The Density of Social Ties and the Equilibrium Selection in Coordination Games: An Experimental study

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Abstract

We conducted a series of experiments in order to investigate the relationship between the density of the local interaction structure and the equilibrium selection in coordination games with Pareto-ranked multiple equilibria. We observed that (1) the proportion of the risk dominant strategy is higher in less dense interaction structures than in more dense interaction structures in the long run, (2) the speed of convergence to the risk dominant equilibrium is faster in less dense interaction structures than in more dense interaction structures, and (3) the spread of the risk dominant strategy occurs earlier in less dense interaction structures than in more dense interaction structures. These findings indicate that the density of the local interaction structure matters in the equilibrium selection in coordination games.

Keywords: Coordination games, experiments, local interaction, density.

1. Introduction

In the literature of game theory, a large number of studies have explored the equilibrium selection problem in coordination games from both theoretical and empirical perspectives. One leading theoretical result is Harsanyi and Selten (1988)'s two selection principles; payoff dominance and risk dominance. The payoff dominance is the equilibrium in which all players get a higher payoff than in any other equilibrium. The concept of the risk dominance can be interpreted as that playing a certain strategy is riskier than playing others given the underlying strategic uncertainty of the game. Of course, the risky strategy may support the payoff dominant equilibrium. In this case, a tradeoff between risk and return emerges, and all players may not be able to explicitly coordinate their strategies to the payoff dominant equilibrium. When this occurs, a coordination failure arises[1)].

While Harsanyi and Selten (1988) argue that the payoff dominance is more forceful than the risk dominance in the equilibrium selection, a number of experiments show that subjects often choose the risk dominant strategy under various conditions. This fact indicates that we still have the need for reevaluating which of these two principles is more important in the play of coordination games.

In the experimental study of Van Huyck, Battalio, and Beil (1990), they used Bryant (1983)'s model of coordination games with Pareto-ranked multiple equilibria. For seven sessions of a group consisting 16 or 14 subjects, they observed consistent pattern of the coordination failure. In the first round choices of subjects were relatively dispersed and a considerable fraction of subjects did choose the payoff dominant strategy. However, most of them changed their choices to the risk dominant strategy as the rounds went on, and subseqrently 72% of the subjects chose the risk dominant strategy in the last round. On the other hand, when subjects played the same game within a fixed group of 2 subjects, about 94% of them chose the payoff dominant strategy in the last round. These two contrasting results indicate that difference in the number of players may affect the dynamics of equilibrium selection in coordination games.

In Cooper, DeJong, Forsythe, and Ross (1992)'s experiment, 11 subjects played the 2x2 Pareto-ranked coordination game. In each round subjects were randomly paired within the 11-subject group and played the game with a sequence of opponents. Each subject played with the 10 opponents twice, but he or she could not observe the identity and past plays of the opponents. In this sense, this experimental setting was a series of one-shot games. Cooper et al. reported that the coordination failure certainly arose. For the last 11 rounds, they found that 97% of the play occurred at the risk dominant equilibrium while there was no observation of the payoff dominant equilibrium. Comparing this two-player random matching procedure to the two-player fixed paring of Van Huyck et al. (1990)'s experiment, we can say that the difference of the matching protocol may affect the equilibrium selection.

On the other hand, the coordination on the payoff dominant equilibrium can be facilitated by the preplay communication even in a random pairing. In another treatment of Cooper et al. (1992)'s experiment, each of the matched two subjects could send a costless and non-binding message about which strategy they would choose in the subsequent game to their opponents. In the 2x2 symmetric coordination game with Pareto-ranked multiple Nash equilibria, this type of communication worked effectively in overcoming the coordination failure. During the last 11 rounds, over 90% of the outcomes were in the payoff dominant equilibrium, which was extremely higher than that observed in the no-communication treatment.

In experimental analysis with local interaction structures, Keser, Ehrhart, and Berninghaus (1998) compared two different interaction structures: three-player fixed group interaction and three-player one-dimensional local interaction. In the fixed interaction, seven of eight groups coordinated on the payoff dominant equilibrium within a few repetitions. On the other hand, in the local interaction structure, all eight groups converged to the risk dominant equilibrium. Berninghaus, Ehrhart, and Keser (2002) ran an experiment using the local interaction with circle and lattice which is similar to our experiment and found that subjects in the local interaction structures tended to choose the risk dominant strategy compared to non-spatial interaction structures.

To summarize, what we know from past experiments is that the number of subjects in a session, the matching protocol, the preplay communication, and the configuration of the local interaction structures may affect the dynamics of equilibrium selection.

In this paper, followed by these empirical results, we examine the equilibrium selection problem in coordination games with local interaction structures. Especially, our experiment is an extension of Berninghaus, Ehrhart, and Keser (2002)'s analysis in the sense that we reevaluate the local interaction structure by categorizing the density, rather than the size of neighbors or its spatial configuration *per se*, and investigate the dynamics of equilibrium selection and the spread situation of the risk dominant strategy.

Through a series of experiments, we observed that (1) the proportion of risk dominant strategy is higher in less dense interaction structures than in more dense interaction structures in the long run, (2) the speed of convergence to the risk dominant equilibrium is faster in less dense interaction structures than in more dense interaction structures, and (3) the spread of the risk dominant strategy occurs earlier in less dense interaction structures than in more dense interaction structures. These findings indicate that not only factors which were observed in past experiments, but the density of local interaction structure also matters in equilibrium selection in coordination games, which is the main contribution of this paper to the related literature.

The remainder of this paper is organized as follows. Section 2 discusses the analytical framework used in experiments, section 3 explains experimental design, section 4 presents the results of experiments, statistical analysis, and its implication, and section 5 concludes.

2. Analytical Framework

2.1 Coordination Game

The payoff matrix we used in the experiment is shown in table 1. Each player chooses a strategy $s \in \{X, Y\}$.

		Player 2	
		X	Y
Player 1	X	45,45,	35,15
	Y	15,35	50,50

Table 1 Coordination game

This game has two Nash equilibria in pure strategy, (X,X) and (Y,Y). The (Y,Y) equilibrium is payoff dominant equilibrium in the sense that both players get a higher payoff than (X,X). (X,X) equilibrium is risk-dominant equilibrium because it satisfies the criterion of risk dominance of Harsanyi and Selten (1988) as $(45-15)^2 > (50-35)^2$.

2.2 Local Interaction Games

In the local interaction structure, each player interacts with his or her immediate neighbors. Let

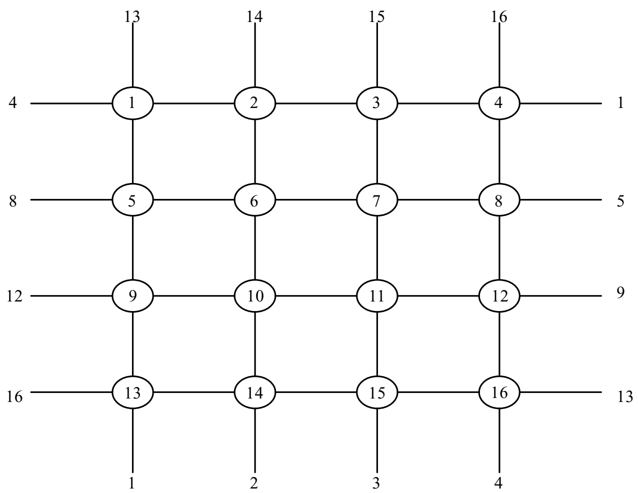


Figure 1 Interaction on 4-neighbor lattice

$\{1,2,...,i...,n\} = N$ be the set of players. Also, let $\Gamma(i)$ be the set of i's neighbors who are linked with player i directly by the line. For example, the interaction structure illustrated in figure 1 has sixteen players (N =16) and each player has 4 immediate neighbors ($\#\Gamma(i) = 4$).

In this case, player 1 located in the leftmost-top circle interacts with four neighbors, namely players 2, 5, 4, and 13. Each player plays the coordination game in table 1 with four neighbors. Note that there is an overlap in neighbors' relationship, that is, player i's neighbors also have three other neighbors except i.

Player i's payoff u_i is determined by his or her own strategy and the distribution of neighbors' strategies. In experimental sessions, we use the following 'average' payoff function as in Berninghaus, Ehrhart, and Keser (2000)

$$u_i(s_i, \{s_j\}_{j\in\Gamma(i)}) = \frac{1}{\#\Gamma(i)} \sum_{j\in\Gamma(i)} G_i(s_i, s_j), \tag{1}$$

where G_i (s_i, s_j) is the payoff function of the coordination game illustrated in table 1.

2.3 Cohesion

We consider the density of the interaction structures among the players. As a measure of the density of interaction, we use the notion "cohesion (Morris 2000)". Cohesion is "a measure of the relative frequency of ties among group members compared to non-members (Morris 2000, p64)". Therefore, if a player in a social group I mostly interacts within the group, such group is "high cohesive", on the other hand, if a player in the group I mostly interacts outside the group, such group is "low cohesive". For a social group I, the more interactions within the group, the more strong ties among the members are.

Given the interaction structure, let I be an arbitrary subset of N[2]. Now, let $\pi[I \mid i]$ be the proportion of i's neighbors who are in group I, i.e.,

$$\pi[I \mid i] = \frac{\#(I \cap \Gamma(i))}{\#\Gamma(i)} \tag{2}$$

Then, we use the next definition.

Definition (Morris 2000)

The cohesion of group I is the smallest π such that each player in I has at least proportion π of his or her interactions within I, i.e., group I is p-cohesive if $p = \min^{i\in I} \pi[I \mid i]$.

Under the measure of cohesion, the density of local interaction structure increases in order of the value of cohesiveness. According to the levels of cohesiveness, we conducted a series of experiments by using the following four different interaction structures.

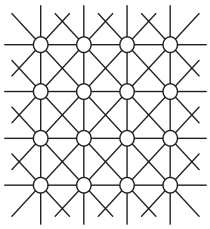
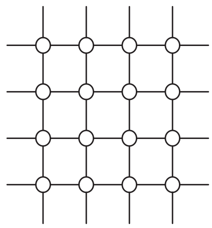
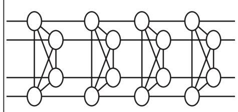
	(A) Uniform	(B) 8-neighbor lattice	(C) 4-neighbor lattice	(D) Region
Number of subjects	16	16	16	16
Number of neighbors	$\#\Gamma(i)=15$	$\#\Gamma(i)=8$	$\#\Gamma(i)=4$	$\#\Gamma(i)=5$
Cohesive-ness	1/15-cohesive	5/8-cohesive	3/4-cohesive	4/5-cohesive
Number of sessions conducted	18	6	6	6
				

Table2 Four interaction structures

In Uniform, each subject interacted uniformly with 15 other subjects[3]. In 8-neighbor lattice, each subject was situated on the lattice and interacted with 8 other subjects who were immediate neighbors[4]. In 4-neighbor lattice, each subject is again situated on the lattice and interacted with 4 other immediate neighbors[5]. In Region, the population was divided into four "regions" consisting of four subjects. Each subject in a region interacted with every other subject in that region. The regions were arranged in a line and each subject also interacted with one subject in each neighboring region[6]. Comparing each value of cohesiveness, the density of local interaction structure increases as (A) Uniform, (B) 8-neighbor lattice, (C) 4-neighbor lattice, and (D) Region in order.

3. Experimental Design

We conducted a series of experiments categorized by four different interaction structures. 16 subjects participated in each experimental session.

In an experimental session, the respective structure of the game was repeated 15 times by the same subjects. In each of 15 rounds, subjects chose strategy X or Y. Subjects' payoffs were determined by their own choices and the distributions of the neighbors' choices. Their neighbors' payoffs were determined by neighbors' own choices and the distributions of the neighbors' neighbors' choices.

We conducted a total of 12 experiments and 3 sessions were run in each experiment by using the ABA crossover experimental design. The reason why we employed the ABA crossover is that we intended to exclude subjects' learning effects in lasting several sessions within one experiment. For example, in experiment 1 we conducted 15 rounds (A) Uniform followed by 15 rounds (B) 8-neighbor lattice and finished with 15 more (A) Uniform, and used the complementary (B) (A) (B) sessions in experiment 2. Then, the difference observed in overall sessions between treatments (A) and (B) would indicate the effect of different interaction structures (The actual order of sessions conducted in each experiment is shown in the 1st and 2nd columns in tables 3-6).

Subjects had complete information about the game in the sense that they knew each subject's strategies and the payoff function. However, subjects did not have perfect information about the entire history of past plays[7]. Instead, after each repetition, subjects were informed about their own choices and the distributions of their neighbors' choices in the round just finished. They were not informed about the identity of the neighbors, their choices, nor their neighbors' neighbor's choices. For the local interaction structure, subjects were not informed about the actual interaction structure, but informed about the number of neighbors with whom they interacted in each session and also informed about the fact that their neighbors also interacted with their own neighbors.

Subjects were recruited from undergraduate students at Keio University. A total of 192 subjects participated in the experiment with no duplication. Subjects were seated at the computer terminal separately. They received the written instructions, which were also read aloud by the experimenter. After the instructions, they were required to fill out the quiz in order to verify whether they understood the rules of the game, the payoff function, and the matching protocol with their neighbors in each session. After all subjects submitted correct answers, the experiment began. During the experiment, any kinds of communication among the subjects were not allowed.

The experiments were computerized by using UNIX workstation. On the screen at each computer terminal, subjects could see the payoff table and information about the previous round including their own choices, the distributions of their neighbors' choices, and the payoffs to the subjects. The choices of all subjects were sent to a server that computed the distribution of the choices and payoffs to each subject. After receiving updated information about the previous round, subjects went on to the next round.

Subjects' payoffs were determined by the sum of their payoffs in all 3 sessions. Payoffs were calibrated to produce average earnings of about 2000 yen in each experiment. The actual average, minimum, and maximum payments realized in experiment were 2090 yen, 760 yen, and 2650 yen respectively. Each experiment took about 80 minutes.

4. Results

(A) Uniform						
Experiment (sessions conducted)	Session	Percentage of X 1^{st} round	Percentage of X All rounds	Converged to	Number of rounds before converging to an Eq.	Percentage of Optimal choice[8)]
1(ABA)	1	87.5	97.5	X	5	98.2
1(ABA)	3	68.8	96.3	X	3	98.2
2(BAB)	2	81.3	97.5	X	4	94.6
3(ACA)	1	81.3	93.8	X	5	89.7
3(ACA)	3	68.8	88.3	X	13	91.0
4(CAC)	2	81.3	91.3	X	13	88.8
5(ADA)	1	75.0	96.3	X	3	88.4
5(ADA)	3	93.8	99.2	X	3	92.9
6(DAD)	2	93.8	93.8	X	6	97.8
7(ABA)	1	87.5	95.4	X	2	95.1
7(ABA)	3	87.5	92.9	-	-	95.1
8(BAB)	2	93.8	92.9	-	-	92.4
9(ACA)	1	87.5	94.6	X	9	99.6
9(ACA)	3	87.5	92.1	X	6	93.8
10(CAC)	2	75.0	87.9	-	-	96.0
11(ADA)	1	75.0	87.5	-	-	98.7
11(ADA)	3	81.3	92.1	-	-	93.3
12(DAD)	2	81.3	94.2	X	5	92.9
Average		82.6	93.5			94.3

Table 3 Result of (A) Uniform

(B) 8-neighbor Lattice						
Experiment	Session	Percentage of X 1^{st} round	Percentage of X All rounds	Converged to	Number of rounds before converging to an Eq.	Percentage of Optimal choice
1	2	68.8	93.8	X	5	95.5
2	1	75.0	94.2	X	7	95.5
2	3	87.5	92.5	-	-	84.8
7	2	81.3	90.0	X	3	92.9
8	1	87.5	96.3	X	6	90.6
8	3	68.8	83.8	X	11	96.9
Average		78.1	91.8			92.7

Table 4 Result of (B) 8-Neighbor Lattice

(C) 4-neighbor Lattice						
Experiment	Session	Percentage of X 1st round	Percentage of X All rounds	Converged to	Number of rounds before converging to an Eq.	Percentage of Optimal choice
3	2	68.8	12.9	Y	7	90.6
4	1	68.8	74.2	-	-	88.8
4	3	81.3	84.2	X	12	92.0
9	2	93.8	92.1	X	9	94.6
10	1	87.5	94.2	X	7	84.4
10	3	68.8	84.2	-	-	84.4
Average		80.2	73.6			89.1

Table 5 Result of (C) 4-Neighbor Lattice

(D) Region						
Experiment	Session	Percentage of X 1st round	Percentage of X All rounds	Converged to	Number of rounds before converging to an Eq.	Percentage of Optimal choice
5	2	62.5	8.3	Y	4	91.5
6	1	68.8	10.4	Y	4	88.8
6	3	75.0	68.8	X	15	87.1
11	2	87.5	85.4	X	8	86.1
12	1	93.8	92.1	-	-	85.3
12	3	81.3	56.3	co-existence	-	92.0
Average		78.1	53.6			88.5

Table 6 Result of (D) Region

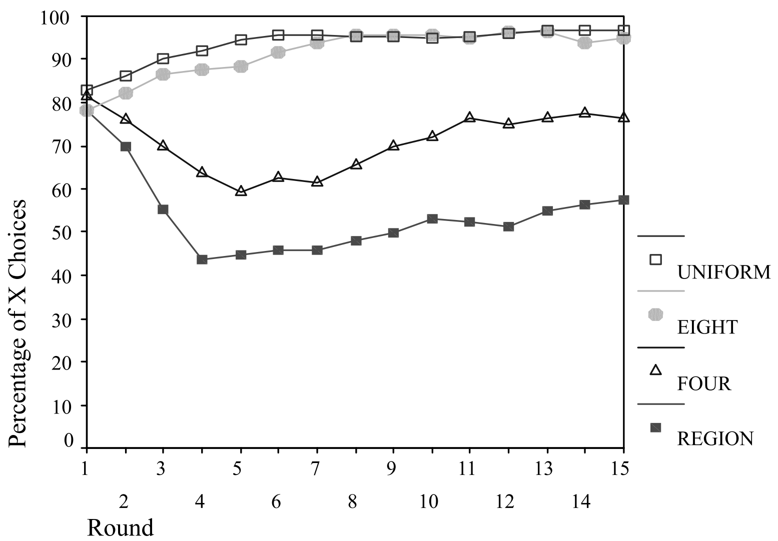


Figure 2 Distribution of X choices

Results are presented in tables 3-6.

4.1 Learning effects

We conducted three sessions in one experiment. If subjects learn converging behavior from the previous session, their choices in the first round may be affected by those in last several rounds in the previous session. When this occurs, the distribution of choices in the first round can vary from one session to another. We need to check whether there is a biased distribution of choices in the first round for each interaction structure. The Kruskal-Wallis test cannot reject the null hypothesis of equal distribution of X choices in the first round for each interaction structure[9]. Therefore, we can say that there is no learning effect within a session[10].

4.2 Convergence to Nash equilibrium

In (A) Uniform, 13 out of 18 sessions (72.2%) converged to X equilibrium at least once within 9 rounds. 5 sessions did not converge to any equilibrium. No session converged to Y equilibrium. In (B) 8-neighbor lattice, 5 out of 6 sessions (83.3%) converged to X equilibrium within 11 rounds. The rest one session did not converge to any equilibrium. In (C) 4-neighbor lattice, 3 out of 6 sessions (50.0%) converged to X equilibrium within 12 rounds and 1 session (16.7%) converged to Y equilibrium in 7 rounds. The rest two sessions did not converge to any equilibrium. In (D) Region, 2 out of 6 sessions (33.3%) converged to X equilibrium and 2 sessions (33.3%) converged to Y equilibrium. One session converged to the co-existence of equilibria in which 8 subjects choose X and the remaining 8 subjects choose Y. The rest one session did not converge to any equilibrium.

We can say that the coordination failure is observed in all interaction structures while convergence to the payoff dominant equilibrium is observed in only three sessions where more dense interaction structures were used.

4.3 The density of interaction structure and the distribution of X choices.

We investigate whether subjects' choices differ in each interaction structure. The overall distributions of choices in 18 sessions for (A) Uniform, 6 sessions for (B) 8-neighbor lattice, (C) 4-neighbor lattice, and (D) Region are shown in figure 2. We can observe that the proportions of X choices decrease as the cohesion of the interaction structure increases. We use the Kruskal-Wallis test to determine whether this observed difference is statistically significant for each round. The results of the tests are shown in table 7. For rounds 1 and 2, we cannot reject the null hypothesis of no difference, whereas for rounds 3-15 the differences in the proportions of X choices are statistically significant. In addition, the difference is also statistically significant for the entire 15 rounds.

Round	1	2	3	4	5	6	7	8
Chi-square	1.603	4.301	13.351	18.359	20.836	20.011	15.564	13.359
Df	3	3	3	3	3	3	3	3
P-value	0.659	0.231	0.004	0.000	0.000	0.000	0.001	0.004
Round	9	10	11	12	13	14	15	Entire 15 rounds
Chi-square	9.362	7.978	7.965	12.593	10.723	10.594	7.879	15.202
Df	3	3	3	3	3	3	3	3
P-value	0.025	0.046	0.047	0.006	0.013	0.014	0.048	0.002

Table 7 Results of the Kruskal-Wallis test
for the equal proportion in distribution of X choices

Thus, we can say that the proportion of X choices is higher in less dense interaction structures than in more dense interaction structures in the long run[11)].

4.4 Spread of risk dominant strategy

Recall that in the experimental sessions subjects were not informed about the entire history of their neighbor's past plays, but were informed about the distribution of neighbors' choices in the round just finished. If subjects react to their neighbors' choices in the previous round, their reaction rule would be the myopic best reply which is often employed in theoretical model such as in Ellison (1993) and Young (1998). The percentage of myopically optimal choices in each session is about 85%-98% (shown in 7th column in tables 3-6) of which difference among four interaction structures is not significant (Chi-square 4.006, Df 2, p-value 0.135).

Given the payoff function (1) if there are more than 1/3 neighbors who choose X, then player i should choose X. As tables 3-6 indicate, the distribution of X choices in the first round was above 1/3 for all sessions. So, given the fact that the majority of subjects respond to the neighbors' choices in the previous round optimally and the distribution of the X choices in the first round is above 1/3, one might think that X choices should have spread to the whole population in all sessions. However, not all sessions converged to X equilibrium, but some sessions did converge to Y equilibrium in more dense interaction structures. In order to consider this anomalous fact, we will investigate the speed of convergence to X equilibrium and the spread dynamics of X strategy.

6th column in tables 3-6 reports the rounds before a session converged to X or Y equilibrium. We can see that subjects in less cohesive interaction structures converged to X equilibrium quickly while those who in more cohesive interaction structures converged to X equilibrium slowly. The Kruskal-Wallis test rejects the null hypothesis which claims that the speed of convergence to X equilibrium is same for all interaction structures (Chi-square 8.781, DF3, p-value 0.032). Therefore, we can say that the speed of convergence to the risk dominant equilibrium is faster in less dense interaction structures than in more dense interaction structures.

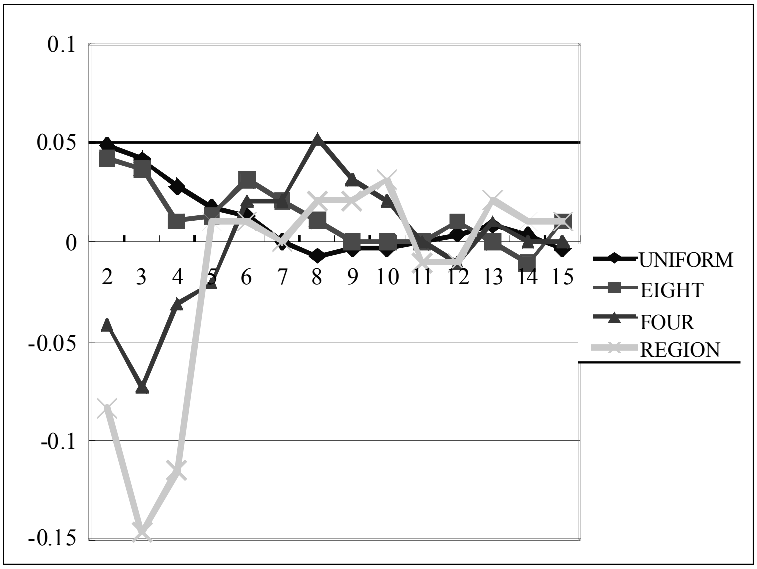


Figure3 Average increase rate of X choices between each round

Figure 3 illustrates the average increase rate of X choices between each round. We can see that it is higher in (A) Uniform and (B) 8-neighbor lattice than in (C) 4-neighbor lattice and (D) Region for the beginning of the session, it is higher in (C) and (D) than in (A) and (B) for the middle of the session, and there is no obvious difference among four interaction structures toward the end of the session. We use the Kruskal-Wallis test to determine whether this difference is statistically significant by dividing a session into three parts, beginning (rounds 2-6), middle (rounds 7-11), and end (rounds 12-15) of the session. The null hypothesis of no difference is rejected in the beginning of the session (Chi-square 12.100, DF 3, p-value 0.007) and the middle of the session (Chi-square 8.253, DF 3, p-value 0.041), while it is not rejected in the end of the session (Chi-square 1.861, DF 3, p-value 0.602). Therefore, we can say that the spread of the risk dominant strategy occurs earlier in less dense interaction structures than in more dense interaction structures.

For an interpretation of the results above, we need to focus on the distribution of neighbors' strategies each subject faces. In more dense interaction structures, the distribution of neighbors' strategies may vary from one location to another depending on the spatial strategy configurations, whereas in less dense interaction structures, it is always (almost) uniform among the whole population. For example, some fraction of subjects in more dense interaction structures would recognize that the proportion of the risk dominant strategy is less than 1/3 as long as less than 1/3 of their neighbors choose the risk dominant strategy even when the proportion in a whole population is more than 1/3. Under the same strategy configuration, however, subjects in less dense interaction structures would recognize that it is more than 1/3 because they interact uniformly with other subjects in a population. When this situation realizes, subjects in more dense interaction structures may choose the payoff dominant strategy because they do not face the global contagion of the risk dominant strategy, while those who in less dense interaction structures would choose the risk dominant strategy because they are confronted with the fact that the majority of the population choose it. As this process works, the risk dominant strategy spreads slowly to the whole population in more dense interaction structures, whereas it does quickly in less dense interaction structures, resulting in the different spread dynamics of the risk dominant strategy and the different speed of convergence to the risk dominant equilibrium. In addition, if the spread of the risk dominant strategy is suppressed enough and the payoff dominant strategy survives for the time being, sessions which do not converge to any equilibrium, or those which converge to the payoff dominant equilibrium may be possible to exist.

The crucial point of the interpretation above is the non-uniformity on the distribution of neighbors' strategies in more dense interaction structures. It plays an important role in the equilibrium selection because it prevents the contagion of the risk dominant strategy[12].

5. Conclusion

In a series of experiments, we observed that the density of the local interaction structure matters in the dynamics of equilibrium selection as follows. Although the coordination failure is observed in all interaction structures, the proportion of the risk dominant strategy is higher in less dense interaction structures than in more dense interaction structures. The speed of convergence to the risk dominant equilibrium is faster in less dense interaction structures than in more dense interaction structures. In addition, the spread of the risk dominant strategy occurs earlier in less dense interaction structures than in more dense interaction structures.

For the spread of the risk dominant strategy, Ellison (1993) showed that players converge to the socially optimal equilibrium faster in the local interaction structure than in the uniform interaction structure under the game in which the risk dominant strategy supports the payoff dominant equilibrium. However with our payoff function where the risk dominant strategy does not support the payoff dominant equilibrium, the majority of sessions did not converge to the payoff dominant equilibrium. This contrasting observation casts us an intriguing question about the relationship between the local interaction structures and the payoff function, and we hope further research both from theoretical and empirical perspectives.

Notes

1) Coordination games are applied to a number of recent models in the literature of macroeconomics and industrial organization including network externalities (Katz and Shapiro (1985)), team production (Bryant (1983)), search (Diamond (1982). In addition, they are used to analyze the evolution of social convention from the socio-economic perspective. For general reference, see Cooper (1999) and Young (1998)
2) In the original paper of Morris (2000), the model assumes infinite population and treats each interaction structure given. Thus, any arbitrary subset of his model has the property of each interaction structure. In order to apply this original definition to our model of a small finite population, any arbitrary finite subset I must also hold the property of each local interaction structure.
3) Uniform does not have the locality and each player i has one-to-one interaction with every other 15 players. Given this interaction structure, an arbitrary subset must be a pair of player i and some other player j. Therefore, $\#(I \cap \Gamma(i)) = 1$ and $\pi = 1/15$.
4) In order to apply the definition of Morris directly, suppose infinite population version of 8-neighbor lattice. Then, the way of taking a subset while keeping the property of 8-neighbor lattice in any subset is dividing the whole population vertically or horizontally. Thus, possible subset we can take in our interaction structure with a finite population is a vertical or horizontal rectangle consisting of 4, 8, or 12 members. Then a member of I located on the boundary of I has the minimum proportion $\pi = 5/8$ because he or she interacts five members within I among eight interactions. On the other hand other members of I located inside the subset I (not boundary of I) has $\pi = 1$ because all of their neighbors are included in I.
5) In 4-neighbor lattice, the way of taking a subset is dividing population vertically or horizontally. Thus possible subset is a vertical or horizontal rectangle consisting of 4,8,or 12 members. Therefore, a member of I located on the boundary of I has the minimum proportion $\pi = 3/4$.
6) Suppose that the four-member region connects each other infinitely. Then the way of taking a subset while keeping the property of the 'region' structure is dividing the four lines which are linked with each region. A member of I located on the boundary of I has the minimum proportion $\pi = 4/5$.
7) Of course, subjects may remember the entire history of their past plays. We cannot exclude such possibility.
8) Optimal choice is to play X if more than 1/3 neighbors have played X and to play Y otherwise in the previous round.
9) The results of the Kruskal-Wallis test for the equal distribution of X choices in the first round for each interaction structure are shown in the table below.

	(A)Uniform	(B) 8-neighbor lattice	(C) 4-neighbor lattice	(D) Region.
Chi-square	13.007	5.036	4.598	5.001
Df	15	5	5	5
p-value	0.731	0.421	0.467	0.419

10) As we can see in tables 4-7, the distribution of choices in the first round varies from 62.5% to 93.8%. However, these differences in the distribution of choices in the first round seem to be offset due to ABA crossover treatment.
11) More precisely, the difference in the proportion of X choices is statistically significant after round 3.
12) This is also consistent with the theoretical result of Morris (2000) in the sense that the "Maximal contagion occurs when local interaction is sufficiently uniform (p57)".

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