: Zurich toolbox for ready-made economic experiments." Experimental Economics **10**(2): 171-178.

Gerber, A. (2006). Learning in and about Games. Working Paper Series. Zurich, Institute for Empirical Research in Economics, University of Zurich.

Goeree, J. K., C. A. Holt, et al. (2003). "Risk averse behavior in generalized matching pennies games." Games and Economic Behavior **45**: 97-113.

Greiner, B. (2004). The Online Recruitment System ORSEE 2.0 - A Guide for the Organization of Experiments in Economics. Working Paper Series of Economics. Cologne, University of Cologne.

Harsanyi, J. C. (1995). "A new theory of equilibrium selection for games with complete information." Games and Economic Behavior **8**: 91-122.

Harsanyi, J. C. and R. Selten (1988). A General Theory of Equilibrium Selection in Games. Cambridge, MIT Press.

Heinemann, F., R. Nagel, et al. (2004). "The Theory of Global Games on Test: Experimental Analysis of Coordination Games with Public and Private Information." Econometrica **72**(5): 1583-1599.

Heinemann, F., R. Nagel, et al. (2006). Measuring Strategic Uncertainty in Coordination Games. CESifo Working Paper Series No. 1364.

Holt, C. A. and S. K. Laury (2002). "Risk Aversion and Incentive Effects." The American Economic Review **92**(5): 1644-1655.

Kahneman, D. and A. Tversky (1979). "Prospect Theory: An Analysis of Decision under Risk." Econometrica **47**: 263-291.

Keser, C., K.-M. Ehrhart, et al. (1998). "Coordination and local interaction: experimental evidence." Economics Letters **58**: 269-275.

Keser, C. and B. Vogt (2000). Why do experimental subjects choose an equilibrium which is neither payoff nor risk dominant? Working Paper. Mannheim, University of Mannheim.

Kraemer, C., M. Nöth, et al. (2006). "Information aggregation with costly information and random ordering: Experimental evidence." Journal of Economic Behavior & Organization **59**(3): 423-432.

Manski, C. F. (2004). "Measuring Expectations." Econometrica **72**(5): 1329-1376.

Nagel, R. (1995). "Unraveling in Guessing Games: An Experimental Study." The American Economic Review **85**(5): 1313-1326.

Nyarko, Y. and A. Schotter (2002). "An Experimental Study of Belief Learning using Elicited Beliefs." Econometrica **70**(3): 971-1005.

Ouwersloot, H., P. Nijkamp, et al. (1998). "Errors in probability updating behaviour: Measurement and impact analysis." Journal of Economic Psychology **19**: 535-563.

Schmidt, D., R. Shupp, et al. (2003). "Playing safe in coordination games: the role of risk dominance, payoff dominance, and history of play." Games and Economic Behavior **42**: 281-299.

Selten, R. (1995). "An axiomatic theory of a risk dominance measure for bipolar games with linear incentives." Games and Economic Behavior **8**: 213-263.

Selten, R. (1998). "Axiomatic Characterization of the Quadratic Scoring Rule." Experimental Economics **1**: 43-62.

Sonnemans, J. and T. Offerman (2001). Is the Quadratic Scoring Rule really incentive compatible? Working Paper CREED. Amsterdam, University of Amsterdam.

Stahl, D. O. and P. W. Wilson (1995). "On Players' Models of Other Players: Theory and Experimental Evidence." Games and Economic Behavior **10**: 218-254.

van Huyck, J. B., R. C. Battalio, et al. (1990). "Tacit Coordination, Strategic Uncertainty, and Coordination Failure." The American Economic Review **80**(1): 234-248.