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Introduction

The thesis consists of three chapters analyzing two prominently discussed topics in the economics literature, coordination and imitation. Chapter 1 and 2 deal with coordination and imitation behavior of elementary school children age 7 to 10. In Chapter 1, we examine the behavior of children in a minimum effort game experiment, analyze whether they are able to coordinate on the same effort level and compare the results with the previous literature on adult behavior. Chapter 2 experimentally analyzes and compares the behavior of children and university students in a multi armed bandit problem where, given thei setup, imitation of others would indeed be beneficial and would lead to strictly higher payoffs. Last, Chapter 3 of the thesis considers coordination from a theoretical point of view and extends an existing model of constrained mobility to more than two locations.

Challenging Coordination - Behavior of a Young Subject Pool in a Minimum Effort Game Experiment

The minimum effort game is a coordination game where n players simultaneously choose a costly effort level. The payoff is determined by the lowest effort level chosen by all players. Whenever players coordinate on the same effort level we are in a

Nash equilibrium. Moreover, when players coordinate on the same, highest available effort level we are in the Pareto dominant equilibrium. Results in the previous literature suggest that adult subjects in groups of two to four players are able to coordinate efficiently and to keep up coordination over time. However, group minima and frequency of coordination are decreasing with group size. Chapter 1 deals with the minimum effort game setup introduced in Van Huyck, Battalio and Beil (1990). We adapt the experimental setup to conduct an experiment with elementary school children age 7 to 10 years and compare the behavior of children with the results of adults in the previous literature. We examine whether children are able to coordinate and conditioned on coordination, what level they coordinate on. The experimental results suggest that children aim for relatively high effort levels and that there is a high variance of effort level choices throughout the experiment. Similar to adult behavior, we find a correlation between the group size and the minimum group effort level where smaller groups achieve higher minima. While coordination failure in larger groups of four and five children is in line with results in the previous literature, we also find smaller groups of two and three children not being able to coordinate efficiently. Although some of these groups coordinate on the same effort level, children are not able to keep up coordination over time. We identify three different types of behavior, which in combination with the limited feedback information in the experiment, make it hard for children to coordinate on the same effort level.

Imitation of Peers in Children and Adults

This chapter is a slightly modified version of the working paper Apesteguia et al. (2015). Imitating the successful choices of others is simple and at first glance attractive learning rule. It has been shown to be an important driving force for the

behavior of (young) adults. In Chapter 2, we study children’s and adults’ behavior in a setting where imitation leads to strictly higher payoffs than those received when ignoring information about other players. We examine whether imitation is prevalent in the behavior of children aged between 8 and 10 and compare the results with behavior of a university student subject pool.

Surprisingly, we find that imitation seems to be cognitively demanding: Most children in this age group ignore information about others, foregoing substantial learning opportunities. While this seems to contradict much of the psychology literature, we argue that success-based imitation of peers may be harder for children to perform than imitation (non-success-based) of adults.

Constrained Mobility and the Evolution of Efficient Outcomes

There are many circumstances where individuals can benefit from coordination on the same action. However, in real life, we will not only observe coordination resulting in a beneficial outcome (HTTP protocol) but also coordination on a less desirable action (almost universal use of the QWERTY keyboard despite there being superior alternatives such as the Dvorak keyboard) or the coexistence of coordination on two different actions in different places (driving on the right side of the road in most countries, driving on the left in some others). Chapter 3 analyzes the question under which circumstance we will observe agents choosing different actions and when everybody will use the same action. We study an evolutionary model akin to the one in Anwar (2002), where a population of agents use myopic best response learning to determine their action in a 2×2 coordination game with a risk dominant and a payoff dominant equilibrium. In addition to their choice in the coordination game, agents can decide on their interaction partner by choosing one out two islands on

which to play the game. We focus on the case where the number of agents maximally allowed on each island is constrained. Without mobility and constraints on capacity, convergence to the risk dominant equilibrium has been observed in the previous literature (Kandori et al. (1993) and Young (1993)). This negative result can be improved by mobility of agents. It allows them to get a higher expected payoff by moving to an island where the payoff dominant action is played (Ely (2002)). Introducing constraints on the capacity of islands opens the door for the coexistence of the two outcomes on separate islands (Anwar (2002)). We extend Anwar's (2002) original analysis by considering the case where there may be more than two islands and are interested in which of the three outcomes will arise in the long run. Most importantly, we find that if the constraint on capacity of the islands are such that one island may be empty, universal coordination on the payoff dominant action will be reached in the long run. As there cannot be an empty island in Anwar (2002) this result is absent in his analysis. Further, if constraints on capacity are such that all islands will be fully occupied, then for relatively mild constraints the coexistence of conventions will occur. In this case, agents on one island will play the risk dominant action whereas agents on all other islands will play the payoff dominant action. For relatively stringent constraints on the capacity of islands all agents will play the risk dominant action. The latter two results present generalizations of the finding in Anwar (2002) to the case of more than two islands.

Chapter 2 is based on joint work with Jose Apesteguia, Steffen Huck, Jörg Oechssler and Simon Weidenholzer and Chapter 3 on joint work with Paolo Pin and Simon Weidenholzer.

Chapter 1

Challenging Coordination: Behavior of a Young Subject Pool in the Minimum Effort Game

There are many situations where the performance of a group depends on the effort of the weakest group member. Think about organizational and economic processes where coordination on the same and "right" action is important and imperfect behavior of one subject can lead to serious problems. Prominent examples are production technologies that are sensitive to the worst input, e.g. constructing a car or plane, or food production where one bad ingredient can make the final product inedible. Or think about a region fighting to eradicate an infectious disease, where all countries must put the same effort in order to achieve a common goal. Or sports, where the performance of a rowboat is only as good as the performance of the weakest rower on the boat.

The minimum effort game (Van Huyck, Battalio and Beil 1990, henceforth VHBB)

is a coordination game where n players simultaneously choose an effort level e_i . A player's payoff depends on the own effort level chosen as well as on the smallest effort level chosen within the group. Coordination of all players on the same effort level results in a Nash equilibrium. These multiple equilibria can be Pareto ranked with coordination on the effort level with the highest associated effort leading to the Pareto dominant equilibrium. In the economic literature on minimum effort game experiments we see that coordination on an effort level with a low associated effort is a common phenomenon. VHBB was the first paper documenting coordination failure in large groups of 14 to 16 players in a minimum effort game experiment conducted in the lab. One explanation for this type of coordination failure is that low effort levels are attractive as they secure a high payoff when others also choose low effort levels or when there is strategic uncertainty about the actions of the other players. The larger this uncertainty (the larger a group), the more attractive the low effort levels will become. The results in VHBB triggered a vivid discussion in the literature. Many others replicated the results and attempted to introduce mechanisms to support coordination on the highest effort equilibrium. Among these mechanism were minimum effort game experiments with financial incentives for high effort coordination, financial penalties for low effort level choices and fees to enter the game (Cachon and Camerer 1996 and Brandts and Cooper 2006), experiments that allowed pre-play communication or announcements (Blume and Ortmann 2007 and Brandts and Cooper 2007) and experiments with variations in group size, group composition and the group entry process (Dufwenberg and Gneezy 2005, Weber 2006 and Engelmann and Normann 2010). While financial incentives in Brandts and Cooper (2006 and 2007), pre-play communication in Blume and Ortmann (2007) and Brandts and Cooper (2007), a special group composition in Engelmann and Normann (2010) and a slow growth in group size in Weber (2006) had a positive impact on the average

group minimum, other mechanisms proved to be less influential. And while a lot of studies considered adult behavior in the minimum effort game little is known on how coordination behavior develops with age.

The psychological literature on the development of children's cooperative and competitive behavior suggests that the capability of balancing one's own needs and the need of others starts to be generated as early as the first year of life (Howes 1987). It develops further during preschool years when children start to have more intense social interactions. In contrast to the large number of economic experiments with adult participants there is a smaller number of papers addressing economic questions in experiments with a younger subject pool. But economists have become more interested in the behavior of children in recent years adding to a large literature on child development in psychology.¹ Our study follows economic experiments on children's behavior which adapt existing experimental setups and make them understandable and suitable for children. Literature in psychology and the late literature in economics include studies on children's ability to coordinate (Madsen 1967, Brownell and Carriger 1990 and Fan 2000), children's altruistic behavior in public good games (Harbaugh and Krause 2000 and Alencar et al. 2008), children's competitiveness in regard to gender (Gneezy and Rustichini 2004, Dreber et al. 2011, Cárdenas et al. 2012 and Sutter and Glätzle-Rützler 2014), children's risk behavior (Harbaugh et al. 2002), children's fairness and inequality acceptance (Fehr et al. 2008 and Almås et al. 2010) and children's abilities for strategic thinking (Perner 1979, Perner and Wimmer 1985 and Sher et al. 2014). The fact that children in previous experiments were able to cooperate and perceive their co-players thinking process, showed increasing altruistic behavior, gave higher public good game donations in smaller groups and acted less risk averse when at a young age encouraged us to study children's behavior

¹ For a comprehensive overview see Eisenberg et al. (2006).

in the minimum effort game setup.

Since coordination is an important aspect in economics and a child's ability to coordinate with others is a fundamental component of social behavior, the experiment tries to bring these two aspects together. In this paper we study a minimum effort game experiment with young school children age 7 to 10 years. The study closely follows the existing experimental design of VHBB which we adapted for children and conducted as a pen and paper experiment within the familiar environment of the classroom. Our objective is to compare existing data on university student behavior with the behavior a younger subject pool and detect similarities and differences in coordination behavior. In line with results in the previous literature, we find that children's frequency of coordination is decreasing in group size. But we further detect differences in the variation of effort level choices and the number of coordination instances between children and adults. Children coordinate less than adults and they are not able to keep up coordination even in small groups of two and three players.

1.1 The Game

The minimum effort game is a coordination game with multiple Pareto ranked equilibria. There are $n \geq 2$ players who simultaneously choose an integer $e_i \in \{c_1, \dots, c_k\}$. Player i 's payoff is determined by his own effort level e_i and the lowest effort level chosen by others in the same group $\underline{e}_{-i} = \min\{e_1, \dots, e_{i-1}, e_{i+1}, \dots, e_n\}$. The payoff function is of the following form

$$\Pi_{e_i, \underline{e}_{-i}} = a [\min(e_i, \underline{e}_{-i})] - be_i \text{ where } a > b > 0. \quad (1.1)$$

Whenever there is coordination on the same effort level by all players, we are in a Nash equilibrium. These multiple equilibria can be Pareto ranked, with coordination on the highest effort level giving the highest payoff to each player. The presence of multiple Pareto rankable equilibria can result in two types of coordination failure.

First, players might not be able to forecast the minimum chosen by all other group members correctly and therefore choose an effort level different from the group minimum. In this case $e_i \neq e_{-i}$ and there is no coordination. Second, since the Nash equilibria can be Pareto ranked, we might find players coordinating on the same effort level but failing to do so on the highest Pareto ranked effort level. In this case

$$\min \{e_1, \dots, e_n\} \neq \max \{c_1, \dots, c_k\}. \quad (1.2)$$

Hence, players face the dilemma that the highest feasible effort level maximizes efficiency by giving each single player the highest possible payoff. Whereas the lowest feasible effort level maximizes individual security by giving the highest payoff in the worst case outcome.

The experiment adopts the minimum effort game design in treatment A of VHBB where players can choose an effort level $e_i \in \{1, 2, \dots, 7\}$. The payoff matrix is such that $a = 2$ and $b = 1$. Further a constant of 6 is added to ensure strictly positive payoffs for all effort levels. These parameters were chosen such that players have an incentive to coordinate on a high effort level and such that any player choosing a higher effort level than the group minimum is penalized with a lower payoff than the minimum player. The payoff structure is given in Table 1.1.

There is a range of different equilibrium predictions for the minimum effort game dilemma. While Nash equilibrium theory only suggests players will coordinate on the same effort equilibrium, Harsanyi and Selten's (1988) concept of payoff dominance

narrows down a player's equilibrium choices. It says that if one equilibrium of the game gives a consistently higher payoff to all players than any other equilibrium of the game, then a rational player should choose the high payoff equilibrium. In the minimum effort game with its strictly Pareto rankable equilibria, payoff dominance solves the individual and collective coordination problem and predicts players to coordinate on the highest effort equilibrium.

Table 1.1: Payoff table

		Minimum Group Effort						
		7	6	5	4	3	2	1
	7	13	11	9	7	5	3	1
Individual	6	-	12	10	8	6	4	2
Effort	5	-	-	11	9	7	5	3
	4	-	-	-	10	8	6	4
	3	-	-	-	-	9	7	5
	2	-	-	-	-	-	8	6
	1	-	-	-	-	-	-	7

Von Neumann and Morgenstern's (1953) maximin concept uses security to find the equilibrium point with an action being maximin if it maximizes a player's payoff in the worst possible outcome scenario. In the minimum effort game a player can secure himself the highest minimum payoff by choosing the lowest available effort level. All players acting according to the maximin rule results in coordination on the inefficient lowest effort equilibrium. The availability of multiple different equilibrium predictions illustrates the difficulties players might have in coordinating on the same effort level.

1.2 The Experiment

Subjects and Treatments

The study was conducted in five elementary schools in Vienna, Austria. The subjects were 151 children age 7 to 10. The average age of the children was 9.22 years and 54 percent were female. The children were recruited by sending emails to the headteachers and if possible to the third grade class teachers in around 200 Viennese schools explaining that we wanted to conduct an economic experiment on children's decision making. With the permission of the Viennese School Authority all sessions were run in June 2011.

The experimental setup consists of four treatments, referred to as N2, N3, N4 and N5 that differ in the number of group members only. Each treatment was included in at least two out of seven sessions to ensure as much random selection as possible. Table 1.2 gives specific numbers on players, groups and the percentage of male players for each treatment. Following VHBB who reminded players about their own effort level choice and gave them feedback on the minimum group effort level only, the feedback information after each period consisted of the player's own effort level chosen, the group's minimum effort level and the player's resulting payoff. The game itself (instructions, payoff table, feedback information) was the same in all treatments. The only difference in the game explanation process was the usage of different numbers for the size of a group (2, 3, 4 and 5) and the numbers on co-players (1, 2, 3 and 4).

Table 1.2: Experimental design table

	N2	N3	N4	N5
number of players	24	54	48	25
number of groups	12	18	12	5
percentage of male players	52	54	40	32

Procedure

The experiment was conducted as pen and paper experiment within the familiar environment of the classroom. Upon arrival in the classroom the children's tables were arranged to face the blackboard and partition walls were put up on the tables to deter children from looking at each other's decision sheets. The instructions were read aloud. Each participating child was told that he would get a 3 euro voucher for the Austrian chain store Libro where he could buy books, CDs, DVDs and stationeries. We further told them that they would have the opportunity to earn more vouchers during the game. In addition to a large payoff table on the blackboard, each child was handed a print of the payoff table to keep on his desk at all times. After giving the instructions on the game itself we carefully explained the payoff matrix. We did so by going through 12 different mock scenarios that were drawn randomly before the experiment. We further let the children work out their payoff in four example situations. If a child answered a question incorrectly, one of the assistants would help him go through the solution process before giving away the next example situation. Children were allowed to ask private questions throughout the whole instruction procedure.²

The game lasted for 10 periods. Children were matched in fixed groups. We

² For full instructions see Appendix.

used an Excel program to calculate payoffs and to gather and print feedback. In each period we first provided the children with the feedback/decision sheet that gave information about their own effort level chosen, the minimum group effort level and the corresponding payoff.³ We gave them 30 seconds to go through the previous period's information and choose an effort level between 1 and 7 (except for the first period where information on the previous period was not available and children had 30 seconds to decide on the effort level only).⁴ In addition to the 3 euro fixed earning each 10 points payoff in the game would give a further 1 euro voucher to the children. Odd numbers were rounded up to the next integer amount. The average earning over all treatments was 7 euro. In-between the decision periods children were allowed to either read a comic or color something on sheets of paper that were provided beforehand. After the last period, they were handed a questionnaire asking about personal details such as date of birth, number of siblings and favorite school subjects, which was filled in with the experimenter's assistance. At the end of the experiment each child was handed an envelope with his final number of points and the corresponding number of vouchers. The whole experiment from entering to leaving the classroom lasted around 100 minutes which is also the duration of two school hours. The game itself lasted for around 60 minutes.

1.3 Results

We first present the distribution of effort levels and minimum group effort levels, consider coordination and children's behavior over time and then compare behavior

³ For an example of the feedback-/decision-sheet see Appendix.

⁴ This time period was carefully chosen after a trial session. It secures to give the children enough time to go through all the information and pick an effort level each period without getting bored and starting to rethink their decision.

of children with results on adult behavior in the existing literature.

1.3.1 Effort levels, group minima and coordination

The average effort level in period 1 varies between 4.67 in N4 and 5.24 in N5 with the majority of children choosing an effort level at the upper half of the effort level scale in all treatments. In line with the previous literature neither security motives, predicting a low effort level choice, nor efficiency motives predicting a high effort level choice are able to fully explain children's behavior in the first period of the experiment where 19.21 percent of all children choose the payoff dominant strategy 7 and only 2.65 percent choose the secure option 1.

Children moreover focus on higher effort levels throughout the experiment. Figure 1.1 depicts statistics on the average effort level choice of individual players over time. There is a graph for each of our treatments as well as for the average individual effort level choice in groups of two and six adult players reported in the previous literature. Data on two-player groups is available from VHBB and Knez and Camerer (2000) and data on six-player groups is available from Knez and Camerer (1994) and Dufwenberg and Gneezy (2005). In each graph there are 10 boxplots representing the distribution of individual effort level choices for each period of the experiment and a reference line at effort level 4 which is the median prediction if players would randomize, i.e. choose each effort level with probability $1/7$. Dots, squares, crosses and triangles outside of the boxplots represent outliers.

First, we see that the median effort level is never smaller than 4 for children. Further, the median of young subjects does not change substantially over time in any of the treatments. In contrast to that, the median of adult subjects depends on group size and lies at the two extremes of the effort level scale. Small groups of two

adult players predominantly choose the highest effort level 7 whereas adult subjects in larger groups of six converge to a median at the lowest effort level 1. To analyze whether children choose effort levels at random, we perform Wilcoxon tests for the first period and binominal tests for all other periods and check whether the median differs significantly from 4. As these tests show that the median is significantly different from 4 for all treatments, we exclude uniform random behavior.⁵

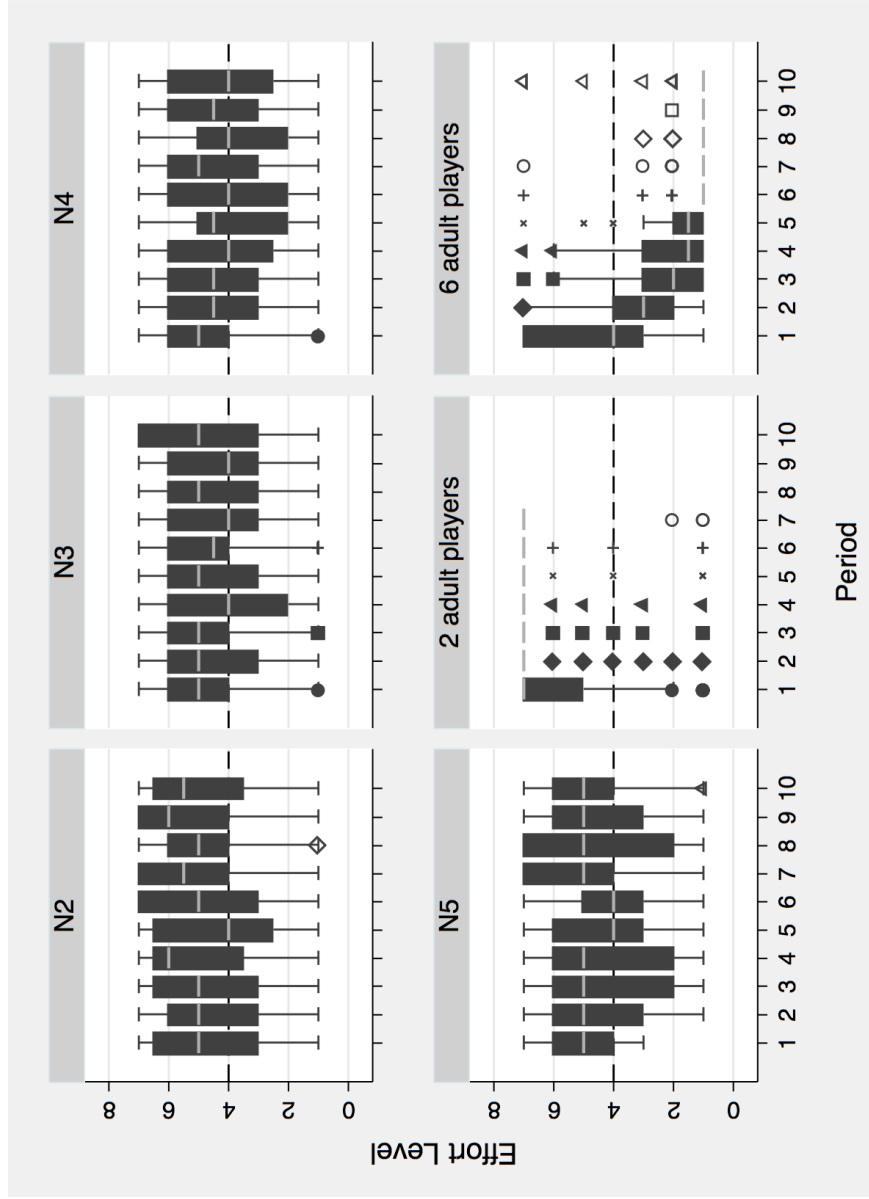
Figure 1.1 further shows that the variance of effort level choices in experiments with an adult subject pool is decreasing over time. Children do not follow the same pattern. The variance of effort level choices stays relatively large over all 10 periods of the experiment. A similar difference can be found for the deviation from the group minimum. Figure 1.10 compares the individual subject's average deviation from the group minimum in each period between children and adults. Data for adult groups is available from VHBB (2 and 14-16 players), Knez and Camerer (1994, 3 and 6 players), Dufwenberg and Gneezy (2005, 6 players). In contrast to adult subjects where deviation is declining over time, the difference between individual effort level choice and group minimum remains relatively large for children over the whole horizon of the experiment.⁶

Table 1.3 provides summary statistics of effort level choices and group minima based on group averages. In line with the previous literature, children obtain higher

⁵ For non-parametric tests, we consider the average within one group as one independent observation. First period Wilcoxon tests show that the median of the group minimum is significantly different from 4 for all treatments ($p < .005$ for all treatments). Binominal tests show that significantly more than 50 percent of the group medians are above 4 in all 10 periods except for period 5 ($p < .02$ for periods 1,2,3,4,7,8 and 9 and $p < .09$ for period 6).

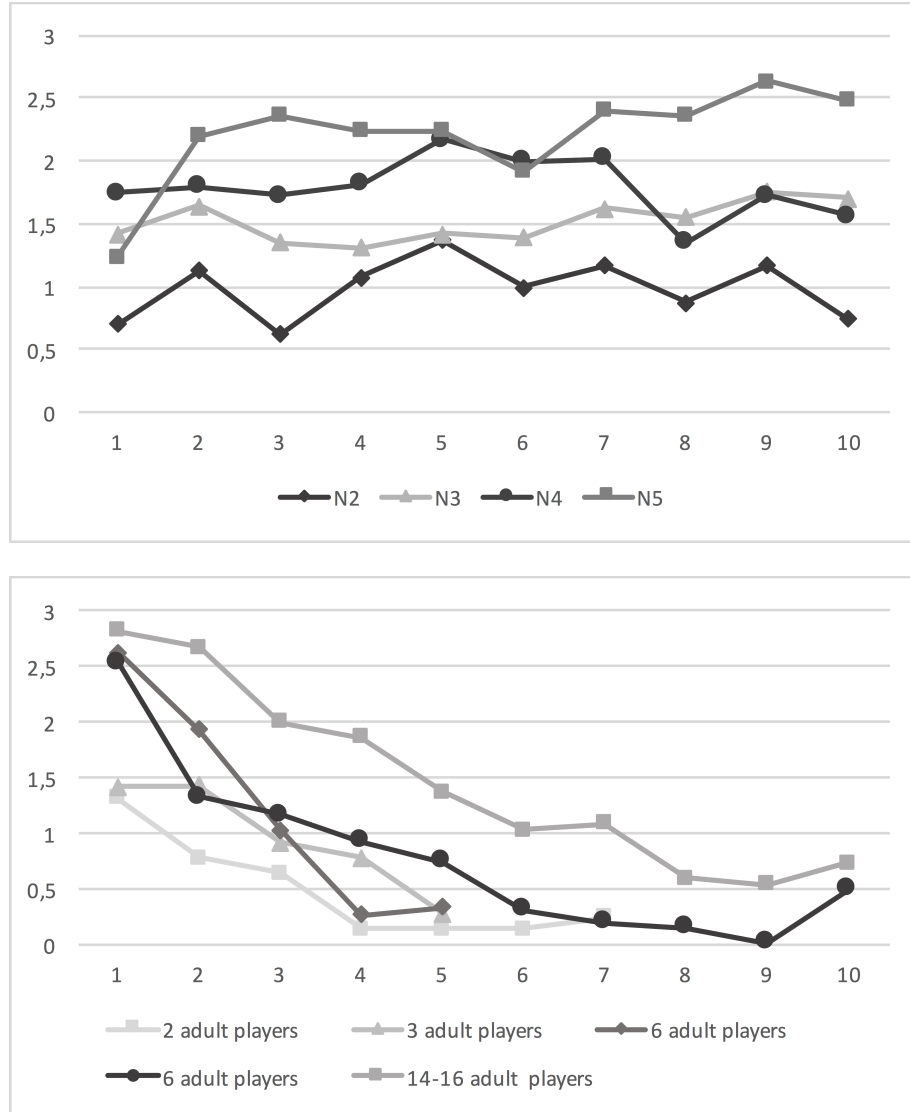
⁶ This observation is supported by regressing the average deviation per group on periods. The coefficient is significantly negative ($p < .01$ for all group sizes) for all adult groups and insignificant for all treatments in our study. For regression results see Table 1.10 in the Appendix.

Figure 1.1: Boxplots of effort level choices over time



Note: Boxplots for two- and six-player adult groups include data reported in VHBB (1990) and Knez and Camerer (2000) for groups of two players as well as data reported in Knez and Camerer (1994) and Dufwenberg and Gneezy (2005) for groups of six players. Boxplots for adult players quickly reduce to the median line with almost all players choosing the same effort level. Dots, squares, crosses and triangles outside the boxplots represent each period's outliers.

Figure 1.2: Average deviation from group minimum per player over time



Note: Graph includes data reported in VHBB (1990) for groups of two players, data reported in Knez and Camerer (1994) for groups of three players, data reported in Knez and Camerer (1994) and Dufwenberg and Gneezy (2005) for groups of six players and data reported in VHBB (1990) for groups of 14-16 players.

Table 1.3: Summary statistics of effort level choices and group minima

	N2	N3	N4	N5
Mean effort over all periods	4.78 (0.9)	4.61 (0.72)	4.2 (0.9)	4.55 (0.5)
Mean effort in periods 1-5	4.67 (1.02)	4.69 (0.78)	4.37 (0.87)	4.5 (0.59)
Mean effort in periods 6-10	4.89 (0.89)	4.53 (0.9)	4.04 (1.13)	4.6 (0.51)
Mean minimum over all periods	3.79 (0.99)	3.09 (0.89)	2.41 (0.84)	2.34 (0.64)
Mean minimum in periods 1-5	3.68 (1.03)	3.26 (0.9)	2.52 (0.99)	2.44 (0.92)
Mean minimum in periods 6-10	3.9 (1.09)	2.92 (1.13)	2.3 (0.99)	2.24 (0.83)

Note: Standard deviation based on group averages in parenthesis.

average group minima in smaller groups.⁷

Next, we assess to what extent children can manage to coordinate on an equilibrium of the game, that is all players choose the same effort level. Table 1.4 presents data on coordination incidences and effort levels groups coordinate on. There is very little coordination occurring. Groups in N2 coordinate 21 out of 120 possible times and groups in N3 in six out of 180 times. There is no single instance of coordination in the larger group treatments N4 and N5. Conditioned on coordination occurring at

⁷ To show this trend we regress the average group minimum on group size with fixed effects for sessions. The results show that the coefficient for group size is negative and highly significant. The coefficient for group size in a regression on the average effort with fixed effects for sessions is significant at a 10 percent level only. For regression results see Tables 1.8 and 1.9 in the Appendix.

all, children predominantly coordinate on effort levels on the upper end of the effort level scale. Only 15 percent of groups coordinate on an effort level below 4.⁸

1.3.2 Comparison with the previous literature

Adult behavior

A number of contributions have analyzed the minimum effort game with an adult subject pool using the original design of VHBB. The subjects were undergraduate students from universities in the United States, Israel and Denmark. All experiments used payoff function (1) mentioned in section 2 of this paper but some used different parameters a and b . Further there are differences with respect to the length of the game and the feedback information. In the comparable studies mentioned below the game was played between 5 and 10 periods and in some experiments subjects got feedback on the whole distribution of effort levels within their group. There are a number of stylized facts emerging from this literature.

1. Adult subjects are often able to coordinate on the same effort level and keep up coordination once it is established in groups of two, three and four players.
2. The average group minimum and payoff of adult subjects is declining in group size.
3. Smaller groups of adult subjects coordinate more often than larger groups.

⁸ One might be tempted to look at learning theories. The most simple adaptive procedure is myopic best response. If children would follow myopic best response this would result in coordination within one period and they would be able to keep up coordination over time. However, coordination does not happen that often in the data and the fraction of best responses lies under 20 percent in all treatments such that we find very limited evidence for myopic best response. For a more detailed discussion of behavior according to myopic best response and Selten's learning direction theory see section "Learning Theories" in the Appendix.

Table 1.4: Coordination over time

Treatment	Number of groups coordinating in period									
	1	2	3	4	5	6	7	8	9	10
N2 (12 groups)	2	3	2	0	2	1	2	4	2	3
Effort levels								4		
groups	2	3			4		5	4	6	1
coordinate	7	6	3			7		5	7	6
on in N2		6	4		7		6	7		7
N3 (18 groups)	1	1	0	1	0	0	1	2	0	0
Effort levels										
groups	4	5		4			6	4		
coordinate								6		
on in N3										
N4 (12 groups)	0	0	0	0	0	0	0	0	0	0
N5 (5 groups)	0	0	0	0	0	0	0	0	0	0

Table 1.5 reports available data on the average group minimum in the last period of the experiment as well as two coefficients measuring the relative frequency of group coordination over all periods of the experiment and how often a group can maintain coordination in two consecutive periods for a number of comparable minimum effort game experiments. The “coordination” coefficient takes the average number of coordination incidences per group and divides it by the total number of periods played. A coefficient of one implies that each group coordinates in every period of the experiment whereas a coefficient of zero implies that none of the groups is able to coordinate in any period of the experiment. The “maintenance” coefficient takes the average number of times a group is able to sustain coordination in two consecutive periods and divides it by the number of periods where maintenance of coordination is possible. If a group can sustain coordination in periods 5 and 6 and periods 8 and 9 of a 10 period experiment, the coefficient would be $2/9$. The same is true for a group which is able to maintain coordination in periods 4 and 5 and periods 5 and 6 of a 10 period experiment. Again, a coefficient close to one means that groups are able to maintain coordination frequently whereas a coefficient close to zero means that groups are not often able to maintain coordination in two consecutive periods.

Table 1.5 shows that small groups of two and three players (VHBB and Knez and Camerer (1994)) are able to coordinate more frequently than groups of six players (Dufwenberg and Gneezy (2005) and Knez and Camerer (1994)) with the coordination coefficient being twice the size for two-player groups than for six-player groups. The same is true for the maintenance coefficient which is sharply decreasing from 0.72 in VHBB’s two-player groups to 0.2 in Knez and Camerer’s (1994) three-player groups. The coefficients provide evidence that both the number of coordination incidences and the number of periods groups are able to sustain coordination are decreasing with group size. Moreover, numbers on the average group minimum in the

Table 1.5: Average group minimum in the last period and magnitude of coordination

Study	Group size	number of periods played /feedback	avg. minimum last period	coordination coefficient	maintenance coefficient
This paper N2	2	10/Group minimum	4.08	0.18	0.02
VHBB	2	7/Group minimum	6.25	0.53	0.72
Knez and Camerer (2000)	2	5/Group minimum	6.79	NA	NA
This paper N3	3	10/Group minimum	2.83	0.03	0
Weber et al. (2004)	3	5-8 Distribution of group min.	5.13	NA	NA
Knez and Camerer (1994, 2000)	3	5/Group minimum	3.07	0.32	0.2
This paper N4	4	10/Group minimum	2.42	0	0
Engelmann and Normann (2010)	4	10/Mixed	5.63	NA	NA
This paper N5	5	10/Group minimum	2.4	0	0
Engelmann and Normann (2010)	6	10/Mixed	5.39	NA	NA
Dufwenberg and Gneezy (2005)	6	10/Group minimum	1	0.24	0.16
Knez and Camerer (1994)	6	5/Group minimum	1.3	0.16	0

Note: The coordination coefficient gives the average of the relative frequency of coordination and the maintenance coefficient gives the average of the relative frequency of maintaining coordination in two consecutive periods of the experiment.

last period show that the group minimum is decreasing in group size as well. Small groups of two and three players (VHBB, Knez and Camerer (1994, 2000) and Weber et al. (2004)) show a higher average minimum in the last period than larger groups of six players (Dufwenberg and Gneezy (2005) and Knez and Camerer (1994)).⁹

Overall, the results in the previous literature show that players in small group treatments are able to coordinate frequently. Raising the number of players in a group causes a decrease in coordination incidences and makes it harder for groups to keep up coordination. In addition, coordination in larger groups almost always occurs on the inefficient lowest effort level equilibrium. However, the results in Engelmann and Normann (2010) are difficult to reconcile with the findings above. In a predominantly Danish subject pool 71 percent of four-player groups and 46 percent of six-player groups coordinate on the highest effort level equilibrium at the end of a 10 period experiment. Payoffs are increasing in the fraction of Danish subjects within a group suggesting cultural differences play a role in achieving coordination on highest effort equilibria. The previous literature further suggests that coordination is established in and maintained from an early stage of the experiment in groups of two players. In larger groups coordination develops more slowly, is path dependent and initial effort level choices are more dispersed. Groups with a high initial group minimum are more likely to coordinate on the efficient equilibrium.

Since a number of contributions (Engelmann and Normann (2010), Knez and Camerer (2000) and Weber et al. (2004)) only report group minima it is not possible

⁹ To show the negative relationship between the size of a group and the average minimum in the last period or the two coefficients respectively we regress them on group size with fixed effects for sessions. The coefficient for group size is significantly negative for the minimum in the last period ($p < .01$ for children and $p < .001$ for adults) as well as for the coordination coefficient ($p < .001$ for children and adults). Further, the group size coefficient is negative and significant for the maintenance coefficient for adults ($p < .02$) but insignificant for children. For regression results see Table 1.11 in the Appendix.

to assess whether all subjects within a group coordinate on the same effort level. Where information on individual effort levels is available, we find that coordination on the same effort level by all players within groups of more than four players is the exception. Although there are still instances where more than four subjects coordinate on the same, usually lowest, effort level, groups are not able to maintain coordination over a longer period of time.

Similarities and differences between children and adult behavior

We find that there are stark differences in the variation of effort level choices and the number of coordination instances between children and adults. Children in all treatments show a higher variation in effort level choice and coordinate less on the same effort level than adult subjects in groups of comparable size. The frequency of coordination is decreasing in group size for both children and adults with coordination failure in larger groups being a common result in the previous literature as well as in our larger group treatments N4 and N5. The most surprising finding of our study is the different behavior of children in small group treatments N2 and N3. Even there, children are not able to coordinate frequently or sustain coordination over a longer period of time.

Possible causes for different behavior

We have shown so far that children choose relatively high average effort levels and that there is large variance of their effort level choices throughout the experiment. We now study where the absence of coordination might come from. We will limit our analysis to small groups in treatments N2 and N3 because results for these treatments are most outstanding from the previous literature. We identify three

forms of behavior that help to explain the large variance of effort level choices and the coordination failure for children. We label these forms of behavior as “aspiring”, “explorative”, and “impatient”.

The following close examination of children’s behavior in individual groups of two and three players suggests that the high variance, the low number of coordination incidences and the failure to keep up coordination in treatments N2 and N3 is caused by a mixture of the three forms of behavior. We find aspiring children who predominantly choose very high effort levels. We find aspiring-explorative children who choose mid- to high-range effort levels and we find children being aspiring, explorative and impatient at the same time. They predominantly choose mid- to high-range effort levels and do not stick to the same effort level long enough to give the other group members a chance to catch up and coordinate. These mixtures of behaviors deters children from coordination on the same effort level and makes it almost impossible to maintain coordination over time.

Children are more “aspiring”

There are a number of facts that point towards children being more aspiring than adults in the sense that they appear to focus on achieving a relatively high group minimum regardless of last period’s group minimum. First, as already shown in Figure 1.1, children focus on effort levels on the upper end of the effort level scale throughout the whole experiment. Figure 1.3 compares the percentage of subjects choosing low effort levels (effort 1, 2 and 3) with subjects choosing high effort levels (effort 5, 6 and 7) over time. The graphs show that the majority of children in treatments N2 and N3 choose high effort levels 5, 6 and 7 throughout the experiment

Second, there is evidence that children not determining the minimum do not lower

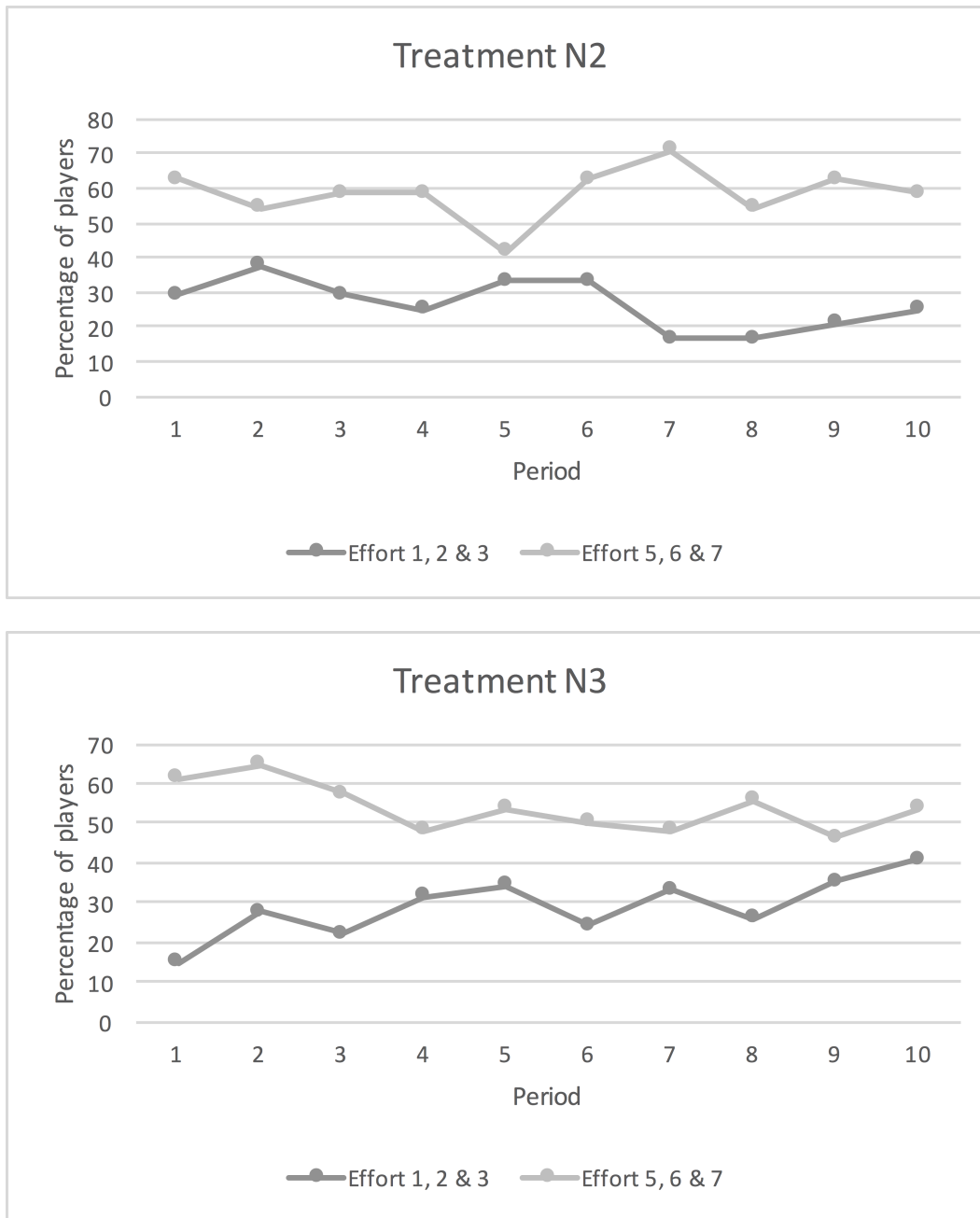


Figure 1.3: Fractions of players in treatments N2 and N3 choosing low- and high-range effort levels over time

their effort level choice when presented with a low group minimum. An average of 57 percent of non-minimum effort players in N2 and 37 percent in N3 appear to aspire to high group minima and do not decrease their effort level. This does not necessarily mean that they stick to the same effort level but they hope for the minimum effort player to increase his effort level in the next period and therefore either stay with or increase their own effort level. This type of behavior can be observed repeatedly. The share of children in N2 and N3 not lowering their effort when facing a low group minimum for the second and third time is around 40 percent and 54 percent respectively.¹⁰

Third, there is a large number of children increasing their effort when determining the minimum. The percentage of minimum effort players choosing a higher effort level in the following period lies between 43 and 69 percent in N2 and between 55 and 76 percent in N3. A minimum effort player acts rational as long as he does not decrease his effort level. Assuming that the other players also best respond, the high number of children increasing their their effort level makes it more difficult for players to coordinate on the same effort level.

The aspiring behavior is in line with findings in the previous economics and psychological literature. Perner (1979) describes that children age 2 to 10 years have a strong preoccupation with their own payoff and that they show some kind of wishful thinking by focusing on their own (high) payoff and projecting the co-player to choose a strategy leading to this outcome. Further Apesteguia et al. (2015) show that children age 8 to 10 focus on their own payoff and feedback even if the consideration of co-players feedback could be beneficial.

¹⁰ Similar behavior was observed in Engelmann and Normann (2010) who suggest that coordination on high effort levels with a predominantly Danish subject pool was partly achieved by Danes being more likely to not lower their effort when facing a low group minimum at the beginning of the experiment.

In principle a mixture of minimum effort players increasing their effort levels and non-minimum effort players not decreasing their effort levels could lead to more coordination on high effort levels. But with our feedback being limited to the group minimum players are not able to easily coordinate on exactly the same high effort level.

Children are “explorative”

In contrast to adults, children are more explorative when choosing effort levels. Meaning that even though they show a preference for higher effort levels they do not limit their effort level choices to the upper half of the effort level scale but choose from a variety of different effort levels. Table 1.6 states the percentages of players choosing a certain number of different effort levels over all periods of the experiment for treatments N2 and N3 as well as for studies with adult subjects with comparable group size. While the majority of adult subjects in groups of two and three players choose 3 or less effort levels children explore a lot more different effort levels over the 10 periods of the experiment. In comparison to 100 percent of adult subjects choosing less or equal to 4 different effort levels, only a little more than 1/3 of the children limit their choices to strictly less than 5 different effort levels. Moreover, more than 60 percent of children in both treatments choose at least 5 different effort levels and around 1/5 of children in N2 and 1/10 of children in N3 make full use of the whole effort level scale and choose each available effort level at least once during the experiment.

The development of children’s explorative behavior was widely discussed in the 70s and 80s psychological literature and findings are twofold. While theorists like Piaget (Piaget et al. 1952) say that children become less curious with age, Nunally

and Lemand (1973) suggest that the amount of exploratory behavior is directly related to the amount of time required to resolve an information conflict. Based on this idea and in line with the relatively large number of children showing explorative behavioral patterns in our paper, Switzky et al. (1974) show experimentally that children age 7 are more curious than children between 2 and 6 because of their bigger conflict of information.

Children are “impatient”

Children further seem to be more impatient than adults as they do not like sticking to the same effort level. Let’s define a player to be impatient if he never sticks to the same effort level in two consecutive periods of the experiment. Table 1.6 reports the shares of impatient players as well as the numbers for less stringent definitions of impatience. We see that 25 percent of children in N2 and 44 percent of children in N3 are impatient. The comparable numbers for adults are very low. The opposite is true for the number of children who often stick to their effort level. While 94 percent of adults in two-player groups and 48 percent in three-player groups stick to their effort level more than two times, the numbers for children are lower with 25 and 16 percent respectively.

This is in line with findings in both the psychological and economic literature on patience in children. Among others, Sutter et al. (2013), Bettinger and Slonim (2013) and Mischel et al. (1989) study children of different ages (between 4 and 16 years) and all conclude that patience increases with age.

Table 1.6: Shares of explorative and impatient subjects

Study/ Group size	Number of periods	Percentage of players choosing x different effort levels							Percentage of players sticking to the same effort level in two consecutive periods		
		$x \leq 3$	$x = 4$	$x = 5$	$x = 6$	$x = 7$	never	once	twice	more than twice	
This study N2 / 2	10	8.3	25	25	20.8	20.8	25	25	25	25	
VHBB / 2	7	82.1	17.6	0	0	0	0	0	5.8	94.2	
This study N3 / 3	10	14.8	22.2	24.1	29.6	9.3	44.4	29.6	9.2	16.6	
Knez and Camerer (1994) / 3	5	90	10	0	NA	NA	10	23.3	18.3	48.3	

Mixture of types

In general the minimum effort game setup would allow three different scenarios leading to group coordination. One way of coordinating is that minimum effort players stick to their effort level choice and non-minimum effort players decrease their effort level to the previous period's group minimum. Another way to coordinate is that non-minimum effort players wait for the minimum effort players to increase their effort level for coordination on the effort level chosen by the non-minimum effort in the previous period. Third, minimum and non-minimum effort player could agree to meet on an effort level in-between the minimum and the effort level chosen by the non-minimum effort players. Given that the feedback in our experiment consists of the previous period's group minimum only, coordination on the same effort level can only be achieved and maintained in the first scenario where minimum effort players stick to their effort level choice and non-minimum effort players decrease their effort level to the previous period's group minimum.

A close examination of children's behavior in individual groups of two and three players suggests that the limited feedback and a mixture of the three behavioral patterns explained above deters children from coordinating efficiently. First, the aspiring behavior drives a lot of minimum players to increase their effort level and non-minimum players to not decrease their effort level. But with feedback being limited to the previous period's group minimum, players do not have enough information to coordinate on the same high effort level. Further, in case minimum and non-minimum effort players show rational behavioral patterns in a sense of not choosing an action that decreases their payoff, meaning they stick to the minimum or decrease their effort levels to the previous group minimum, respectively, then explorative effort level choices by other subjects in subsequent periods add to the

difficulties of coordination in groups of three players. The same is true for impatient players' decisions who in the course of not being able to stay with the same effort level over a longer period of time take away any chance of strategic group coordination.

We would like to emphasize that our three behavioral patterns are not exclusive and that it is indeed a mixture of behavior patterns found in players that makes it hard for young subjects to coordinate and keep up coordination, even in small group treatments N2 and N3.

1.4 Conclusion

In studies on young adults, small groups of two and three players are able to coordinate on the same, often efficient, effort level over time. Larger groups of four to six players are also able to coordinate but not as frequently as small groups and often on the inefficient, lowest effort level equilibrium. In this paper we explore the behavior of children age 7 to 10 in a minimum effort game experiment and compare the results with data presented in the previous literature. First, we find that, independent of group size, children choose high average effort levels over all 10 periods of the experiment and that the variance of the effort level choices is high. Moreover, in contrast to adults, the variance of the effort level choices is not declining over time suggesting that the children's behavior is not changing a lot over time. Then, we analyzed children's ability to coordinate on the same effort level. Children never coordinate in larger groups of four and five players and they coordinate very little in smaller groups of two and three players. And while coordination failure in larger group treatments is in line with results in the previous literature, the very small number of coordination incidences in our small group treatments is surprising.

As a step towards addressing coordination failure in smaller group treatments we

look at different behavioral patterns among children. We find that there are three forms of behavior discouraging children from coordinating more frequently. Some children are “aspiring” high group minima by choosing predominantly high effort levels and being reluctant to decrease their effort level when facing a low group minimum. Some children are “explorative”, sampling from a wider range of effort levels over the 10 periods of the experiment. And some children are “impatient”, not sticking to the same effort level in two consecutive periods. The behavioral patterns are not exclusive. Many players shows signs of one or more of the three characteristics, making it hard to coordinate on the same effort level even within very small groups.

Our results suggests that children age 7 to 10 are not able yet to establish and sustain coordination in a minimum effort game setup. This is a similar finding to Apesteguia et al. (2015) who show that children of the same age fail to engage in success-based imitation in a simple multi-armed bandit problem. Further, our “aspiring” behavioral pattern is in line with findings in Perner (1979) who shows that children between 4 and 10 years who play a 2×2 coordination game are preoccupied with their own payoff and have a tendency to center on high payoffs. He further shows that children show some wishful thinking by predicting their co-player will also focus on the high payoffs which could help explain minimum effort players increasing their effort level and non-minimum effort players not decreasing their effort level.

We think that further research with a larger subject pool and a wider age variation could give more insight on to what age children develop the skills to coordinate frequently and efficiently in the minimum effort game.

1.5 Appendix

Instructions

The non-verbal part of the instructions is in (*Italics characters*).

Hello, my name is Elke Weidenholzer and this is (Name Help 1) and (Name Help 2). Thanks for letting us visit you in class today. Maybe your teacher has already told you, we're working at the University of Vienna and we would like to play a game with you today.

In our game you will have the possibility to earn points. These points will be transferred into LIBRO vouchers at the end of the game. Do all of you guys know the LIBRO store? You can buy pencils, CDs or little toys there. For your participation in the game you will get a 3 euro voucher for sure. In addition to that you can earn points that will be transferred into further vouchers by the end of the game. 10 points in the game will give you an extra 1 euro voucher. The voucher look like this (*Show some sample vouchers to the children*). The colorful vouchers are worth 1 or 5 euro. The more points you earn in the game the more vouchers you will get by the end of the game and the more vouchers can spend in the shop.

Before we can start to play the game, I will explain the rules.

From now on, I would like to ask you not to talk to any of you classmates. If one of you talks to any other child in class we will exclude you from the game and you will not get any vouchers at the end of the game. Please listen carefully to my instructions. The better you listen to me and understand the game the more points you can earn and the more voucher can you spend in the store afterwards.

Please raise your hand if you have a question concerning the game. One of us will come to your table and answer the question in private. Otherwise just stay silent and listen carefully.

- For the game we will put all children in class randomly into a group of 2/3/4/5 players. This means that each of you will play with one/two/three/four other child(ren) in this classroom. You will play with the same child(ren) throughout the whole game. However we will not tell you who the other child(ren) in your group is (are). Who your co-player(s) is (are) will stay a secret throughout as well as after the game. No one will ever get to know with whom he or she played the game.
- Further no one in this classroom will ever learn which decisions you're making during the game. In order that no other child can read your name, each of you will play with your own number. This number will be displayed on every single decision sheet that we will hand out later.
- After we've finished the game we will fill in a questionnaire together and each child will get an envelope with his vouchers.

Everything ok so far?

Let us talk about the game itself then.

- The game is going to last for 10 periods. We will tell you when the last period starts.
- Your task in each period is to pick a number between 1 and 7. The number of points that you can earn in each period depends on the number you decide to pick yourself and the lowest numbers chosen by any player within your group, including yourself.
- There aren't any right or wrong answers in this game. The only important thing for you to understand is that you can earn a different number of points when picking a different number.
- We have provided each of you with a payoff table where you can look up the number of points you can earn with different numbers. (*Show payoff table to the children*)

- You can see the numbers that you can pick from in the left column of the table. You can see the term “My number”. The first row of the table shows the smallest number picked within your group. You can see the term “Smallest number within my group”.
- The payoff table is the same for every player. The number of points that you can earn always depends on the row that your own number indicates and on the column that indicates the smallest number within your group.

Let's practice reading the payoff table with some examples. I will provide you with an example of numbers and you will try to find the according number of points. If you know the answer, raise your hand please.

Read out four examples of the following form and show the solution on the large payoff table provided on the blackboard. (The numbers were drawn randomly before the experiment and stayed the same throughout a treatment)

In the situation where I am part of a group of three players and I decide to choose number 7 and the other two players in my group choose numbers 6 and 3. Then I will find my number of points when looking at the row where my number is 7 and the column where the smallest number within the group is 3. How many points will I earn? 5 - *After four examples erase the large payoff table.*

I will erase the large payoff table from the blackboard now such that you have to use your own paper payoff table. We will go through some more examples where I provide you with your own number and the smallest number within your group.

Read out eight examples of the following form.

How many points do I earn if I choose number 6 and the smallest number within my group is 1? In this case I will look for the row that indicates my number 6 and the column that indicates 1 as the smallest number chosen within my group. How many points will I earn? 2

- At the beginning of each period we will provide you with a decision sheet. (*Show a period 1 decision sheet to children*) On top of the sheet you will find your unique player number, the period in which we're in and the number of children in your group. Underneath you can see the payoff table that we just used to practice finding the points you can earn. Your task in each period is to look at the payoff table and decide which number you would like to pick. If you've decided on a number, tick off your number in the according row of the column marked "my number". After that you wait until we collect the decision sheet.
- Starting with the second period you will find some additional information on your decision sheet. The decision sheet looks like this. (*Show a period 2 decision sheet to the children*) On top of the paper you will again find your individual player number, the period in which we're in and the number of children in your group. Underneath, there are three lines.
 - In the first line you can check again which number you chose in the previous period. It reads: My number in the previous period.
 - In the second line you can check what the smallest number chosen within your group was. It reads: The smallest number within my group in the previous period.
 - The third line will tell you how many points you've earned. It reads: My points in the previous period.
- Please make sure that you go through this information very carefully. Afterwards, have a look at the payoff table and think about which number you want to choose next.

Before we start to play the game, we will give each of you four more examples to solve on paper. The examples are similar to the ones we used to practice reading the payoff

table. Read carefully through the provided information. Have a look at the payoff table and write down the number of points on the paper. We will watch you solve the examples, check whether you get the right answers and help you in case that there is a problem or a question.

Good. Now everybody has solved the problems. Before we start to play the game each of you will be provided with a comic book and some sheets of paper. Whenever there isn't any decision sheet on your table you're allowed to read the comic or to color on the blank sheets of paper. You will have to close the comic books, put away the drawings and concentrate on the new decision sheet as soon as I tell you that a new period of the game is going to start until we pick up the decision sheet again.

In every period of the game you will have 30 seconds to read carefully through the previous period's information, look at the payoff table and choose a number. Remember, in each period you can choose a number between 1 and 7. There are no guidelines which number to choose when or how often. It is completely up to you if you want to choose a different number in each period or if you want to go for the same number in some consecutive periods.

Remember, the more points you earn in the game, the more money in form of voucher you will get at the end of the game. If anybody has any more questions raise your hand now. Otherwise I wish you the best of luck and don't forget not to talk to any other children.

Before handing out the decision/feedback sheet each period: Please close the comic book and put away all the drawings. (*Wait for some seconds*) We will now provide you with the decision sheets for the next period. You will play the same game with the same co-players. Please read carefully through the information provided. Have a look at the payoff table and decide which number you would like to choose in this period. *After the last period:* The last period is now over. First, we will collect the comic books. Second, we will provide you with a questionnaire. Since we will fill it in together, please wait until everybody has

been provided with the questionnaire. In the meantime, the computer is going to calculate your earnings. When we are finished filling in the questionnaires each child will receive an envelope with his vouchers.

Before giving away the envelopes: Before each of you gets his envelope we would like to thank you for spending some time with us today and also thank your teacher for allowing us to visit your class. We will now hand each of you an envelope with your player number on the outside. Inside the envelope you will find a sheet of paper that tells you how many points you've earned in the whole game and how many vouchers this number of points is going to give you. The vouchers look like this. (*Show them sample vouchers*) They are labeled 5 euro or 1 euro. We wish you a lot of fun with you envelopes and the vouchers.

Decision sheet

Figure 1.4: Decision sheet for period 2

Spieler: 1

Runde: 2

Anzahl der Kinder in meiner Gruppe:

Meine Zahl in der letzten Runde:

Die kleinste Zahl in meiner Gruppe in der letzten Runde:

Meine Punkte in der letzten Runde:

Schau dir die Punktetabelle an und wähle eine Zahl:

		Kleinste Zahl in meiner Gruppe					
Meine Zahl		7	6	5	4	3	2
	7	13	11	9	7	5	3
	6	-	12	10	8	6	4
	5	-	-	11	9	7	5
	4	-	-	-	10	8	6
	3	-	-	-	-	9	7
	2	-	-	-	-	-	8
	1	-	-	-	-	-	-

Learning Theories

We further assess to what degree subject's behavior is consistent with various learning theories. One problem arises with belief based learning theories that condition on previous behavior for players who determine the minimum group effort. These players cannot infer from the available information whether it is them who solely determine the minimum or whether there are other players who also choose the minimum effort. In the former case it will pay off to at least slightly increase one's effort level. In the latter case such a move would be payoff decreasing. For this reason we believe that analyzing the behavior of non-minimum effort players offers a clearer picture of the level of subjects' sophistication. Under myopic best response learning, subjects choose a best response against the distribution of play in the previous period. This is based on the implicit assumption that the behavior of others will not change. A non-minimum effort player will thus have the minimum effort of the previous period as his best response. Table 1.7 reports the fractions of subjects not determining the minimum who give a best response. The fraction of subjects playing a best response is rather low and does not seem to vary across treatments or time. (Wilcoxon tests do not show any significant difference between P1-P5 and P6-P10.)

A weaker form of belief learning is Selten's learning direction theory (Selten et al. 2005) which is based on ex-post rationality. It suggests that if players change their behavior at all, they do so by orientating themselves towards additional payoffs they might have earned by choosing a different action in the previous period. A non-minimum effort player looking for additional payoff given the group minimum in t needs to lower his effort level to a level above or equal to period t 's group minimum. We report the fractions of non-minimum effort players whose behavior is consistent with this theory in Table 1.7. As expected, the fractions for the "weaker" learning

direction theory are higher than for best response learning. Between a third and a half of the subjects behave according to learning direction theory in all treatments. Again, behavior is roughly similar across treatments. (Wilcoxon tests on the average number of LDTH moves of non-minimum effort players do not show any significant difference between P1-P5 and P6-P10 for any treatment.)

For the reasons discussed above, it is more challenging to classify behavior of minimum effort players. In case subjects hold the belief that they are not the only ones determining the group minimum both myopic best response learning and Selten's learning direction theory would dictate to stick to the current effort level. Table 1.7 suggests that a fairly low share of minimum players act according to best response behavior. All treatments show an increase in best response behavior with treatment N4 showing the highest increase in the second half of the game. (Wilcoxon tests show a significant difference between P1-P5 and P6-P10 for N4 ($p < .0378$) only.) However, if a subject believes that he is in fact the only player determining the group minimum his behavior cannot be classified without further knowledge on the beliefs he holds about his co-players' behavior. And since we do not have any information about the beliefs of our subjects, we conclude that neither of the two learning theories is able to fully account for the children's behavior in our experiment.

Table 1.7: Fractions of players acting according to best response or learning direction theory

	Best response period 1-5	Best response period 6-10	Learning direction th. period 1-5	Learning direction th. period 6-10
N2 non-minimum players	0.19	0.16	0.34	0.41
N2 minimum players	0.16	0.22		
N3 non-minimum players	0.16	0.21	0.47	0.46
N3 minimum players	0.12	0.14		
N4 non-minimum players	0.14	0.20	0.50	0.46
N4 minimum players	0.16	0.33		
N5 non-minimum players	0.19	0.12	0.51	0.46
N5 minimum players	0.11	0.13		

Regression Results

Table 1.8: OLS regression: average group minimum

group size	-0.59*** (0.13)
constant	4.91*** (0.47)
N	47

Standard errors in parentheses. ***, **, * significant at 1%, 5%, 10% level. $R^2 = 0.23$.

Table 1.9: OLS regression: average group effort

group size	-0.19* (0.11)
constant	5.16*** (0.42)
N	47

Standard errors in parentheses. ***, **, * significant at 1%, 5%, 10% level. $R^2 = 0.01$.

Table 1.10: OLS regressions: deviation from minimum

Treatment	period	constant	R^2	N
N2	0.01 (0.02)	0.93*** (0.08)	0.001	120
N3	0.03 (0.02)	1.35*** (0.10)	0.01	180
N4	-0.02 (0.03)	1.91*** (0.17)	0.005	120
N5	0.09 (0.07)	1.73*** (0.39)	0.08	50
2 adult player groups	-0.18*** (0.06)	1.20*** (0.32)	0.16	98
3 adult player groups	-0.29*** (0.05)	1.84*** (0.25)	0.22	100
6 adult player groups	-0.23*** (0.02)	2.03*** (0.18)	0.47	125
14 adult player groups	-0.29*** (0.02)	3.19*** (0.15)	0.63	70

Notes: Standard errors in parentheses. ***, **, * significant at 1%, 5%, 10% level. Regressions include data reported in VHBB (1990) and Knez and Camerer (2000) for groups of two adult players, data reported in Knez and Camerer (1994) and Knez and Camerer (2000) for groups of three adult players, data reported in Knez and Camerer (1994) and Dufwenberg and Gneezy (2005) for groups of six adult players as well as data reported in VHBB (1990) for groups of 14 adult players.

Table 1.11: OLS regressions: group minimum in last period, coordination and maintenance coefficient

Study/ Group sizes	Estimates for coefficient "group size"		
	group minimum last period	coordination coefficient	maintenance coefficient
This study/ 2, 3, 4 and 5 players	-0.74*** (0.18)	-0.05*** (0.01)	-0.01 (0.004)
VHBB (1990)/ 2 and 16 players	-0.42*** (0.05)	-0.06*** (0.01)	-0.05*** (0.01)
Knez and Camerer (1994)/ 3 and 6 players	-0.53*** (0.21)	-0.05 (0.04)	-0.07** (0.03)

Notes: Standard errors in parentheses. ***, **, *, significant at 1%, 5%, 10% level.

Chapter 2

Imitation of Peers in Children and Adults¹¹

2.1 Introduction

Imitation learning can be an attractive heuristic in many circumstances; it saves on decision costs and requires relatively low cognitive ability.¹² Offerman and Schotter (2009) have, thus, referred to it as “poor man’s rationality”. Imitation learning is however far from being flawless, as under particular adverse circumstances it may lead to suboptimal outcomes. For instance, in Offerman and Schotter (2009) a random idiosyncratic component to payoffs may lead imitators to adopt actions that only performed well due to luck. Similarly, Vega-Redondo (1997) observed that in Cournot games imitation learning leads to the emergence of Walrasian states with payoffs lower than those obtained in the Nash equilibrium. Much of the experimental-empirical literature in economics has consequently focused on circumstances under

¹¹ This chapter is a slightly modified version of the working paper Apesteguia et al. (2015).

¹² See Alós-Ferrer and Schlag (2009) for a broad review.

which imitation is harmful.

In contrast, scholars in other disciplines are less pessimistic about the merits of imitation learning. In the words of Albert Bandura (1971, p.2): “Man’s capacity to learn by observation enables him to acquire large, integrated, units of behavior by example without having to build up the patterns gradually by tedious trial and error.”

We have thus decided to cast our study in a setting where imitation is not self-harming, but will in fact lead to outcomes with strictly higher payoffs than those received under rules that ignore information received by others. In particular, we study a multi armed bandit problem where the distribution of payoffs across urns is known to subjects. In this setting, imitation is not only attractive at first glance, as in previously studied settings, but indeed payoff-improving as compared to only reinforcing own previously successful actions.

Our main contribution lies in showing that imitation is not necessarily a straightforward heuristic subjects are able to apply regardless of their age. In particular, we compare behavior of children between the age of 8 and 10 (the vast majority of whom are aged 9) with university students. We identify imitative behavior through two treatment variations. In a *Baseline* treatment subjects cannot observe other participants such that imitation cannot occur. In the *Observation* treatment subjects do observe the choice and outcome of one other subject such that imitation is possible and desirable.

While university students make efficient use of being able to observe others, we find that most children almost completely ignore the feedback they receive about others and refrain from imitation despite clear evidence that they do understand the rules of the game. Children use the feedback they receive about their own choices in a rational manner and stick to high payoff urns over time. There is, however, a

subgroup of children from elite schools that does better on average but still does not imitate as efficiently as university students.

2.1.1 Related literature

Imitation has been studied in economics, psychology, anthropology, and many related fields. As a comprehensive review of the literature is beyond the scope of the current paper, we try to focus here on the experimental literature that is most relevant to the current study. For our purpose it is useful to divide the literature on imitation into two strands: i) *success-based imitation*, where imitation is based on the success other people were observed having with a given action, and (ii) *non-success-based imitation*, where actions are imitated regardless of their success. The latter includes conformity based imitation (Asch 1952) or reflex-driven, automatic imitation (Ray and Heyes 2011). Most of the evidence from child psychology also falls into this category since infants mostly imitate parents or other adults without accounting for or even observing the (relative) success of an action. For example, Meltzoff (1988) in a famous experiment found that infants imitated adults by using their foreheads to switch on a lamp. However, there is also evidence that even infants can perform “rational imitation”. This term was coined by Gergely et al. (2002) and refers to the observation that the infants in Meltzoff’s study, noticing that the adult declined to use her hands although they were free, may have inferred that the adult, using her head, must have known what she is doing. Gergely et al. (2002) replicated Meltzoff’s study with the adult’s hands visibly occupied during her head action, and in these circumstances imitation of the head action dropped from 69 percent to 21 percent.

A second important dimension in the imitation literature is the question who

the role models are. Most studies in child psychology use adults as models.¹³ With adults as models, children may assume that it is a good idea to imitate even if they do not observe or understand the success of an action simply because they trust the adult to have a reason for choosing a certain action. When peers are role models, this is much less clear. Zmyj and Seehagen (2013) review the literature on children's imitation of peers. One of their main conclusions is that young children are more likely to imitate adults than peers when the setting is unfamiliar.

In the experimental economics literature, imitation has also been an important agenda, mostly in the form of success-based imitation of peers.

The theoretical economics literature on imitation learning can be categorized in two strands: i) imitation in *decision problems* where actions do not (directly) influence other players' payoffs and ii) imitation learning in *games* where payoffs also depend on others' actions.

Contributions to the first category include Ellison and Fudenberg (1995) and Schlag (1998). In Ellison and Fudenberg (1995) a continuum of agents decides between two actions. The payoffs of these actions are subject to both a common and an idiosyncratic shock. Revising agents draw a random sample from the population and imitate the action that has yielded the highest average payoff. If the two actions yield the same payoff in expectation the population is more likely to reach a convention for small sample sizes and diversity is likely to obtain otherwise. Further, if one of the actions is superior, small sample sizes also increase the likelihood of converging to the superior convention. Schlag (1998) considers a multi armed bandit problem where agents choose actions yielding uncertain payoffs. He analyzes how subjects should optimally imitate in an environment where each agent may sample one other

¹³ There are a number of exceptions, see e.g. Hanna and Meltzoff (1993), and the review by Zmyj and Seehagen (2013), where peers are used as models.

agent from a finite population.¹⁴ Following “proportional imitation rules” turns out to be optimal. Under such rules agents never imitate an action that has yielded a payoff smaller than their current action and otherwise imitate the other action with probability proportional to the payoff difference between the own and the observed action.

The second category in the literature studies imitation learning in games. Eshel et al. (1998) study imitation learning in prisoners’ dilemma games played by agents situated around a circle. If agents imitate actions that have yielded high average payoffs to their neighbors, cooperative outcomes may arise. A number of contributions discuss coordination games where there is a conflict between risk dominant actions and payoff dominant actions.¹⁵ Which convention will be adopted in the long run is essentially driven by the way in which individuals interact and receive information from each other. When each agent interacts with everybody else imitation leads to risk dominant conventions (see Kandori et al. 1993). However, if agents are randomly matched into pairs each period (see Robson and Vega-Redondo 1996) or if interactions are characterized by a network and information spreads to large groups of agents payoff dominant conventions will arise (see e.g. Alós-Ferrer and Weidenholzer 2006, 2008).

Imitation learning has also been examined in the context of oligopoly games. In the Cournot framework convergence to the Walrasian state - where quantities are such that price equals marginal cost - will occur (see Vega-Redondo 1997). Friedman et al. (2015) state that “this (for firms) unfortunate outcome arises from a blind spot in the imitation heuristic. It ignores the fact that prices fall with greater quantities.”

¹⁴ Schlag (1999) analyzes the case where agents sample two others from a countably infinite population.

¹⁵ See Weidenholzer (2010) for a survey.

Alós-Ferrer et al. (2000) study imitation learning in Bertrand games with decreasing returns to scale and find convergence to a strict subset of the Nash equilibria.

In an experimental context Huck et al. (1999) and Offerman et al. (2002) consider various scenarios where subjects differ in the information they receive in Cournot games. If subjects do not know how payoffs are determined but are informed about profits and quantities in the market, imitation learning is a good predictor of actual behavior and convergence to the Walrasian state can be observed. Apesteguia et al. (2007) show that it matters both empirically and theoretically whether agents observe their competitors or firms in different markets. If subjects observe their competitors, convergence to Walrasian states remains. If subjects observe others in different markets (whose payoff they do not influence) we are essentially in a situation which is reminiscent of a decision problem. As predicted by theory Apesteguia et al. (2007) observe convergence to the Nash equilibrium in this case.

Relatively close to the current design is the experiment by Offerman and Schotter (2009) as it also studies success-based imitation in a decision problem. There is a random idiosyncratic component to payoffs, which may lead imitators to adopt suboptimal actions that only performed well due to luck. A group of agents is presented with the opportunity to observe another group of agents who have already participated in the same decision problem. In theory the ability to observe others would allow subjects to derive the optimal solution to the problem. However, this is not observed in the experiment. Instead, subjects sample those who performed best and also copy their actions. Imitation in this context, thus, leads to a situation where suboptimal strategies, which happened to have performed well in one instance, are adopted by a large fraction of society.

Our paper also contributes to a recent literature that studies decision making in children. Harbaugh et al. (2007) document strategic sophistication in bargaining

games in children as young as 8. Fehr et al. (2008) show that egalitarianism in simple distributional conflicts increases between the ages of 3 and 8. Almås et al. (2010) show how children who enter adolescence start to accept inequality that is the result of effort differentials as fair and how efficiency concerns are acquired in adolescence. Sutter et al. (2013) show how adolescents' risk attitudes, ambiguity attitudes, and time preferences correlate with their real life behavior. Lergetporer et al. (2014) study how third party punishment in children can increase cooperation rates in prisoner's dilemma games. Finally, Sher et al. (2014) analyse how children's ability to reason about others incentives and thinking develops in a strategic setting with age.

2.2 Experimental Design

In total, 162 subjects participated in the experiment, of which 82 were fourth grade school children from 4 different elementary schools in Vienna. The comparison group consisted of 80 adults recruited from the subject pool of the experimental lab at the Department of Economics, University of Vienna. The average age of the school children was 9.6 (Std. Dev. = 0.47 with a minimum age of 8.8 and a maximum of 11.1) and 37.8 percent were female. The average age of the adults was 25.5 (Std. Dev. = 3.9) and 41.0 percent were female.

The task for all subjects was to repeatedly choose among six different “urns”, $i = 1, \dots, 6$. Each urn i contained two balls that determined payoffs, $P_i \in \{i, i + 1\}$. That is, the worst urn either yielded a payoff of 1 or 2, the next best urn either gave a payoff of 2 or 3, and so forth. The best urn either yielded a payoff of 6 or 7. Each urn was labeled with a sign (circle, triangle, cross, square, star, and hexagon) but subjects did not know which sign corresponded to which pair of potential payoffs. In

each round subjects chose one of the six urns by opting for a sign. After subjects had made their choice, one of the two balls contained in the chosen urn was randomly drawn with fifty-fifty probabilities and subjects received feedback about the drawn ball and the corresponding payoff. The task, thus, was to find better and better urns. We have selected a decision problem that is easy to explain even to children yet fairly hard to solve optimally. In fact, we do not expect anyone (even the university students) to use the optimal solution.¹⁶ There were 10 rounds and the points from all rounds were added up to obtain the final payoff. We used an Excel program to randomly draw one of the two balls contained in the chosen urn, calculate the payoff, and gather and print feedback information.

There were two treatments. In the Baseline treatment, subjects only received feedback from their own chosen urn. In the Observation treatment, we had fixed groups and subjects received additional information about the choice and payoff from one other fixed subject who was facing the exact same decision problem. That is, after each round, subjects received a sheet detailing “...what one of the other kids in class who plays the exact same game as you do chose to do in the previous period and how many points this kid earned with its choice.” See Figure 2.6 in the Appendix for a feedback/decision sheet in the Observation treatment. It is important to notice that in the context of this game, this was useful information. Indeed, the information about the other’s choice and payoff was as informative as the information about one’s own payoff. Both should have received equal weight.

For the school children, the experiment was conducted with pen and paper within the familiar environment of the classroom. Upon arrival the tables were arranged to face the blackboard. Partition walls were put up (see Figure. 2.1). Six different urns

¹⁶ In fact, one would have to assume a particular utility function to solve the problem. Even then, it is extremely tedious, although possible, to solve the problem via backward induction.

were set up on a table clearly visible to all children. To prevent framing effects, the displayed urns were not labeled with the actual signs but were covered with different colored clothes. The instructions were read aloud. To illustrate the distribution of balls across urns, the experimenter reached into each of the urns, presented the two balls in front of the children and put the balls back into the urn. The distribution of balls was also displayed on the blackboard and remained visible for the entire duration of the experiment. To explain the random selection of balls (by the Excel program), the experimenter reached into a random urn blindfolded, displayed the drawn ball to the subjects and put it back into the urn. To make sure children understood the random draw concept this process was repeated with three random colored urns. The children were paid in vouchers for a book and stationery chain and made aware of the exchange rate between points and vouchers (10 cents vouchers for each point). On average, children received vouchers with a value of 5.41 euro.

The experiment lasted approximately 90 minutes including instructions, questionnaire, and payment of subjects. In each period we first provided the children with the feedback/decision sheet containing information on the previous round. Each period, we gave them 30 seconds to go through the previous period's information (chosen urn and resulting payoff) and choose an urn. In-between these decision periods children were allowed to either read a comic or draw something on sheets of paper provided beforehand. After the last period, they were handed a questionnaire, which was filled in with the assistance of the experimenters. At the end of the experiment each child was handed an envelope containing his vouchers. In addition, we also asked teachers to fill in questionnaires about all children. In particular, we asked them whether they expected that a child was likely to be accepted for the "Gymnasium", the higher (selective) track in the Austrian school system. The instructions (see Appendix) were carefully adjusted to the children's age group.

Figure 2.1: The classroom experimental setting.



Like for school children, the experiment for university students was conducted with pen and paper. The students received almost the same instructions, with the only difference being the use of the German polite form of address. The experiments with adults were conducted in 6 sessions at the Vienna VCEE experimental lab. Adults received monetary payoffs with an exchange rate of 25 cents per point. Average payoffs were 14.74 euro.

2.3 Results

Before discussing numbers on urn choices and learning dynamics in detail, let us rule out random play of younger subjects and stress that children in our experiment indeed understand the rules of the game. To show that children make efficient use of their own feedback, we look at urn choices conditional on feedback received in the previous period. Figure 2.2 plots the probability of sticking to the same urn after receiving a certain payoff over time for children and university students in both treatments. It shows players in both groups search for a better urn when observing a payoff smaller than 5 with sticking probabilities being very low for students and below 20 percent for children. Further, the probability to stick to the best or second best urn after observing a 6 or 7 increases over time for both children and students. The learning curve is flatter for students as they start out with a higher probability to stick to high payoff urns than children. The learning curve for children increases from period 4 onwards. The learning process seems to be more noisy for children where the probability to stick to the same high urn at the beginning of the game is decreases in some periods of the experiment.¹⁷ However, the flatter curves for

¹⁷ Differentiating between Gymnasium and other children shows Gymnasium children's behavior resembles student's behavior closer than other children's sticking behavior. See figure 2.7 in the Appendix.

Table 2.1: Summary statistics urn choice

	Children				University students	
	Gymnasium		Other		Baseline	Observation
	Baseline	Observation	Baseline	Observation		
mean	4.20	4.32	3.89	3.90	5.03	5.40
std.dev.	1.75	1.77	1.75	1.76	1.40	1.31
obs.	27	12	15	28	40	38

urns with lower payoffs and the increasing slopes of the curves for high payoff urns suggest children indeed understand the game and, like students, stick to urns with high payoffs over time.

Table 2.1 presents summary statistics on urn choices. It shows the overall means and standard deviations of the chosen urn’s number, with 6 being the best and 1 being the worst urn. For children, we distinguish between pupils who were assessed by their teachers as suitable for the “Gymnasium”, a selective kind of grammar school, which is attended by about 1/3 of pupils in Austria, and all other pupils. In terms of their cognitive abilities, Gymnasium children are, adjusted for age, probably closer to university students than other children.

We present three main findings on the differences in behavior between children and students in our experiment.

- University students significantly outperform all children in both treatments (Mann-Whitney U-test, two-sided, $p < .0001$ for the Baseline and for the Observation treatment).¹⁸
- University students are doing significantly better in the Observation treatment

¹⁸ For non-parametric tests, we consider the average choice of one subject (in the Baseline treatment) or one pair of subjects sharing their feedback information (in the Observation treatment) as one independent observation.

Figure 2.2: Probability of staying with the same urn after observing payoff x

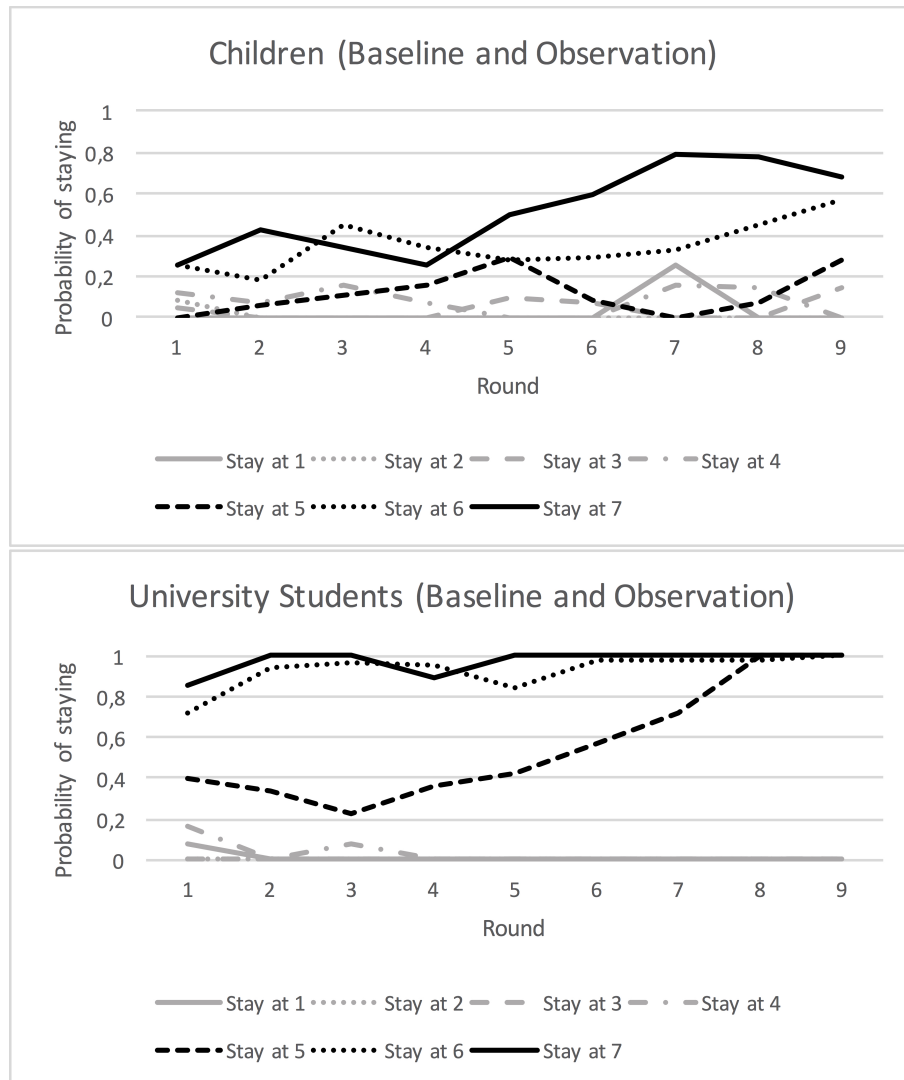
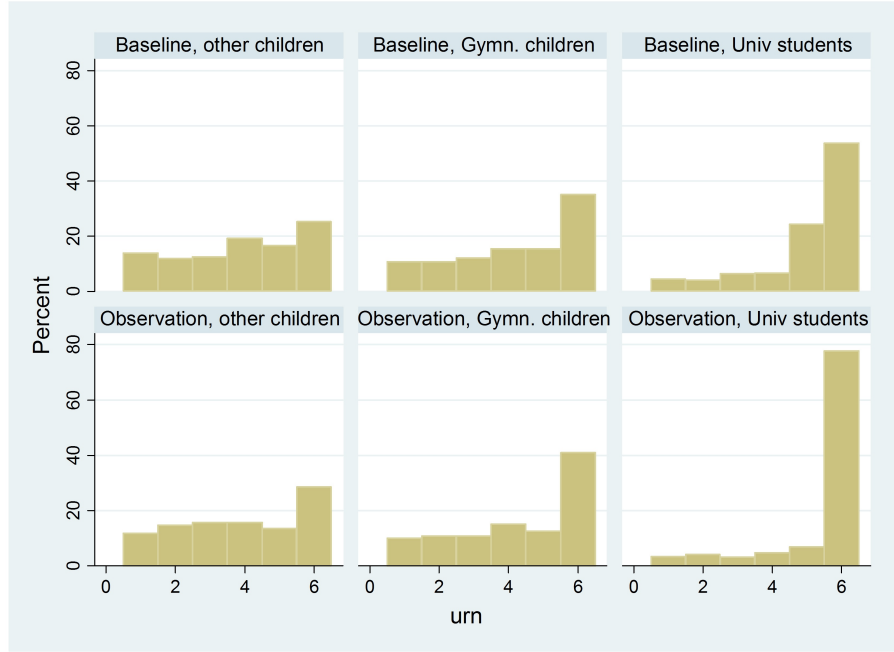


Figure 2.3: Histograms of urn choices

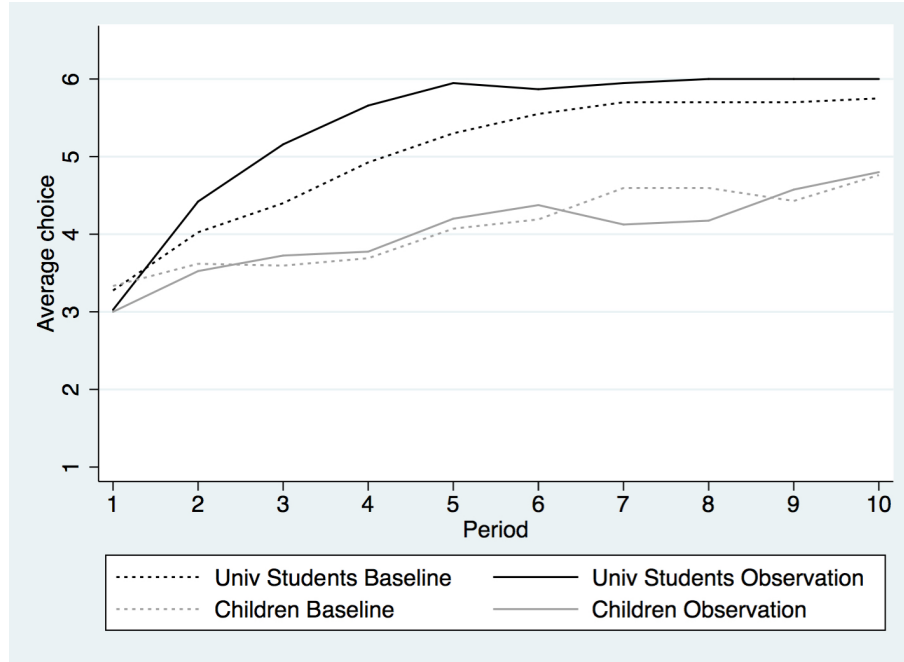


than in the Baseline treatment as predicted by imitation ($p = .01$).

- There is no significant difference between the behavior in the Baseline and the Observation treatment for the children, neither for Gymnasium ($p = .53$) nor for other children ($p = .96$).

Figure 2.3 plots histograms of urn choices for the six different cells. The histograms support our three facts graphically. First, in all six cells, the best urn is also the most frequently chosen one but the frequency for students choosing the best urn is higher than for children. Second, the incidence of the optimal urn vastly increases for university students when they receive additional information about another subject in treatment Observation. This is not the case for children where, as shown above, the behavior is neither significantly different between treatments nor between

Figure 2.4: Average Choices over time



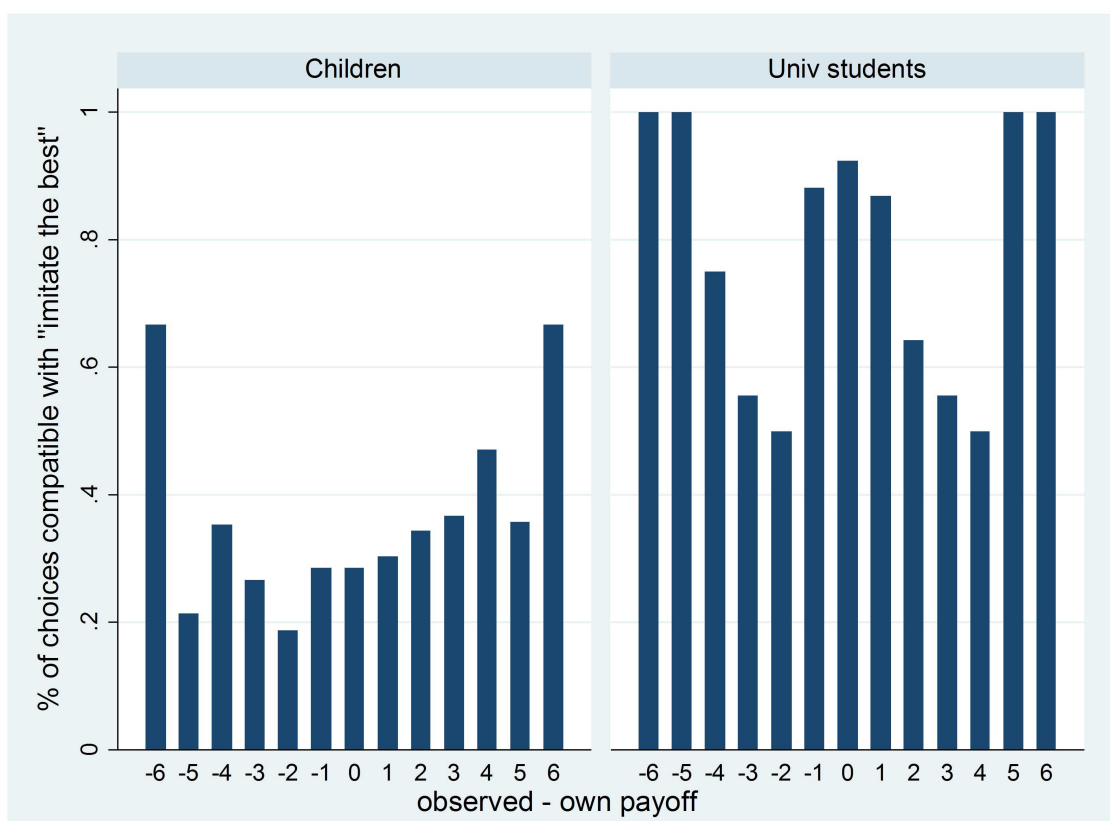
Gymnasium and other children in the same treatment.

In order to study learning dynamics, we first examine how the average choice moves over time. Figure 2.4 plots the development of the average choice for children and adults.¹⁹ Fundamentally, the figure reveals that all subjects are able to learn. Learning is steeper for university students and steepest for university students in treatment Observation. In contrast, there are no treatment differences in the development of the average choice for children over time.

While the absence of treatment differences in children is strongly indicative of the absence of imitation, the evidence is, of course, indirect. Direct evidence can be obtained by examining how often subjects copy others' behavior when others have found a better urn. We define the rule “imitate the best” as follows. Subjects

¹⁹ Differentiating between Gymnasium and other children does not change the result (see Figure 2.8 in the Appendix).

Figure 2.5: Share of choices that are compatible with “imitate the best” depending on payoff difference (= observed payoff - own payoff from previous period)



always pick one of the actions that yielded maximal payoff in the previous period. If the partner's payoff was higher, they should adopt the partner's urn. If their own payoff was higher, they should stick to their own urn. If both obtained the same payoff, either urn could be chosen. All other urns constitute experimentation. In Figure 2.5 we show the percentage of choices that are compatible with "imitate the best" depending on the difference in payoffs ($=$ observed payoff - own payoff). While university students stick to their choices when they have earned substantially more than the other player and imitate others with higher payoffs, the picture is much more noisy with children. This becomes most apparent at the two extremes of the distribution of payoff differences where children display a much stronger taste for experimentation.²⁰ Neither do they imitate the other's action as much as one would expect when the difference in payoffs is 5 or 6, nor do they stick to their action as much as one would expect when they are actually the ones earning the maximum payoff with a payoff difference of -6 and -5 .

We now investigate whether the differences between university students and children can be accounted for by the composition of treatment groups in terms of "Gymnasium" and "non Gymnasium" rather than age. To do so, we employ the entire data set and regress urn choice on treatments and dummies for university students and children viewed suitable for higher school education ("Gymnasium") and also include interaction terms that capture heterogenous treatment effects. The results in Table 2.2 show that while more able children are doing generally better in our task than those predicted not to reach the "Gymnasium", they fail to do better in the Observation treatment. That is, they too ignore the additional information from

²⁰ The number of students sticking to an urn with a payoff of 6 or 7 is significantly different from the number of children sticking to high payoff urns (Mann Whitney Test, $p < .0001$ for urns with a payoff of 6 or 7).

others' urn choices. In other words, our finding that, in contrast to adults, children at the age of 9 are unable to engage in rational imitation is not due to selection bias in our sample. Smarter children do better at the learning task but still fail to make use of feedback about others' choices and outcomes which is, in principle, as valuable as their own feedback.

Table 2.2: OLS regression: urn choice

dummy treatment observation	0.02 (0.18)
dummy university	1.15*** (0.15)
dummy Gymn	0.31* (0.19)
dummy observation \times univ	0.35* (0.21)
dummy observation \times Gymn	0.10 (0.30)
constant	3.89*** (0.13)
N	1600

Clustered standard errors in parentheses. ***, **, * significant at 1%, 5%, 10% level. $R^2 = 0.13$.

2.4 Conclusion

While much of the recently growing literature on economic and strategic decision making in children points to various forms of sophistication being acquired early on in life, we document that children at the age of around 9 fail to engage in success-based imitation of peers. In our experiment, where the additional information about one other player's choice and payoff should have gotten equal weight as information about the own payoff, children were unable to extract relevant information from others.

Despite the urn with the highest payoff being the urn chosen most frequently for students and children, as well as both groups learning to stick to urns with high payoffs over time, we find that students outperform children in both of our treatments. Students make efficient use of the additional information and do significantly better in the Observation treatment, whereas there is not any significant difference between the performance of children in the Baseline and Observation treatment.

Given the prevalence of other forms of imitation in child behavior, we find this surprising and we realize that our finding seems to contradict much of the earlier literature. Nevertheless, we believe such contradictory findings need to be published (in particular to avoid publication bias). More research is required to find out what could account for the different findings.

We document that our result is not due to selection bias. Even the most able children do not gain an advantage through rational imitative behavior. Instead, all children appear to discard information that stems from others' choices even though the symmetry between own and others' actions is made explicit.

Another aspect that may account for our findings is that in our experiment, children had to learn from observing peers. Most of the literature in child psychology

uses adults as role models. Moreover, in line with previous literature in psychology, it has been argued that in unfamiliar settings, children trust their peers less and rely more on their own experience. We speculate that evolution might have forced prepubescent children to focus very carefully on own feedback. The wealth of new information provided to children at this age is enormous and a clear focus on feedback about their own behavior might have been extremely useful (and perhaps still is).

2.5 Appendix

Instructions Treatment BASELINE - Additional text for Treatment OBSERVATION in [].

The non-verbal part of the instructions is in (*Italics characters*).

Hello, my name is (Name of Instructor) and these are (Name Helper 1) and (Name Helper 2). Thanks for letting us visit you in class today. Maybe your teacher has already told you, we're working at the University of Vienna and we would like to play a game with you today.

In our game you will have the possibility to earn points. These points will be transferred into LIBRO vouchers at the end of the game. Do all of you guys know the LIBRO store? You can buy pencils, CDs or little toys there. Each point in the game will give you a 10 cent voucher. The vouchers look like this (*Show the kids some sample vouchers*). The colorful vouchers are worth 1 or 5 euro. The more points you earn in the game the more vouchers you will get by the end of the game and the more vouchers you can spend in store.

Before we start to play the game, I will explain the rules.

From now on, I would like to ask you not to talk to any of you classmates. If one of you talks to any other child in class we will exclude you from the game and you will not get any vouchers at the end of the game. Please listen carefully to my instructions. The better you listen to me and understand the game the more points you can earn and the more vouchers you can spend in store afterwards.

Please raise your hand if you have a question concerning the game. One of us will come to your table and answer the question in private. Otherwise just stay silent and listen carefully.

First, I'm going to explain the rules of the game to you. Then, we will play 10 periods of the game. After we've finished the game we will fill in a questionnaire together and each child will get an envelope with his vouchers.

Everything ok so far? Let us talk about the game itself then.

Drawing on the blackboard: six bowl-shaped urns with two balls inside each.

- There are six urns in our game (*Point at the urns on the blackboard*)
- There are two balls in each of these urns (*Point at the balls in the urns on the blackboard*)
- Inside one of these urns is a ball worth 1 point and a ball that gives you 2 points (*Label the balls in one of the urns on the blackboard with numbers 1 and 2*)
- Inside another one of these urns is a ball worth 2 points and a ball that gives you 3 points (*Label the balls in one of the urns on the blackboard with numbers 2 and 3*)
- Inside another one of these urns is a ball worth 3 points and a ball that gives you 4 points (*Label the balls in one of the urns on the blackboard with numbers 3 and 4*)

- Inside another one of these urns is a ball worth 4 points and a ball that gives you 5 points (*Label the balls in one of the urns on the blackboard with numbers 4 and 5*)
- Inside one of these urns is a ball worth 5 points and a ball that gives you 6 points (*Label the balls in one of the urns on the blackboard with numbers 5 and 6*)
- Inside another one of these urns is a ball worth 6 points and a ball that gives you 7 points (*Label the balls in one of the urns on the blackboard with numbers 6 and 7*)
- Your task in each period is to choose one of the urns.
- After you've chosen one of the urns the computer is going to draw one of the balls inside the urn at random and you will get the points stated on that ball.

Six bowls with two tennis balls inside each, numbered from 1-7 and covered with colored lids are placed in front of the class.

- You can think of the game as follows. Here are six urns.
- If you, for example, decide to choose the red urn, the computer will compute your points as if it would randomly draw a ball out of this urn. (*Draw a ball out of the red bowl blindfolded and show the ball with its associated number to the kids.*) After having drawn the ball and after having allocated the associated points to you, the computer will put the ball back into the same urn and the next period of the game is about to begin. (*Put the ball back into the bowl.*)

- If you decide to choose the blue urn in the next period, the computer will draw a ball out of the blue urn. You get the points that are written on this ball and the ball is placed back into the urn. (*Draw a ball out of the blue bowl blindfolded and show the ball with its associated number to the kids and put the ball back into the bowl.*)
- If you decide to choose the blue urn again in the next period, the computer will again draw one of the two balls, you get the points that are written on this ball and the ball is placed back into the urn. (*Again, draw a ball out of the blue bowl blindfolded and show the ball with its associated number to the kids and put the ball back into the bowl.*)

Drawings of the six different signs (circle, square, triangle, cross, star, hexagon) are drawn on the blackboard.

- However, the urns in our game will not be differentiated by colors. Each urn will be associated with a sign. We have one urn marked with a circle (*point to the circle on the blackboard*), one urn with a square (*point to the square on the blackboard*), one urn with a triangle (*point to the triangle on the blackboard*), one urn with a cross (*point to the cross on the blackboard*), one urn with a star (*point to the star on the blackboard*) and one urn with a hexagon (*point to the hexagon on the blackboard*). The urns will have the same sign throughout the whole game but we will not tell you which sign belongs to which urn.
- What you know is that there is one urn with a ball labeled 1 and a ball labeled 2. There is one urn with a ball labeled 2 and a ball labeled 3. In one urn there is a ball labeled 3 and a ball labeled 4. In one urn there is a ball labeled 4 and

a ball labeled 5. In one urn there is a ball labeled 5 and a ball labeled 6 and in one urn there is a ball labeled 6 and a ball labeled 7.

- In order for you to decide on one urn and to get to know how many points you've earned with one of the urn's balls we will provide you with a decision sheet at the beginning of each period. (*Show a period 1 decision sheet.*)
- On top of the sheet you will find your unique player number, which lets the computer know who you are and you will find the period in which we're currently in.
- Underneath you will see the six signs of the urns. In each period your task is going to be to decide on one of the signs. As soon as you've decided on one of the signs, you tick off the box underneath the sign and wait for us to collect your decision sheet.
- From the second period on, you will find some more information on your decision sheet. On top of the sheet you will again find your player number and the current period. (*Show a period 2 decision sheet.*)
- Underneath, you will see what happened in the previous period.
- You can see what urn you did choose. The sheet tells you "my choice" and shows you a ticked off box underneath your previous period's sign.
- You can have a look at how many points you did get with your choice. The sheet says "my points".
- Underneath, you will again find the six signs of the urns and you can again decide on an urn's sign.

- **[Only in treatment Observation:** Additionally, we will tell you what one of the other kids in class who plays the exact same game as you, chose to do in the previous period and how many points this kid earned with his choice.]
- The game will last 10 periods. We will tell you when the last period is.
- The important thing is that you understand that different urns can give you different numbers of points.

Before we start to play the game each of you is going to be provided with a comic book and some sheets of paper. Whenever there isn't any decision sheet on your table you're allowed to read the comic or to color on the blank sheets of paper. You will have to close the comic books, put away the drawings and concentrate on the new decision sheet as soon as I tell you that a new period of the game starts until we pick up the decision sheet again.

Each game period is going to last for 30 seconds. In this time you will carefully read through the previous period's information and decide on an urn for the current period afterwards.

Remember, in each period you can decide on one of the urn's signs. There are no guidelines on which sign to choose when or how often. It is completely up to you if you want to choose a different sign in each period or if you want to go for the same sign in some consecutive periods.

Remember, the more points you earn in the game, the more money in form of voucher you get at the end of the game. If anybody has any more questions raise your hand now. Otherwise I wish you the best of luck and don't forget not to talk to any other kids.

Before every new period: Please close the comic book and put away all the drawings. (*Wait for some seconds*) We will now provide you with the decision sheets for the next period. Please read carefully through the information provided and decide which sign you would like to choose in this period.







After the last period: The game's last period is now over. First, we will collect the comic books. Second, we will provide you with a questionnaire. Since we will fill it in together, please wait until everybody is provided with the questionnaire. In the meantime, the computer is going to calculate your earnings. When we are finished filling in the questionnaires each child is going to get an envelope with his vouchers.







Before giving away the envelopes: Before each of you gets his envelope we would like to thank you for spending some time with us today and also thank your teacher for allowing to visit your class. We will now hand each of you an envelope with your player number on the outside. Inside the envelope you will find a sheet of paper that tells you how many points you've earned in the whole game and how many vouchers this number of points is going to give you. The vouchers look like this (*show them sample vouchers*). They are labeled 5 euro or 1 euro. We wish you a lot of fun with your envelopes and the vouchers.

Figure 2.6: Feedback/decision sheet in the Observation treatment

Player 4
Round 4

Previous Round:

						
My Choice:		X				
My points:		5				

						
Choice of my co-player:				X		
Points of my co-player:				7		

Next Round:







						
My Choice:	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure 2.7: Probability of staying with the same urn after observing payoff x

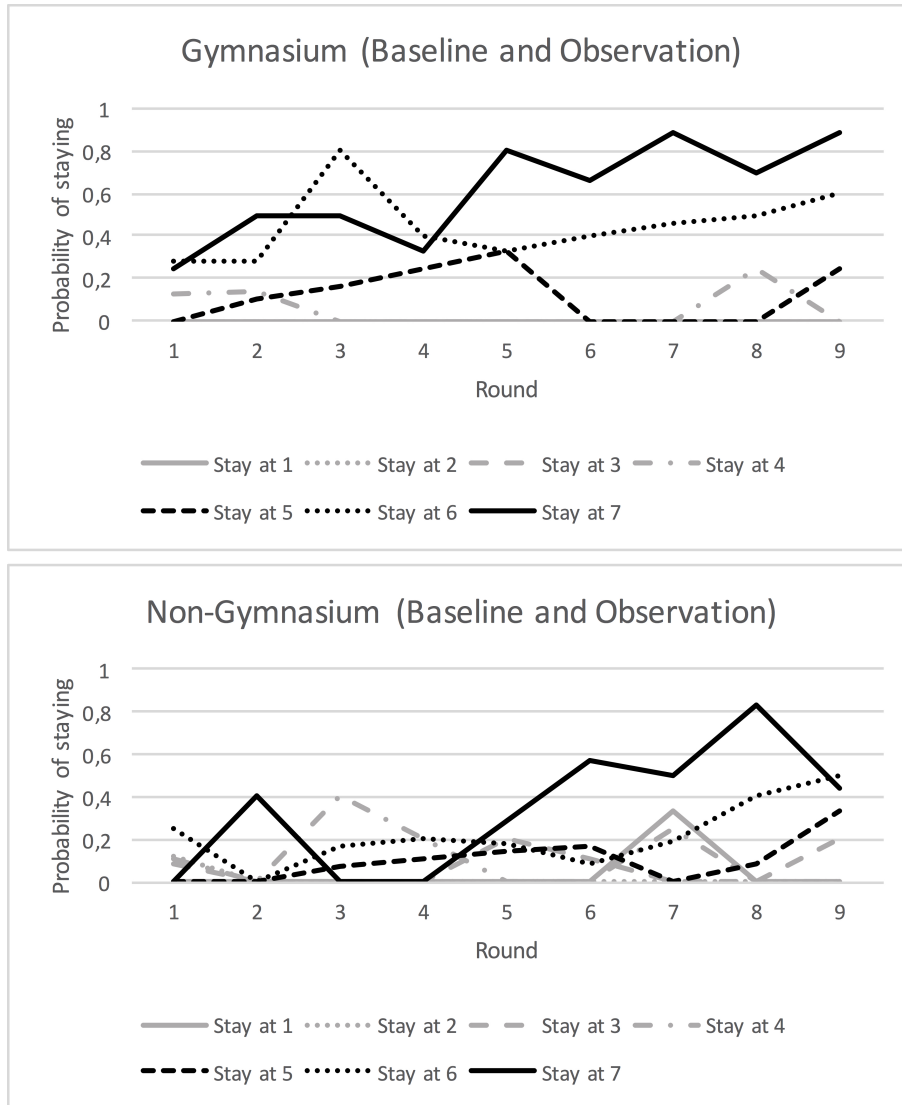
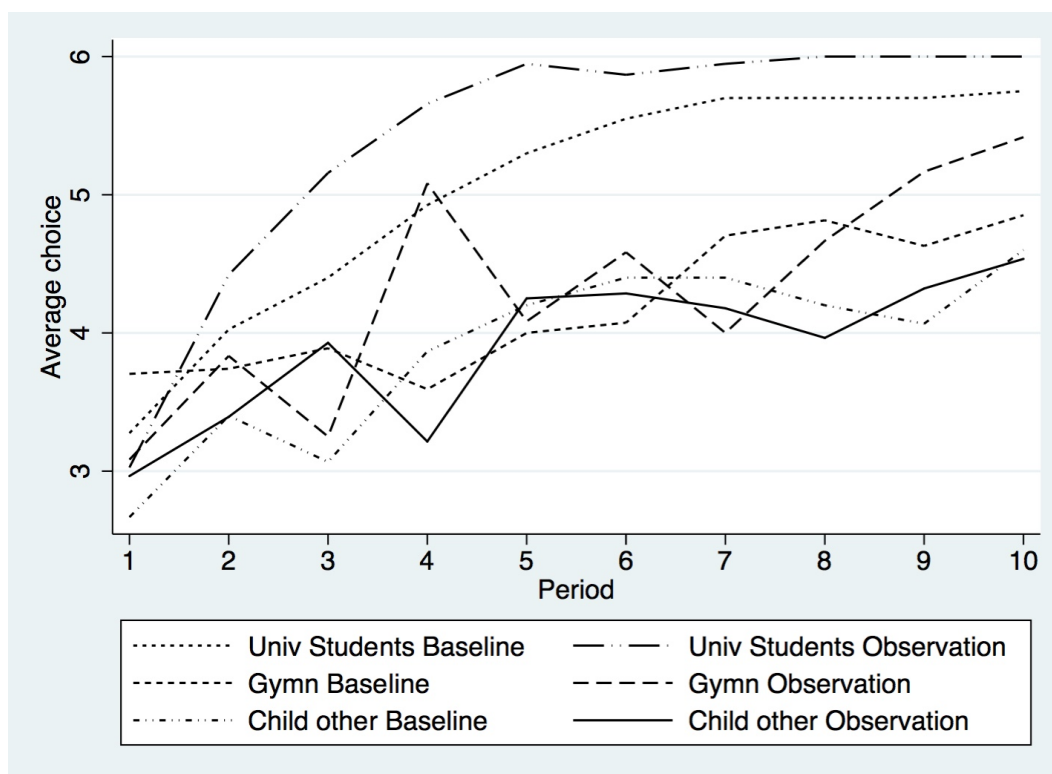


Figure 2.8: Average Choices over time



Chapter 3

Constrained Mobility and the Evolution of Efficient Outcomes

3.1 Introduction

There are many circumstances where individuals can benefit from coordinating on the same action as a common technology standard (e.g. IOS vs. Android OS) or norm (metric vs. imperial system of measurement). These situations give rise to coordination games with multiple strict Nash equilibria. The question under which circumstances a particular technology standard or norm will eventually be adopted by a society has large implications for a variety of stakeholders. For instance, regulators who standardize products or services can benefit from a better understanding of the circumstances (e.g. the attributes of products or the interaction structure among consumers) that lead to efficient outcomes. Likewise, firms can benefit from knowing under which circumstances their product can capture a large market share. In this spirit, a large literature has addressed the question of which equilibria emerge in

the long run when agents adopt their behavior using simple rules of thumb, such as imitation or (myopic) best response learning (see e.g. Weidenholzer (2010) for a survey). The main message that arises from this literature is that when the interaction structure is fixed, players reach profiles where everybody chooses the same action. Moreover, when agents use myopic best response learning risk dominant conventions will emerge, that is the population will end up using strategies that do well against mixed profiles, but do not necessarily carry a high payoff when everybody adopts them (see e.g. Kandori et al. (1993) and Young (1993)).²¹

In such a setting it is a natural question to ask what happens if agents are not organized in a fixed interaction structure, but may influence the set of their interaction partners. One way of choosing one's interaction partners is presented by models of network formation, see e.g. Jackson and Watts (2002), Goyal and Vega-Redondo (2005), and Staudigl and Weidenholzer (2014). An alternative branch of the literature has considered settings (see Oechssler 1997, Dieckmann 1999, Anwar 2002, Ely 2002, Blume and Temzelides 2003) where agents may identify their preferred interaction partners by deciding on which of multiple islands to play the game on. The interaction structure on islands is fully connected, meaning that everybody interacts with everybody else on their island, and there are no interactions across islands. Interactions on islands are thus characterized by extreme clustering. This form of endogenously formed interactions corresponds to choosing circles of friends or cliques rather than individually picking interaction partners.

If there are no limits on the number of players allowed on each location, such location choice or “voting by one's feet” has been found to lead to outcomes where payoff dominant actions are adopted by the population (see e.g. Oechssler (1997)

²¹ On the contrary, under imitation learning payoff dominant actions may be elected, see e.g. Robson and Vega-Redondo (1996) and Alós-Ferrer and Weidenholzer (2008).

and Ely (2002)). We contribute to this literature by studying the implications of constraints limiting the number of players that may reside at each location. Such constraints may be the result of natural limitations such as the space available on each island or arise in a context when agents only have time to socialize with a limited number of agents.

In particular, we present a model similar to the one of Anwar (2002) where a population of agents uses myopic best response learning to i) determine their action in a coordination game with a payoff dominant and a risk dominant equilibrium and to ii) choose on which of two islands to play the game on. Under myopic best response learning players play a best reply to the distribution of strategies used by their opponents in the current period. This captures the idea that players are not able to form a forecast on their opponents' future behavior and, thus, react to the current distribution of play.²² (For similar statements and arguments see Weidenholzer (2010)). We believe this assumption to be particularly apt for consumers' choices of a technology standard or norm which most probably rely to a large extent on the current distribution in the population rather than the consumers' beliefs on future distributions of play.

Agents only interact with other agents on their island and there is no interaction across islands. There are constraints limiting the mobility of agents across islands. In particular, the number of agents that may reside on each island is subject to a capacity constraint. An alternative interpretation of this location choice model is one of endogenous interaction partner choice characterized by extreme clustering and (time) constraints on the number of agents one socializes with. We extend

²² We remark that the main results of our model would also hold under the imitate the best max rule (see e.g. Robson and Vega-Redondo 1996) where players imitate the actions of the most successful agents in the population. See footnote 29 for details.

Anwar's (2002) model by allowing the set of available locations to be larger than two. By considering this more general and realistic setting, we are able to provide a comprehensive picture of the role of (restricted) mobility on long run behaviour.

We find that the best response dynamic will converge to states with the following properties: i) On each island only the same action is played. ii) The population is concentrated on the fewest possible islands. The reason behind the latter observation is that agents who are indifferent among islands where the same action is played will move across islands. Thus, the process will at some point reach a state where certain islands are empty. Note that whether there are empty islands or not will depend on the capacity constraint. iii) Islands where the payoff dominant action is played will be at capacity. If there are such islands, agents on islands where the risk dominant action is played will change their action and move to them.

We are interested in which of these states will emerge in the long run when the agent's choices are perturbed by occasional mistakes à la Kandori et al. (1993) and Young (1993). In a nutshell, states that are most robust to mistakes will emerge as *long run equilibria*, *LRE*.

Anwar (2002) has shown that with two islands either all agents will choose the risk dominant action or agents on the island that is at its capacity will choose the payoff dominant action and agents on the other island will be stuck with the risk dominant action in the long run.²³ In the case where there may be more than two islands, we find that if the constraints are such that one island may be empty, universal coordination on the payoff dominant action will obtain in the long run. If the constraints on capacity are such that all islands will be occupied, our results

²³ See Dieckmann (1999) and Blume and Temzelides (2003) who also study restricted mobility in different settings and see Goyal and Janssen (1997) and Alós-Ferrer and Weidenholzer (2007) for models where the co-existence of conventions may be observed on the circle.

generalize those in Anwar (2002) to more than two islands. In particular, if the constraints are relatively mild (within the range of relevant constraints) such that the smallest size of a populated island is relatively small compared to the largest size of an island (implied by capacity), the coexistence of conventions will occur, with one island coordinating on the risk dominant action and all remaining islands coordinating on the payoff dominant action. For relatively stringent constraints on capacity all agents will play the risk dominant action.

Let us provide some intuition for Anwar's (2002) and our findings. First, consider the case where, as in Anwar (2002), the constraints and the population are such that it requires all of the islands to shelter the entire population. If the payoff dominant action is played on some (but not all) of the islands, then all agents want to move to these islands, up until the point where they are at full capacity. On the contrary, the population on the islands where the risk dominant action is played will be relatively small. Thus, while islands where the payoff dominant action is played take a small fraction of a large population to make a mistake in order for the island to switch, islands where the risk dominant action is played will take a large fraction of a small population to switch. Hence, whenever constraints on capacity are relatively mild we will observe all but one island coordinating on the payoff dominant action. If the constraints are relatively strict, universal coordination on the risk dominant action will obtain. With more than two islands we may have a third force at play, as the constraints can be such that some islands are empty. If now an agent makes a mistake, moves to an empty island and starts playing the payoff dominant action, other agents will follow up to the point where the island is fully occupied. Thus, with one mistake we can increase the number of payoff dominant islands. This implies that whenever the population size and the constraints are such that there may be empty islands, the payoff dominant convention will be a long run equilibrium.

Our results, thus, suggest that from the perspective of consumers or a regulator constrained mobility does not necessarily have to go hand in hand with inefficient outcomes. What matters more is the questions of whether the constraints are such that there can be empty islands from which payoff dominant action may spread or whether there are no such islands.

3.2 The model

We consider a population of kN agents who reside on $k \geq 2$ different islands. Each of these islands can only shelter M agents. We assume $N < M < kN$, so that one location may not shelter the entire population and there is enough total capacity to shelter the entire population. Using the notation of Anwar (2002), the maximal number of agents on an island is $M = dN$ with $1 < d < k$.²⁴

Agents only interact with other agents on their island and have to use the same action in all of their interactions. The payoff of an agent is given by the average payoff of playing the following coordination game against all other agents on her island.

	s_1	s_2
s_1	A, A	B, C
s_2	C, B	D, D

We assume $A > C$ and $D > B$, so that (s_1, s_1) and (s_2, s_2) are strict Nash equilibria.

We further assume $A > D$, so that the equilibrium (s_1, s_1) is payoff dominant, and

²⁴ In fact, Anwar (2002) considers two forms of restriction on mobility. First, as in our contribution, there are constraints on the maximally allowed number of agents on each island. Second, a certain fraction of the population of each island (the so-called patriots) may never change location. We only consider constraints on the maximal capacity of each island. If there are only two islands the two forms of restricted mobility are equivalent. However, with more than two islands the implications of the two forms of restricted mobility might be different from one another.

$C + D > A + B$, so that (s_2, s_2) is risk dominant, i.e. s_2 is the unique best response against an agent playing both strategies with probability $\frac{1}{2}$. We denote the critical mass on action s_1 in the mixed strategy Nash equilibrium by

$$q^* = \frac{D - B}{A - C + D - B}.$$

Note that by risk dominance $q^* > \frac{1}{2}$. In addition, we focus on coordination games where $C \geq D$.²⁵ We further assume that an agent who is alone on an island earns a payoff of $\bar{u} < B$, implying that agents prefer playing the game over being alone on an island.

Time is discrete $t = 1, 2, \dots$. Each period each agent chooses an action that gives the highest average payoff against the profile of actions played on her island in the previous period. In addition, with positive probability each agent may choose an island to reside. When such an opportunity arises an agent chooses an action and a location that maximize the payoff given the overall distribution of actions across all islands in the previous period. We assume random tie breaking, i.e. in case of multiple best responses an agent randomizes among all of them. If an island is at capacity M , an agent is not allowed to move to this island and stays on his original island. If the number of agents intending to move to an island exceeds available capacity, then only a random subset (equal to available capacity) is allowed to move. Thus, as in Anwar (2002), we consider a myopic best response process without inertia in the action choice but with inertia in the choice of islands. With probability ϵ , independent across agents and time, an agent ignores the prescription of the adjustment process

²⁵ It has been observed by Shi (2013) that if $C < D$, the transitions among the various absorbing sets can differ from the one found in Anwar (2002). For ease of exposition we have decided to focus on the case where this does not occur. The qualitative results of the present model will stay the same, though, if $C < D$. See also footnote 28.

and chooses a location and an action at random.

We denote by n_i the number of players on island i and by n_i^1 the number of s_1 players on island i . The number of s_2 players on location i is, thus, given by $n_i^2 = n_i - n_i^1$. In the following we refer to a populated island i where all players play the payoff dominant action, $n_i^1 = n_i > 0$, as payoff dominant island and to a populated island i where all players play the risk dominant action, $n_i^2 = n_i > 0$, as risk dominant island. Using vector notation, so that $\vec{n}, \vec{n}^1, \vec{n}^2 \in \mathbb{R}_+^k$, we denote a state of this system by a tuple of vectors (\vec{n}, \vec{n}^1) . Note that $\vec{n}^2 = \vec{n} - \vec{n}^1$.

The state space of our model can, hence, be characterized as

$$S = \{(\vec{n}, \vec{n}^1) \mid n_i \in \{0, \dots, M\}, n_i^1 \in \{0, \dots, n_i\}\}.$$

We denote by $\underline{k} = \lceil \frac{kN}{M} \rceil$ the smallest number of locations required to shelter the entire population. Finally, we denote by m the size of the location when the other $\underline{k} - 1$ locations are at capacity,

$$m = kN - M(\underline{k} - 1).$$

3.2.1 Review of techniques

The following exposition draws heavily on Jiang and Weidenholzer (2016). The process without mistakes ($\epsilon = 0$) is called *unperturbed* process. Ω denotes the set of absorbing sets of this process and $\omega \in \Omega$ denotes one such absorbing set. The process with mistakes ($\epsilon > 0$) is referred to as *perturbed process*. Any two states can be reached from each other under the perturbed process. Hence, there is only absorbing set which process corresponds to the entire state space, implying that the process is ergodic. The unique invariant distribution of this process is denoted by

$\mu(\epsilon)$. We are interested in the *limit invariant distribution* (as the error rate goes to zero), $\mu^* = \lim_{\epsilon \rightarrow 0} \mu(\epsilon)$. This distribution exists (see Foster and Young (1990), Young (1993), or Ellison (2000)) and it is an invariant distribution of the unperturbed process. It provides a stable prediction for the unperturbed process. If ϵ is small enough the play in the long run corresponds to the distribution of play described by μ^* . States in the support of μ^* , are referred to as stochastically stable states or *Long Run Equilibria (LRE)*. We denote the set of LRE by $\mathcal{S} = \{\omega \in \Omega \mid \mu^*(\omega) > 0\}$. Jiang and Weidenholzer (2016) proceed in their exposition by providing an overview of the Freidlin and Wentzell (1988) algorithm to identify the set of LRE.²⁶ Consider two absorbing sets of states ω and ω' and let $\tau(\omega, \omega') > 0$ be the *transition cost*, i.e. the minimal number of mistakes under the unperturbed process for moving from ω to ω' . An ω -tree corresponds to a directed tree where the nodes of the tree are given by the set of all absorbing sets, and the tree is directed into the root ω . The cost of a tree is calculated as the sum of the costs of transition on each edge. Freidlin and Wentzell (1988) have shown that a set ω is a LRE (or stochastically stable) if and only if it is the root of a minimum cost tree.

3.3 Results

We first characterize the absorbing sets of our process. In a nutshell, these will be made up of states where i) the population is concentrated on the fewest islands possible, ii) on each island all players play the same strategy, and iii) all islands where the payoff dominant action is played will be at capacity (unless the entire population chooses the payoff dominant action). In the following we refer to islands where all

²⁶ See Samuelson (1997) for a textbook exposition. Ellison (2000) provides an alternative way of identifying LRE. We work with the original formulation which also allows for a characterization in case of multiple LRE.

players play the risk dominant action as risk dominant islands and to islands where all players play the payoff dominant as payoff dominant islands. Note there are various ways in which the populated islands can be distributed among all islands and there are numerous ways in which payoff- and risk- dominant islands can be distributed among the occupied islands. Thus, formally characterizing the absorbing sets is a bit more cumbersome and requires more notation.

We use $C(a, \vec{x})$ to indicate the occurrences of element a in vector \vec{x} ,²⁷ We start with the following observation.

LEMMA 1. *Any absorbing set $\omega \in \Omega$ is such that for all states $(\vec{n}, \vec{n}_1) \in \omega$,*

$$i) \ n_i^1(n_i - n_i^1) = 0 \text{ for all } i = 1, \dots, k$$

$$ii) \ C(0, \vec{n}) = k - \underline{k}$$

Proof. The first part follows from the observation that on each island all players have to adopt the same action. Thus, if for some island $n_i^1 > 0$, it has to be the case that $n_i^2 = 0$ and if $n_i^2 > 0$, $n_i^1 = 0$ has to hold. To see the second part, observe that agents who are indifferent between various islands will move to each of these islands with positive probability. Thus, with positive probability the process converges to states where the population is concentrated on the fewest islands possible, \underline{k} . Thus, $k - \underline{k}$ islands will have to be empty. \square

Note that each absorbing set ω may contain multiple states which the process visits with positive probability. In order to characterize theses states, we introduce

²⁷ As an example, if $\vec{x} = (1, 2, 3, 1)$, we have that $C(1, \vec{x}) = 2$, $C(3, \vec{x}) = 1$ and $C(5, \vec{x}) = 0$. This operator is called *count* operator in the *Z notation*, used in computer science (see e.g. Spivey and Abrial (1992)).

a distance relationship between them. Consider two islands, x and y , we define

$$\delta(x, y) = \begin{cases} 0 & \text{if } n_x = 0 & \& n_y = 0 \\ 0 & \text{if } n_x^1 = n_x > 0 & \& n_y^1 = n_y > 0 \\ 0 & \text{if } n_x - n_x^1 = n_x > 0 & \& n_y - n_y^1 = n_y > 0 \\ 1 & \text{otherwise} \end{cases}.$$

In words, $\delta(x, y) = 0$ if both islands are empty or the same action is played on them.

We then define the distance between two states (\vec{n}, \vec{n}^1) and (\vec{n}', \vec{n}'^1) as

$$d((\vec{n}, \vec{n}^1), (\vec{n}', \vec{n}'^1)) = \sum_{i=1}^k \delta(n_i, n'_i).$$

We now have:

LEMMA 2. *For any two states (\vec{n}, \vec{n}^1) and (\vec{n}', \vec{n}'^1) contained in a non-singleton absorbing set ω we have $d((\vec{n}, \vec{n}^1), (\vec{n}', \vec{n}'^1)) = 0$.*

Proof. In any absorbing set the process will only move among states where the same islands are populated and on the populated islands the same action is chosen, implying $d((\vec{n}, \vec{n}^1), (\vec{n}', \vec{n}'^1)) = 0$. \square

Let now Ω_ℓ denote the set of absorbing sets where on ℓ islands the payoff dominant action is played, i.e.

$$\Omega_\ell = \{\omega \in \Omega \mid C(0, \vec{n}) = k - \underline{k} \& C(0, \vec{n}^1) = k - \underline{k} + \ell \forall (\vec{n}, \vec{n}^1) \in \omega\}.$$

An element of Ω_ℓ is denoted by ω_ℓ . We refer to the set of absorbing sets Ω_0 and $\Omega_{\underline{k}}$ as the risk dominant- and the payoff dominant- convention, respectively. All other sets of absorbing sets feature the coexistence of conventions and are referred to as mixed

sets. The following lemma characterizes the size of the population on each occupied island in an absorbing set.

LEMMA 3. *Consider an absorbing set ω_ℓ . Then it holds:*

- i) If $0 \leq \ell \leq \underline{k} - 2$, for all states $(\vec{n}, \vec{n}^1) \in \omega_\ell$, $n_i^1 = M$ for all islands i with $n_i^1 > 0$ and $n_j - n_j^1 \in \{m, m+1, \dots, M\}$ for all islands j with $n_j - n_j^1 > 0$.*
- ii) If $\ell = \underline{k} - 1$, then for all states $(\vec{n}, \vec{n}^1) \in \omega_\ell$, $n_i^1 = M$ for all islands i with $n_i^1 > 0$ and $n_j - n_j^1 = m$ for the island j with $n_j - n_j^1 > 0$.*
- iii) If $\ell = \underline{k}$, then for all states $(\vec{n}, \vec{n}^1) \in \omega_{\underline{k}}$, $n_i^1 \in \{m, m+1, \dots, M\}$ for islands i with $n_i^1 > 0$.*

Proof. Let us start with ii) where the risk dominant action is played on one island. As agents who are given the opportunity to switch islands will move to islands where s_1 is played, the $\underline{k}-1$ islands where s_1 is played will be full. On the only islands where s_2 is played m agents will be stuck using the risk dominant action. To see i), note that if s_2 is played on more than one island, again islands where s_1 is played (provided that there are any) will have to be full. The population on the islands where s_2 is played will be indifferent on which of the s_2 islands to reside and, thus, will move among those islands. Hence, the population on the s_2 islands will fluctuate between m and M . In case iii) s_1 is played on all islands and, thus, agents are indifferent among which of them to reside. \square

Thus, in mixed states islands where the payoff dominant action is played will be at capacity. If there is only one island where the risk dominant action is played, its population is m . If there is more than one island where the risk dominant action is played the population on these islands will fluctuate between m and M . Similarly,

if the payoff dominant action is played on all islands the population on each of these islands will also fluctuate between m and M .

Having characterized the absorbing sets of our process, we now move on to determine transition costs among them. To this end, we say that two absorbing sets ω and ω' are *adjacent* if every state $(\vec{n}, \vec{n}^1) \in \omega$ is at distance one to every state $(\vec{n}', \vec{n}'^1) \in \omega'$, i.e. the same islands are occupied and on all but one of these islands the same action is played. Furthermore, if an absorbing set ω_ℓ (with $1 \leq \ell \leq \underline{k} - 1$) is adjacent to another absorbing set ω_m , it follows that either $m = \ell - 1$ or $m = \ell + 1$.

The following series of lemmata characterizes transition costs among absorbing sets. The first two of those focus on the case when there are empty islands, which means that $\underline{k} < k$.

LEMMA 4. *If $\underline{k} < k$, then for every absorbing set ω_ℓ with $0 \leq \ell \leq \underline{k} - 1$ there exists an absorbing set $\omega_{\ell+1}$ with $\tau(\omega_\ell, \omega_{\ell+1}) = 1$.*

Proof. Assume an agent who resides on an island where everybody chooses the risk dominant action makes a mistake, moves to an empty island, and starts playing the payoff dominant action. All agents given revision opportunity will follow the mutant up to the point where the island is full. \square

LEMMA 5. *If $\underline{k} < k$, then all absorbing sets $\omega_\ell \in \Omega_\ell$ can be reached from one another via a chain of single mutations.*

Proof. Again, assume one agent mutates, moves to an empty island but, this time, keeps his current action. With positive probability, agents from other islands where that strategy is played will follow and we reach a new state where the initially empty island is occupied and some initially occupied island is empty. Iterating this argument, we can move among all sets in Ω_ℓ via a chain of single mutations. \square

The following lemma characterizes transitions to sets of states with more risk dominant islands.²⁸

LEMMA 6.

- i) For any two adjacent absorbing sets $\omega_{\underline{k}}$ and $\omega_{\underline{k}-1}$, the transition cost is $\tau(\omega_{\underline{k}}, \omega_{\underline{k}-1}) = \lceil m(1 - q^*) \rceil$;
- ii) For any two adjacent absorbing sets ω_{ℓ} and $\omega_{\ell-1}$, with $0 \leq \ell \leq \underline{k} - 1$, the transition cost is $\tau(\omega_{\ell}, \omega_{\ell-1}) = \lceil M(1 - q^*) \rceil$.

Proof. Consider part i). For any absorbing set $\omega_{\underline{k}}$ the process moves among states where the population on each island fluctuates between m and M . Consider a state where the number of s_1 players on one island is minimal at m . If $\lceil m(1 - q^*) \rceil$ agents mutate to s_2 all remaining s_1 players will find it optimal to switch to s_2 and we reach an adjacent state in $\Omega_{\underline{k}-1}$.

Part ii) follows from the fact that in all absorbing sets ω_{ℓ} with $1 \leq \ell \leq \underline{k} - 1$ the s_1 islands are full. Thus, it takes $\lceil M(1 - q^*) \rceil$ mutations to reach an adjacent state in $\Omega_{\ell-1}$. \square

The next lemma analyzes transitions where the number of payoff dominant islands increases in the scenario where all islands are populated.

LEMMA 7. If $\underline{k} = k$, for any two adjacent absorbing sets ω_{ℓ} and $\omega_{\ell+1}$, with $0 \leq \ell \leq \underline{k} - 1$, the transition cost is given by $\tau(\omega_{\ell}, \omega_{\ell+1}) = \lceil mq^* \rceil$.

²⁸ Shi (2013) has shown that if $D > C$, transitions that increase the number of islands on which s_2 is played may occur through an alternative cheaper route. In a first step, s_1 players have to mutate to s_2 such that all players allowed will move to an s_2 island. Once this is achieved, $\lceil m(1 - q^*) \rceil$ of the remaining players still have to switch. While this may change the number of mutation required, it is, however, still true that a certain fraction of players on an island have to mutate. While the derivation of the number of mistakes required for a transition may be different when $D > C$, the qualitative nature of the results in Anwar (2002) remains.

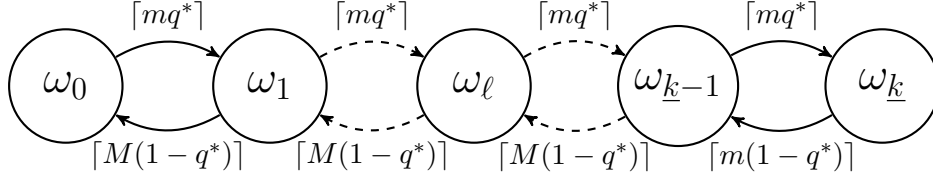


Figure 3.1: Transition costs for $\underline{k} = k$

Proof. For any absorbing set ω_ℓ , with $0 \leq \ell \leq \underline{k} - 1$, the process moves among states where the population on the risk dominant islands is either m or fluctuates between m and M . Consider a state such that the number of s_2 players on a risk dominant island is minimal at m . If $\lceil mq^* \rceil$ players on this island mutate to s_1 all remaining s_2 players will find it optimal to switch to s_1 and we have reached an adjacent state with one more payoff dominant island. \square

We summarize the transition costs in the case where $\underline{k} = k$ in Figure 3.1.

The final lemma shows that when finding minimum cost trees for the various absorbing sets, it is sufficient to restrict attention to sets of absorbing sets Ω_ℓ . To this end, we define a *reduced ω_ℓ -tree* as a tree directed into the root ω_ℓ with the set of nodes being comprised by one absorbing set ω_m for each of the sets of absorbing sets Ω_m with $m \neq \ell$.

LEMMA 8. *If for an absorbing set ω_ℓ there exists a reduced minimum cost ω_ℓ -tree, then for each $\omega'_\ell \in \Omega_\ell$ there also exists a ω'_ℓ -minimum cost tree.*

Proof. If $k > \underline{k}$ lemma 5 implies that all absorbing sets $\omega_\ell \in \Omega_\ell$ can be reached from one another via a chain of single mutations and the claim follows. Next, consider $k = \underline{k}$. Since there are no empty islands, Ω_0 and Ω_ℓ each contain one unique absorbing set. Consider an absorbing set ω_ℓ . We can now construct a branch from $\omega_{\underline{k}}$ to an adjacent absorbing set $\omega_{\underline{k}-1}$, and so forth, finally connecting an adjacent absorbing

set $\omega_{\ell+1}$ into ω_ℓ . In the same way, we can construct a path connecting ω_0 into ω_ℓ . As the cheapest way to escape every absorbing set is to move to an adjacent set and since in this construction only one island is changed at a time, the constructed reduced ω_ℓ -tree will have a cost no larger than the cost of any alternative reduced ω_ℓ -tree. Further, note that in the same fashion we can construct a reduced ω'_ℓ -tree of the same cost for each $\omega'_\ell \in \Omega_\ell$.

We now show that if there exists a reduced minimum cost ω_ℓ -tree there also exists a minimum cost ω_ℓ -tree. To this end, we will connect all remaining absorbing sets to the reduced ω_ℓ -tree. Again, note that the cheapest way to leave an absorbing set is by only changing the population on one island (i.e. moving to an adjacent set). By lemmata 6 and 7, for all absorbing sets, different from ω_0 and $\omega_{\underline{k}}$, it is either cheaper to increase or decrease the number of s_1 islands. Thus, if it is cheaper to increase (decrease) the number of s_1 islands for some ω_m , with $1 \leq m \leq \underline{k} - 1$, then it is cheaper to increase (decrease) the number of s_1 islands for all absorbing sets ω_g , with $1 \leq g \leq \underline{k} - 1$. Thus, we can link all remaining absorbing sets (possibly through a sequence of other sets) to the already existing part of the tree, by simply adding branches to each absorbing set ω_g that go either to an adjacent set in $\Omega_g + 1$ or in $\Omega_g - 1$ (depending on which direction is cheaper). By moving only in the least costly direction the total cost of the added part is minimal. Since also the first part is of minimum cost, the resulting tree is a minimum cost tree rooted into ω_ℓ . \square

We can now state our main result.

PROPOSITION 1. *For sufficiently large N ,*

a) if $\underline{k} < k$ and

i) if $\lceil m(1 - q^) \rceil > 1$, then $\mathcal{S} = \Omega_{\underline{k}}$*

ii) if $\lceil M(1 - q^*) \rceil > \lceil m(1 - q^*) \rceil = 1$, then $\mathcal{S} = \Omega_{\underline{k}} \cup \Omega_{\underline{k}-1}$

iii) if $\lceil M(1 - q^*) \rceil = \lceil m(1 - q^*) \rceil = 1$, then $\mathcal{S} = \bigcup_{\ell=0}^{\underline{k}} \Omega_{\ell}$

b) if $\underline{k} = k$ and

i) if $\lceil mq^* \rceil < \lceil M(1 - q^*) \rceil$, then $\mathcal{S} = \Omega_{\underline{k}-1}$.

ii) if $\lceil mq^* \rceil > \lceil M(1 - q^*) \rceil$, then $\mathcal{S} = \Omega_0$.

iii) if $\lceil mq^* \rceil = \lceil M(1 - q^*) \rceil > \lceil m(1 - q^*) \rceil$, then $\mathcal{S} = \bigcup_{\ell=0}^{\underline{k}-1} \Omega_{\ell}$.

iv) if $\lceil mq^* \rceil = \lceil M(1 - q^*) \rceil = \lceil m(1 - q^*) \rceil$, then $\mathcal{S} = \bigcup_{\ell=0}^{\underline{k}} \Omega_{\ell}$.

Proof. By lemma 8 we only have to consider reduced minimum cost trees. Note that such a reduced minimum cost tree will necessarily only involve transitions among adjacent absorbing sets as any transition involving two or more islands at the same time is more costly. Let us first consider ω_0 trees. By lemma 6 the cost of every reduced minimum cost ω_0 -tree is $(k-1)\lceil M(1 - q^*) \rceil + \lceil m(1 - q^*) \rceil$. Now consider the case where $\underline{k} < k$. By lemma 4 the cost of every reduced minimum cost $\omega_{\underline{k}}$ -tree is \underline{k} . Combining lemma 4 and lemma 6 reveals that the cost of every reduced minimum cost ω_{ℓ} -tree (with $1 \leq \ell \leq k-1$) is $\ell + (\underline{k} - \ell - 1)\lceil M(1 - q^*) \rceil + \lceil m(1 - q^*) \rceil$. Pointing out that $\lceil M(1 - q^*) \rceil \geq \lceil m(1 - q^*) \rceil \geq 1$ establishes the claim in part a).

Finally, consider the case $\underline{k} = k$. By lemma 7 the cost of every reduced minimum cost $\omega_{\underline{k}}$ -tree is $\underline{k}\lceil mq^* \rceil$. By lemmata 7 and 6 the cost of every reduced minimum cost ω_{ℓ} -tree (with $1 \leq \ell \leq k-1$) is $\ell\lceil mq^* \rceil + (\underline{k} - \ell - 1)\lceil M(1 - q^*) \rceil + \lceil m(1 - q^*) \rceil$. Noting that $\lceil mq^* \rceil \geq \lceil m(1 - q^*) \rceil$ and $\lceil M(1 - q^*) \rceil \geq \lceil m(1 - q^*) \rceil$ and comparing the costs of the various reduced minimum cost trees establishes part b). \square

To interpret the result, recall that the smallest number of islands required to shelter the entire population \underline{k} is given by $\lceil \frac{kN}{M} \rceil$. Thus, whenever the restrictions on

mobility are weak and M is large enough so that some islands will be empty, coordination on efficient outcomes will be observed (abstracting from the non-generic cases). If, however, there are no such islands ($\underline{k} = k$), then either the co-existence of conventions or universal coordination on the risk dominant action will be observed. Note in this case $m = M - k(M - N)$. Thus, m approaches M if the constraint becomes stricter (and M approaches N). If the constraint is relatively weak (M large relative to m), the co-existence of conventions may occur whereas if the constraint is relatively stringent (m large relative to M), universal coordination on the risk dominant convention will obtain. Thus, (abstracting from non-generic cases) as the constraint becomes stricter, the prediction switches from the payoff dominant convention, to the co-existence of conventions, and finally to the risk dominant convention.²⁹

Let us provide some technical intuition for proposition 1. If the constraint is such that there may be empty islands, a single mistake is enough to move to states where the efficient action is played on more islands. This ensures universal coordination on the efficient convention in the long run. If the constraint is such that all islands will be occupied the picture is more complicated. If all agents choose the payoff dominant action, then the population on each island will fluctuate between m and M . Thus, with $\lceil m(1 - q^*) \rceil$ mistakes we can traverse from these states to states where on one island the risk dominant action is chosen. Note that now all payoff dominant islands will have to be full, implying that further increasing the number of payoff dominant islands will take $\lceil M(1 - q^*) \rceil$ mistakes. Thus, states where there is

²⁹ A similar result can be obtained when players base their decisions on the imitate the best max rule. The only substantial difference is that it becomes slightly more difficult to populate previously empty islands as a lonely player on an island earns the lowest possible payoff and will never be imitated. Instead, two mutations are required to populate an island. Thus, the thresholds in Proposition 1 would change accordingly.

one island choosing the risk dominant action and the rest of the population chooses the payoff dominant action are more resilient to further increasing the number of risk dominant islands than states where everybody chooses the payoff dominant action. Finally, note that increasing the number of payoff dominant islands always takes $\lceil mq^* \rceil$ mistakes. Thus, whenever m is small relative to M and/or q^* is close to $\frac{1}{2}$ we observe the coexistence of conventions. Conversely, whenever q^* is small and m is large, we will observe everybody choosing the risk dominant action. Note that by the argument above, it also follows that whenever the coexistence of conventions emerges, only one island will choose the risk dominant action.

We end this section with a simple corollary that shows simple sufficient conditions for which only one part of Proposition 1, (a) or (b), holds.

COROLLARY 1. *i) If $k = 2$, then $S \cap \Omega_{\underline{k}} = \emptyset$.*

ii) If $k > \frac{M}{M-N}$, then $S \cap \Omega_0 = \emptyset$.

Proof. If $k = 2$, by definition we have $M < 2N$, and so $\underline{k} = k$. This means that only part (b) of Proposition 1 holds.

If instead $k > \frac{M}{M-N}$, we have $k - 1 > \frac{N}{M-N} > \frac{kN}{M}$. This finally implies $k - 1 \geq \lceil \frac{kN}{M} \rceil = \underline{k}$, and so only part (a) of Proposition 1 holds. \square

This last corollary implies that, as in Anwar (2002), when there are only two islands we cannot have full coordination on the payoff dominant action. Moreover, when there is a large enough number of islands, we cannot have full coordination on the risk dominant action.

3.4 Conclusion

We have extended the results from Anwar (2002), where agents had the possibility to move between two islands. We have relaxed constraints in a very natural way, increasing the number of available islands, and we have shown that when the constraints are less binding we have a long run stable equilibrium that was not considered in the original model: a configuration in which all agents play the payoff dominant strategy. The driving force behind this result is that whenever the restrictions are relatively weak there may be empty islands. This provides the payoff dominant action with a springboard from which it can play out its superiority. We can also reinterpret our results in the context of a model where agents choose circles of friends which are characterized by extreme clustering. In this context, universal coordination on the payoff dominant action in a society requires it to be possible that agents may completely abandon their current circle of friends and form new circles of friends. From this point of view, sufficient flexibility in creating new interaction structures leads to more efficient outcomes.

One dimension our analysis has neglected is the potential role of agents who will never switch islands. As shown by Anwar (2002), with two islands it does not matter whether islands are subject to a capacity constraint or whether agents simply do not want to move across islands. With more than two islands the implications of these two forms of restricted mobility are however different. While we believe considering such immobile agents may lead to a more complete picture of the role of constrained mobility we leave this topic for further research.

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Abstract

The thesis is a compilation of three papers on coordination and imitation.

Chapter 1 examines the behavior of children in a minimum effort game experiment. Children age 7 to 10 years from five Austrian primary schools played a minimum effort game adopted from the Van Huyck, Battalio and Beil (1990) experimental setup. Data suggests that children aim for relatively high effort levels throughout the experiment and that there is a high variance of effort level choices. We find a correlation between the group size and the minimum group effort level where smaller groups achieve higher minima. While coordination failure in larger groups is in line with results in the previous literature we also find smaller groups of two and three players not being able to coordinate efficiently. Although some of these groups coordinate on the same effort level, children are not able to sustain coordination on the efficient equilibrium over time.

Imitating the successful choices of others is a simple and superficially attractive learning rule. It has been shown to be an important driving force for the strategic behavior of (young) adults. In Chapter 2 we examine whether imitation is prevalent in the behavior of children aged between 8 and 10. Surprisingly, we find that imitation seems to be cognitively demanding: Most children in this age group ignore information about others, foregoing substantial learning opportunities. While this

seems to contradict much of the psychology literature, we argue that success-based imitation of peers may be harder for children to perform than (non-success-based) imitation of adults.

Chapter 3 studies a model where agents use myopic best response learning to determine their action in a 2×2 coordination game and choose on which of multiple islands to interact. We focus on the case where the number of agents allowed on each island is constrained. We find that if the constraints are such that one island may be empty universal coordination on payoff dominant action will be obtained in the long run. If the constraints are such that all islands will be full, then for relatively mild constraints the coexistence of conventions will occur, with one island coordinating on the risk dominant action and all remaining islands coordinating on the payoff dominant action. For relatively stringent constraints all agents will play the risk dominant action.

Zusammenfassung

Diese Dissertation umfasst drei Artikel zu den Themen Koordination und Imitation.

Das erste Kapitel untersucht das Verhalten von Kindern in einem Minimum-Effort-Spiel Experiment. Kinder aus fünf Wiener Volksschulen, im Alter von sieben bis zehn Jahren, spielen ein Minimum-Effort-Spiel, welches aus dem Aufbau des Experimentes in Van Huyck, Battalio und Beil (1990) adaptiert wurde. Die gesammelten Daten zeigen, dass Kinder über das ganze Spiel hinweg hohe Effort Levels wählen und dass die Varianz in ihrer Wahl relativ hoch ist. Wir zeigen, dass eine Korrelation zwischen Gruppengröße und Gruppenminimum besteht. Kleine Gruppen erzielen ein höheres durchschnittliches Minimum. Des weiteren zeigen wir, dass Kinder selten bis gar nicht koordinieren und selbst in kleinen Gruppen von zwei und drei Spielern keine Koordination aufrechterhalten können.

Die Imitation von erfolgreichen Strategien anderer ist eine attraktive, weil oberflächlich und einfache, Verhaltensregel. Es wurde gezeigt, dass diese Form von Imitation eine wichtige Antriebskraft im strategischen Verhalten von (jungen) Erwachsenen darstellt. Im zweiten Kapitel untersuchen wir die Verbreitung von Imitation im Verhalten von Kindern im Alter von acht bis zehn Jahren und finden, dass Imitation kognitiv anspruchsvoll zu sein scheint. Die meisten Kinder in diesem Alter ignorieren Informationen über andere und verzichten dadurch auf die Chance zu lernen.

Auf dem ersten Blick scheint dies im Widerspruch zu Resultaten in der psychologischen Literatur zu stehen. Wir hingegen argumentieren, dass auf Erfolg basierende Imitation von Gleichaltrigen anspruchsvoller ist als (nicht auf Erfolg basierender) Imitation von Erwachsenen.

Das dritte Kapitel beschreibt ein Model, in welchen Agenten die myopische beste Antwort als Strategie in einem 2×2 Koordinationsspiel benutzen und sich zusätzlich dafür entscheiden müssen an welchem Ort sie dieses Spiel spielen möchten. Wir konzentrieren uns auf den Fall, in welchem die maximale Anzahl an Agenten pro Ort beschränkt ist. Wir finden, dass unter der Voraussetzung, dass ein Ort frei bleiben darf (kein Spieler entscheidet sich dort zu spielen), sich alle Spieler auf die auszahlungs-dominante Aktion des Spieles koordinieren. Sind die Parameter des Modells jedoch so, dass kein Ort frei bleibt kann es zu zwei Szenarien kommen. Sind die Kapazitätsbeschränkungen relativ schwach, kommt es zur Ko-Existenz verschiedener Konventionen, wobei an einem Ort das risiko-dominante Gleichgewicht gespielt wird und an den verbleibenden Orten das auszahlungs-dominante Gleichgewicht gespielt wird. Sind jedoch die Kapazitätsbeschränkungen relativ stark, so werden alle Spieler an allen Orten das risiko-dominante Gleichgewicht spielen.