Strategic Interactions in Networks: An Experimental Approach*

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Abstract

This paper experimentally investigates how characteristics of a network influence the equilibrium selection and individual behavior in a public goods games played on networks. Bramoullé et al. (2014) shows that the equilibrium of the public good game can be characterized according to the simple characteristics of the underlying network. Precisely, guided by the theoretical predictions from Bramoullé et al. (2014), I explore whether underlying networks can predict equilibrium selection and subjects' behavior in the controlled laboratory. The data implies that 1) there is some aspect in which agents' actions are consistent with the claims of Bramoullé et al. (2014), but 2) degree distribution of the network are more fundamental in influencing behavior and equilibrium selection. Specifically, I show that asymmetry in degree distribution inside of a network is a major factor that explains the actions of individual economic agents.

Keywords: Network, local public good games, experiment, strategic substitute
JEL classification: C91, D00, D81, D85, C72, H41

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1 Introduction

Although the traditional economics model yields a number of powerful insights about implications of rational decisions for resource allocation and welfare, it seems not to be able to explain some tenacious empirical regularities, like persistent inequalities, patterns of technology diffusion, or sociological phenomena like segregation of neighborhoods. In the recent past the traditional model of human activities, occurring within markets with anonymous and centralized interaction, has been further developed to also take into account the network in which the actors are embedded. In fact, the economics of social networks has gained increasing attention in the past decade, manifested in an explosion of game theoretical models on formation, stability, efficiency of networks. In the real world, there are a wide variety of settings where social network play a role; this leads to an almost endless set of interesting avenues to investigate (Jackson (2005)). As predictions from models proliferate, I test these trend of network theories to determine whether they truly understand the behavior of economic agents.

I conduct the first of such a test for the well-known network model of Bramoullé et al. (2014). They are motivated by their previous work Bramoullé and Kranton (2007) which made a first set up for local public good games in which individuals are part of networks and invest the contribution of public goods. Model of Bramoullé et al. (2014) is characterized by two main features: first, agents are embedded in a fixed network. second, agents' payoffs are directly affected by their partners' actions only. In Bramoullé et al. (2014), they suggest theory explaining the impact of network structure to the equilibrium profile. Their set-up is quite similar with Bramoullé and Kranton (2007). However, they introduce a "decay" factor between agents, which means that there is a smoothed impact of each players' action to their connected neighbors. Their main result is that the structure of network can affect the amplification of the agents' actions. Their analysis leads to these insights. First when the global networks structure sufficiently amplifies the strategic substitute of contributions (override the decay factor between agents), networks can lead to specialization, and that in any network there is a specialized equilibrium[1]. Second, when the global networks structure cannot amplify the strategic substitute of action between agents, then the network has a unique and active Nash equilibrium[2]. These theoretical results show that the network structure is critical to equilibrium prediction and individual behavior.

I designed an experiment to explicitly address and identify the impact of network structure to the equilibrium selection and behavior of agents described in Bramoullé

[1]Specialized equilibrium is an equilibrium where some contribute fully, while others free-ride on equilibrium.

[2]Active equilibrium is an equilibrium where all agent have positive contribution

et al. (2014). The main results and hypotheses of this paper are followings: First, this paper test whether individuals are indeed able to coordinate on equilibria prediction of Bramoullé et al. (2014). This paper finds that there is no clear statistically significant changes in equilibrium selection described in Bramoullé et al. (2014). However, this paper finds some changes in individual behavior which implies that the treatment effect is not strong enough to changes the selection of equilibrium. Second, this paper finds that equilibrium selection is strikingly depend on other network structure, especially, degree distribution. Specifically, when there is asymmetric degree distribution between agents, agents are coordinate on specialized equilibrium more frequently by following their degree. Possible mechanism explaining this behavior is focal point (Schelling (1960)). This results shows that agents' equilibrium selections are strongly correlated with their degree distribution which is not described in Bramoullé et al. (2014). Third, I test other network characteristics which have been described as important for individual behavior in other literature. By using this network characteristics, I find significant changes in equilibrium selection.

2 Previous Literature

There are large literature regarding experiment and theory regarding strategic choice under network. The first group of experiments which have interest on network structure and equilibrium selection. Keser et al. (1998) present the first experiments that consider the role of the global structure of networks in coordination games. In their experiment, agents are located on a circle, and on a two-dimensional lattice, and while the size of an agent's neighborhood remains constant across treatments, the neighborhood structure differs.Rosenkranz and Weitzel (2012) is the first paper about relation between individual choice in public good games and network. They made 7 networks variation under theoretical basis of Bramoullé and Kranton (2007) to see the effect of equilibrium selection. However, they find coordination failure to the equilibrium. They adopted continuous action space, therefore, on average less than 3% of samples can coordinate on the equilibrium even though they lessen the concept of equilibrium. It is hard to see the equilibrium selection issues. Rosenkranz and Weitzel (2012), however, find evidence that network structure affect to free-riding incentive of individuals. They find that as average degree increases, the free-riding incentive increases significantly. Another literature Charness et al. (2014) find the informational uncertainty and equilibrium selection on networks. They find that stable equilibrium is selected most frequently. They examined also that uncertainty about network structure seriously harms efficiency of contribution.

A second group of experiments focuses on cooperation on networks. Kirchkamp and

Nagel (2007) investigated the effect of local interaction on learning and cooperation in repeated prisoners' dilemmas. They compare interaction neighborhoods of different size and structure, and observe choices under different information conditions. Interestingly their experimental findings contradict the theoretical predictions of naive imitation models. Cassar (2007) studies coordination games and prisoners' dilemmas in local, random and small-world networks. She finds a tendency for coordination on the payoff-dominant equilibrium on all three networks. Her results suggest that local interactions do cause faster coordination than random interactions, but do so on the payoff-dominant equilibrium rather than on the risk-dominant equilibrium. For the cooperation game, she finds insufficient cooperation on all three networks. Average cooperation is found to be lower in small-world networks than in random and local networks. Pla et al. (2009) conducted an experiment to estimate subjects' bounded rationality in a network game with unique equilibrium predictions. They find evidence that subjects are boundedly rational in the sense that they only consider their neighborhood of distance two.

A third line of experiments investigates individual incentives for network formation. Goeree et al. (2009) analyze a pure network formation game and find that equilibrium predictions fail completely with homogeneous agents, while heterogeneity fosters the formation of an efficient structure over time. Corten and Buskens (2010) find some evidence that subjects will form networks that lead to play of the efficient Nash equilibrium in a simple coordination game, if they can choose their network partners themselves. Burger and Buskens (2009) test whether formation processes lead to predicted stable outcomes in different simple settings and find largely support of the theory. Van Dolder and Buskens (2009) find varying evidence for effects of social motives on network formation process.

Results of the experiments so far have shown that network configurations have important effects on economic outcomes, such as the convergence towards equilibrium selection, coordination, and network formation. This paper contribute to this research by focusing on the effect of network configurations on equilibrium selection while conducting experiment on the basis of Bramoullé et al. (2014).

3 Theoretical Background

In this section, I briefly summarize the model and findings of Bramoullé et al. (2014) and bring the theory to a testable hypothesis. Suppose that there are N agents who are located in fixed networks and let $x_i \geq 0$ denote agent i's level of actions while x_{-i} denote the actions of all agents other than i. Agents play the simultaneous local public good games. Agents are arranged in a network which is represented by an undirected network g, $g_{ij} \in \{0,1\},\ g_{ij} = g_{ji},\ for\ all\ i,j \in N$. By collecting this link information we can construct the $n \times n$ adjacency matrix G. A payoff parameter $\delta \geq 0$ measures how much i and j affect each others' payoffs given they are connected. Each agent receives benefit from their neighbors' action given network structure and her marginal cost to her own contribution is constant. Therefore, agent i's payoff can be represented as $u_i(x_i, x_{-i}, \delta, G) = b(x_i + \delta \sum g_{ij}x_j) - \kappa_i x_i \ with \ b^{'} > 0, b^{''} < 0$. They assume $b^{'}(0) > \kappa_i$ to avoid trivial cases. It is straightforward to show that agents have a linear best-reply form as follows.

$$f_i(x_{-i}, \delta, G) = \begin{cases} \bar{x}_i - \delta \sum_j g_{ij}x_j & if \quad \delta \sum_j g_{ij}x_j < \bar{x}_i \\ 0 & if \quad \delta \sum_j g_{ij}x_j \geq \bar{x}_i \end{cases}$$

The amount of action between neighbors are strategic substitutes ; the more action an agent take, the less incentive neighbors' take. In Nash equilibrium, all agents in the network take the linear best reply from described as above. The action profile of a network is active when the amount of actions are strictly positive for all agents. This means that there is no free-rider in a network. The action profile in a network is specialized when the action of agents in a network is either 0 or $\bar{x}$. This suggests specialization between agents. Some agents fully contribute to the public goods, while some agents do not contribute and free ride their contribution. They suggest one simple measure to capture the strategic substitute which represent as the lowest eigenvalue of adjacent matrix. As the absolute value of lowest eigenvalue increases, the structure of network amplifies well the substitute between agents. This can be interpreted as the incentive of free-riding increases because of network structure.

The first hypothesis is about the main result of Bramoullé et al. (2014). In their theory, as the lowest eigenvalue increases, a specialized equilibrium profile is added to the equilibria set. Therefore, the prediction of equilibrium selection is that agents coordinate on the specialized equilibrium profile more easily Rosenkranz and Weitzel (2012), show that the frequency of converging specialized equilibria is less than 0.5% even though the specialized equilibria is in the theoretical prediction. This means that agents have a tendency to avoid the specialized equilibrium. However, they did not control the global and local network characteristics. To test this concern more systematically, I controlled global and local characteristics except the lowest eigenvalue, and I made the following first hypothesis.

(H.1) As the lowest eigenvalue increases, individuals are able to coordinate on the corresponding specialized equilibria.

The second hypothesis is about the role of δ. Different from the $|\lambda_{min}|$, δ is related more directly to the agent's payoff.Rosenkranz and Weitzel (2012) and Charness et al. (2014), did not include δ treatments. From a theoretical perspective, as δ increases, the incentive to take a free-ride on the other player's contributions will increase. Bramoullé et al. (2014) show that the increase of δ is interpreted as the magnitude of amplifying the strategic substitute between players increases. This effect is the same as an increase of $|\lambda_{min}|$ in theoretical perspective. Therefore this paper tests whether the equilibrium selection changes following a change of δ.

(H.2) As δ increases, Individuals are able to coordinate on the corresponding specialized equilibria.

The third hypothesis is stated to capture the behavioral aspect in an equilibrium selection. In Bramoullé and Kranton (2007) made statement about the asymmetry of degree distribution in networks : on any core-periphery graph, there exists the following Nash equilibrium: No core agent exerts effort, each peripheral agent exerts effort. These results imply that in a core-periphery network, the specialized equilibrium becomes salient. Therefore, I test the impact of asymmetry of network to the specialized equilibrium selection.

(H.3) In a core-periphery network, individuals are able to coordinate on specialized equilibria more frequently.

The fourth hypothesis is about the average degree of networks. Rosenkranz and Weitzel (2012) find that the contribution decreases as a link is added to the agent. This means that an increase in the average degree also increases the incentive to free-ride. I hypothesized that the behavior of agents are specialized easily when the average degree is higher. Therefore, the specialized equilibria are selected more frequently.

(H.4) As average degree increases, individuals are able to coordinate on the specialized equilibrium more frequently.

4 Experimental Design

4.1 Network games

In the experimental set-up, each agent plays a simultaneous game that is implemented by random positioning and random matching. To prevent people from recognizing the game as a type of repeated game, I recruited 24 people in each session and divide them into groups which is composed of 12 people. Inside each group, people were randomly assigned in each position by every period. 6 individuals were randomly matched in a in a 12 person group to form a connected network g. In the game, individuals' pure strategies at each stage consists of choosing 0,1, or 2. Agents can choose among free-riding action (choose 0), moderate action (choose 1), and full action (choose 2). Payoffs at each period are calculated using the following benefit function.

$$u_i(x_i, x_{-i}, G, \delta) = 1000(x_i + \delta \sum g_{ij}x_j)^{\frac{1}{2}} - 500x_i$$

The above utility function satisfies the assumptions of Bramoullé et al. (2014). The exchange rate of real money is 10 :1. As treatments, I considered a series of 7 combinations of δ and different network structures, as depicted in the following Figure 1. In the figures there are 6 circles and lines. Circles represent the position of players and lines designate when two agents are connected.

$$-Figure 1-$$

The first network characteristic is the lowest eigenvalue of network. Turtle, Circle and Core-periphery network have the same lowest eigenvalue 2, while Wheel network has 3. The second network characteristic is symmetry in degree distribution. Turtle, Wheel, and Circle networks have a symmetric degree distribution which means that all of the agents in the networks have the same number of agents. However, in core-periphery network the degree distribution is asymmetric. There exists core-position players who have more neighbors than the periphery-position. The third characteristic is average degree. Turtle, Wheel and Core-periphery networks have 3 average degrees for all agents, while the circle network has 2 average degrees. The characteristics of each of the networks are given in Table 1.

$$-Table 1-$$

When $\delta \times |\lambda_{min}|$ is greater than 1, there exists multiple equilibria. On the other hand, when $\delta \times |\lambda_{min}|$ is less than 1, there exists a unique equilibrium. More specific equilibrium profiles are shown in Table 2.

$$-Table 2-$$

In Table 2, the equilibrium profile of each of the networks is shown. when $\delta \times |\lambda_{min}|$ is less than 1, there exists a unique equilibrium and active equilibrium which all agents contribute positive amount of contribution in equilibrium. The main hypothesis is captured by the treatment of Wheel, $\delta_{0.35}$ and Turtle , $\delta_{0.35}$. sustain specialized equilibrium, on the other hand, Turtle, $\delta_{0.35}$ cannot sustain the specialized equilibrium. There is unique and active equilibrium only.

As δ increases from 0.35 to 0.75, the equilibria set are multiple and include the specialized equilibrium profile. For example, in Circle network, $|\lambda min|$ is 2. When δ is 0.35, (1,1,1,1,1,1) is unique and equilibrium. While δ is 0.75, (1,1,1,1,1,1) and (2,0,2,0,2,0) are equilibria. This setting is to test the main results of Bramoullé et al. (2014) which means players can coordinate this specialized equilibrium (2,0,2,0,2,0) also as δ increases because the equilibria set include this new profile.

4.2 Procedural details

In total 17 sessions were run at the experimental laboratory at CEBSS at Seoul National University in December 2015 and April 2016. Participating subjects were recruited from an online website that can be only used by Seoul National University students. The procedure during the sessions was same and all sessions, and all sessions are computerized, using a program written with z-Tree (Fischbacher (2007)). 256 subjects participated and were seated in a random order at PCs in a laboratory. Instructions (see Appendix1) were then read aloud and questions were answered in private. Subjects were randomly assigned to groups of size N=12, within each group, subjects were randomly positioned in the network N=6. Throughout the sessions students were not allowed to communicate each other and could not see others' screen. The summary statistics for each network are shown in Table 3.

$$-Table3-$$

In the experiment, each subject played 2 independent sections of experiment. The first section consists of network games where each player makes a decision, the second part is a risk assessment. In the first part, subjects make a decision in a network for 40 periods. For each period, they are assigned to a random position in a network. Their payment is decided by the sum of earnings they earn by each period. This design is a direct translation from the original settings in Bramoullé et al. (2014). During every period, subjects were informed about their position and payoff matrix on the screen and they determined the actions among 0,1, and 2 to take in that period. After each period ended, each player received a detailed feedback about what his/her neighbors chose (not all the players in networks) and payoff at that period. The sequence of treatments for the 17 sessions has been processed by several concerns: I used a random assignment rule in the 12 agents not 6 agents to reduce the probability to match people with each other again. This set-up is crucial to understanding game rules because Bramoullé et al. (2014) assumes simultaneous game with strangers. To prevent the issue regarding an ordering effect, I designed the experiment as between subjects design. Thus, agents selected their choice only in a certain given network and given delta for 40 periods.

5 Empirical Results

5.1 Impact of Lowest eigenvalue

5.1.1 Equilibrium selection

In this section, I compare the equilibrium convergence between (Turtle, $\delta_{0.35}$) and (Wheel,$\delta_{0.35}$). The difference between these two networks is the lowest eigenvalue, whereas all other network characteristics are controlled. The summary of the network characteristics and convergence ratios are presented in Table 4.

$$-Table 4-$$

When $\delta = 0.35$, there is an active unique equilibrium in (Turtle, $\delta_{0.35}$) while (Wheel, $\delta_{0.35}$) has multiple equilibria including the specialized equilibrium ((2,0,2,0,2,0)). To be specific, (1,1,1,1,1,1) is an active equilibrium that is compatible in both networks. However, (2,0,2,0,2,0) is only compatible in the wheel network. This theoretical prediction implies that agents can coordinate on the specialized equilibrium more frequently.

In Table 4, the overall convergence rate in active equilibrium is not different under 5% level between two networks. Regarding specialized equilibrium, in (Turtle,$\delta_{0.35}$) the frequency of choosing (2,0,2,0,2,0) (out of equilibrium path) is 1[3]. in (Wheel,$\delta_{0.35}$) the frequency of choosing (2,0,2,0,2,0) (out of equilibrium path) is 6(2.5%). The overall frequency on the specialized equilibria between (Turtle, $\delta_{0.35}$) and (Wheel, $\delta_{0.35}$) is not different at 5% level. This results shows that agents coordinate on the active equilibrium not specialized equilibrium even though there is a changes in theoretical prediction. This pattern is in line with Rosenkranz and Weitzel (2012). Their results show that in circle which is composed of 4 agents and complete networks, all agents contribute strictly more than 0 which implies active equilibrium in this case.

$$-Figure 2-$$

[3]I checked the out of equilibrium frequency.

Figure 2 checks the equilibrium convergence ratio across periods. In both network, there is an increasing convergence trends as period flows. The correlation between convergence rate and period is 0.254 in Turtle and 0.246 in Wheel which are statistically significant at 1% level in both treatments. They have very same trend of convergence in active equilibrium ratio which is not statistically different at 5% level across first 10 period, period 11 30, and last 10 period. This means that the trend to converge on the active equilibrium is the same for all periods. Second, if we divide the period as 3 parts, there is significant increase on the convergence of the specialized equilibrium which is statistically different at 5% level in the first 10 periods. In (Wheel, $\delta_{0.35}$), the equilibrium convergence on the specialized equilibrium is 7.9% in the first 10 period and last 10 period 0%. This difference is statistically significant at 5% level in the first 10 periods only . This results implies that the convergence to the specialized equilibrium decreases as period goes which means agents learn to coordinate on the active equilibrium.

5.1.2 Individual Behavior

In the previous section, the results shows that people coordinate on the active equilibrium not on the specialized equilibrium. However, the equilibrium convergence is possible only when all 6 agents in the group chose the best response to each other. Therefore, in this section, I check whether the individual behavior of agents between the two networks is different. To verify, define specialized action to mean that 0 (Free-ride) or 2 (full contribution). In theoretical perspective, the individual behavior changes in a more speicalized way because specialized equilibrium is in the theoretical prediction in (Wheel, $\delta_{0.35}$) while not in (Turtle, $\delta_{0.35}$). Figure 3 shows the ratio of choice between the (Wheel, $\delta_{0.35}$) and (Turtle, $\delta_{0.35}$).

$$-Figure 3-$$

Figure 3 shows the contribution across (Wheel, $\delta_{0.35}$) and (Turtle, $\delta_{0.35}$). There are 14.3% decreases those of who select 1(moderate action). This also means that there is increase on the proportion those of who select specialized actions. On average there is a 1.10 contribution in (Wheel, $\delta_{0.35}$) and 1.04 in (Turtle, $\delta_{0.35}$). They are statistically different at 5% level. To test this in a regression table, I set the dependent variable c_{spec} as follows.

$$c_{spec} = \begin{cases} 1 & if \;\; c \in \{0, 2\}, \\ 0 & O.W \end{cases}$$

This dependent variable captures the specialized behavior of agents that is not captured by the equilibrium selection part. Table 5 shows the effect of increased lowest eigenvalue to the specialized actions. The average degree and symmetry in degree distribution is controlled as described in the previous section. Therefore, the wheel network dummy variable demonstrate the effect of lowest eigenvalue on the specialized action. Fixed effect includes period dummies and position dummies. Standard errors are clustered by each individuals.

$$-Table 5-$$

Table 5 shows the effect of the increased $|\lambda_{min}|$ on the specialized behavior. In all specifications, the proportion of agents who chose specialized action increased by about 7% which is significant at the 5% level in the model (1). After controlling for the woman, risk aversion and period fixed effect, there is an 6% increase which is significant at 5% level on the specialized action. Table 5 shows that the specialized action of agents increases in the wheel network. This is consistent with the theory of Bramoullé et al. (2014). These are the first results that find changes of individual behavior caused by global network characteristic after controlling for the local network characteristics. However, this result is too weak to increase the convergence of specialized equilibrium.

5.2 Impact of δ in Networks.

5.2.1 Equilibrium selection

In the previous section, this paper showed the impact of $|\lambda_{min}|$ in the equilibrium selection. In this part, I test the theory related with δ, the payoff decay factor. In theory, δ has an interaction with $|\lambda_{min}|$. This means that from a theoretical perspective, as δ increases, the strategic substitute between agents increase also. This paper have 3 networks variation according to the increase of δ. In Turtle and Circle network, the equilibrium set expands while, Wheel network has the same equilibria set.

$$-Table 6-$$

Table 6 represents the amount of equilibrium convergence in each of the networks. First, regardless of δ, there is a trend to converge to the active equilibrium. In the multiple equilibria case, there is a strong trend to converge to the active equilibrium which is significant at 5% level for all networks. Therefore, the first observation is that agents still coordinate on the active equilibrium even though there is an increase of δ. Second, in all 3 networks there are significant increases in the convergence to a specialized equilibrium which is significant at 1% in Turtle network 5% in Wheel and Circle network. This means that the increased effect of δ is significant in all three networks. Specifically, in Turtle and Circle network, their theoretical equilibrium spans including the specialized equilibrium while Wheel network's equilibrium set remains the same. This prediction implies that the convergence to specialized equilibrium will increase in Circle and Turtle networks.) However, in Wheel network, theoretically we cannot predict what equilibrium will be selected. Empirical evidence shows that there is a significant increase on the converging trends to the specialized equilibrium.

5.2.2 Individual Behavior

This parts is about the individual behavior in each of the networks. First, in the equilibrium selection parts, there is a significant increase in the specialized equilibrium. Figure 4 shows the amount of contribution chosen by agents. In all three networks, there is a significant increases at 1% level on the specialized action as shown in Table 2. This means that like $|\lambda_{min}|$, there is a significant increase in the specialized action. This effect increases convergence to the specialized equilibrium. Specifically, in Wheel network, there is an 8% increase toward the specialized action. In Wheel network, there are 12% increases to specialized actions. In these two networks, there is a significant increases on the free-riding action. In the case of full contribution there is no significant increases in both network. This means that the increase of specialized action mostly comes from the free-riding actions. The difference of free-riding action is statistically increases at 1% level in both case, while the ratio of full-contribution is not statistically difference in both case. Theoretically, the increase of δ increase the incentive to free-riding and simultaneously increase the full contribution. Our empirical evidence shows that the increase of δ primarily increase the free-riding effect. In Circle network, there is 22.1% increases in the specialized action which is the most effective. In Circle network, the increases on the specialized action comes from the free-riding and full contribution both. They are increased by 11.2% and 8.6% respectively which is significant at 1% level.

$$-Figure 4-$$

These results shows that the increase of δ causes the individuals to choose specialized actions more frequently. This is consistent with the theory because Bramoullé et al. (2014) point out the specialized action is more prevalent when δ is high.

5.3 Impact of Asymmetry in Networks

In this section, I investigate the impact of asymmetry in degree distribution of networks. These features are not captured by the theory of Bramoullé et al. (2014). The asymmetry in degree distribution refers to when the degree distribution is unequal inside the network. For example, Circle, Turtle, and Wheel networks are symmetric network because all agents in the networks have the same amount of neighbors. However, Core-periphery network is an asymmetric in degree distribution because some of the agents in the network have 4 neighbors while some of the agents have 2 neighbors. Core-periphery network has an average degree of 3 and $|\lambda_{min}|$ is 2. These are same characteristics with Turtle network. The sole difference between Core-periphery and Turtle networks is the asymmetry in the degree distribution.

5.3.1 Equilibrium selection

$$-Table 7-$$

When δ is 0.75, in the equilibria set, Turtle and Core-periphery networks have multiple equilibria sets with active and specialized equilibria. Their global network characteristics including average degree and $|\lambda_{min}|$ are controlled. First, in Core-periphery network, every equilibrium selection occurred in the specialized equilibrium. The difference between the convergence ratio to the specialized equilibrium is significant at 1% level. The difference is also presented as the period flows in Figure 5.

$$-Figure 5-$$

Figure 5 shows the amount of equilibrium convergence to the specialized equilibrium for the first 10 periods , the periods 11 29, and the last 10 periods. In the Core-periphery network, the convergence ratio increases with the period. This means that the agents' learning effect is toward the specialized equilibrium, while, in Turtle network, the agents' learning effect is toward the active equilibrium. In Table 8, I set the dependent variable 1 if agents are coordinate on the specialized equilibrium , 0 if not. Below Table 8 represents the regression results.

$$-Table 8-$$

Table 8 shows the regression results for the convergence on the core-periphery networks. There is significant increase of convergence to the specialized equilibrium(8.4%) in Core-periphery network. After I controlled the period dummies for fixed effects, the results is also robust at 5% level. This result clearly shows that the changes of asymmetry inside agents affects the specialized equilibrium selections between agents.

5.3.2 Individual behavior

Asymmetry also affects the specialized actions on the agents. In (Turtle, $\delta_{0.75}$), 56.8% of agents chose 1. However, about 23.1% of agents chose 1 in Core-periphery network. The ratio of action are presented below Figure 6. The ratio of agents who chose free ride increases about 13.2%. Also the ratio of agents who chose full contribution increases about 21.2%. This means that there is a 33.4% decrease in the proportion who chose 1. These results clearly show that the local characteristics in network(i.e. asymmetry in degree distribution) have more impact than the global characteristics in network which is describe in the theory.

$$-Figure 6-$$

$$-Figure 7-$$

Figure 7 represent the proportion of individual behavior in Core-periphery network following each positions. In the core position, 64.1% of agents chose 0 (free-ride), while 74.6% of agents chose 2(full-contribution) in periphery position. These results show that the local degree distribution of agents plays as a power law of agent. This behavior is an empirical evidence that the role of local chracteristics can play an important role to the individual contribution which is not captured by the global network characteristics.

$$-Table 9-$$

Table 9 shows the regression results for the specialized action in core-periphery networks. The fixed effects include the period dummies. Across all specifications, there is a significant increase in the specialized action in core-periphery networks. It is the first paper to find the relationship between the specialized action and local network characteristics after we control the global network characteristics. Therefore, the conclusion of this section is that asymmetry of degree distribution strongly impacts toward the specialized action and equilibrium selection.

5.4 Impact of Average Degree

In the theoretical perspective, it does not address the number of links which each agent has, average degree. Therefore, I controlled network characteristics and check how the changes of average degree in networks affects the equilibrium selection on the networks and individual behavior.

5.4.1 Equilibrium selection

$$-Table10-$$

Table 10 shows the equilibrium selection comparison between (Circle, $\delta_{0.35}$) and (Turtle, $\delta_{0.35}$). Both networks have the same unique active equilibrium. Note that the frequency of convergence decrease 6.7% which is significant at 5% level. This result implies that local degree distribution of agents plays as a focal point to the agents.

The two network have the same active and unique equilibrium set when they belong to $\delta = 0.35$. Therefore in the case of $\delta = 0.35$, it is worthwhile to determine whether there is a difference in equilibrium selection even though they have a same equilibria set. This could be important because we can verify in what circumstance people frequently can coordinate on the equilibrium. In the circumstance of $\delta = 0.75$, they have the multiple equilibria set. Specifically, both networks have one active equilibrium and one specialzied equilibrium. In the circle network, each agent has the same number of neighbors as 2. On the other hand, in the Turtle network, each agent has 3 neigbors. They have symmetric degree distribution.

In the equilibrium selection part, the effect of choosing active equilibrium has increased in Circle network. Table 10 shows the amount of frequency coordinate on the equilibrium. It is quite interesting that the frequency of convergence in the active equilibrium is much higher in Circle Network. This is because people have more equal contribution on the equilibrium set. This result is in line of the result with Rosenkranz and Weitzel (2012) who showed that in public good games played on network, people have a tendency to locally coordinate more on the network that have lower average degrees.

5.4.2 Individual behavior

The percentage of choosing the specialized action is different across the networks with regards to individual behavior. There is a significant increase on the behavior of choosing the specialized action in the high degree cases. Table 11 shows regression results. they are statistically significant at 5% level In summary, There was a significant increase on the number of people those who select moderate contribution. Model (1) shows that there is 32% increase in the specialized behavior. This result is also robust if we controlled the fixed effect and other individual properties. In summary, as average degree increases, people have a tendency to select specialized actions.

$-Table 11-$

6 Concluding Remarks

This paper explore the effect of network characteristics in network positions in an experiment in which actions are strategic substitutes. The theory behind this experiment is given by Bramoullé et al. (2014).

Main treatment variable in the experiment is the structure of the underlying network, especially the lowest eigenvalue of networks. This paper find that individual behavior is significantly affected by the lowest eigenvalue but it is difficult to change equilibrium selection because the treatment effect is not strong. Regarding payoff discount factor, in general, exhibits clear effect to the equilibrium selection. This paper finds there is clear increase on the specialized equilibrium when the payoff discount factor is high.

Another main result of this paper, asymmetric degree distribution have most significant effect to the equilibrium selection. This results implies that the incentive to free-riding drastically increases if agents have many neighbors. This results is consistent with the finding of Rosenkranz and Weitzel (2012) because they find the free-riding incentive increases as the degree centrality of agents increases. Lastly, average degree of networks also plays important role to equilibrium selection. Especially, this paper confirms that the as average degree increases, people sustain specialized equilibrium more frequently. This implies that

Although all subjects had complete information about the whole network structure and although these structures were quite simple, the subjects often seem to behave as if they were only partially informed about the network structure like Kosfeld (2004) find. This finding may indicate that, in order to fully understand behavior on networks, theory should focus on models with local networks characteristics rather than global network structure, such as, Galeotti et al. (2010). This paper confirms that people behave with limited information about network structure even though the structure of network is quite simple.

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Table 1: Network characteristics of treatments.

Network	δ	$\vert\lambda_{min}\vert$	Equilibrium	Average Degree	Degree Distribution
Turtle	0.35	2	Unique	3	Symmetric
	0.75		Multiple		
Wheel	0.35	3	Multiple	3	Symmetric
	0.75		Multiple		
Cricle	0.35	2	Unique	2	Symmetric
	0.75		Multiple		
Core-periphery	0.75	2	Multiple	3	Asymmetric

Table 2: Equilibrium Prediction

Network	δ	$\vert\lambda_{min}\vert$	Equilibrium profile	Characterization
Turtle	0.35	2	(1,1,1,1,1,1)	Active
	0.75		(1,1,1,1,1,1)	Active
			(2,1,0,2,1,0)	Specialized
Wheel	0.35	3	(1,1,1,1,1,1)	Active
			(2,0,2,0,2,0)	Specialized
	0.75		(1,1,1,1,1,1)	Active
			(2,0,2,0,2,0)	Specialized
Circle	0.35	2	(1,1,1,1,1,1)	Active
	0.75		(1,1,1,1,1,1)	Active
			(2,0,2,0,2,0)	Specialized
Core-periphery	0.75	2	(1,1,1,1,1,1)	Active
			(2,0,2,0,2,0)	Specialized

Table 3: Summary statistics

Treatments	Subjects	Sessions	Earnings		
			avg	max	min
(Turtle,$\delta_{0.35}$)	36	2	\$14.4	\$18.2	\$12.9
(Turtle,$\delta_{0.75}$)	36	2	\$19.3	\$24.4	\$16.9
(Wheel,$\delta_{0.35}$)	36	3	\$14.1	\$19.9	\$12.3
(Wheel,$\delta_{0.75}$)	36	2	\$18.9	\$24.0	\$13.1
(Circle,$\delta_{0.35}$)	36	2	\$12.1	\$14.5	\$11.5
(Circle,$\delta_{0.75}$)	36	3	\$15.7	\$17.2	\$14.0
(Core-periphery,$\delta_{0.75}$)	36	3	\$18.2	\$25.6	\$10.2

Table 4: Equilibrium convergence : $|\lambda_{min}|$

Network	$\lvert\lambda_{min}\rvert$	δ	Equilibrium profile	Characterization	N	Convergence(%)
(Turtle, $\delta_{0.35}$)	2	0.35	(1,1,1,1,1,1)	Unique	240	80(33.3%)
(Wheel, $\delta_{0.35}$)	3	0.35	(1,1,1,1,1,1)		240	72(30%)
			(2,0,2,0,2,0)	Specialized		6(2.5%)

Table 5: Regression for the specialized actions

	(1)	(2)	(3)	(4)
Wheel	0.072***	0.076***	0.071***	0.062**
	(0.0177)	(0.0179)	(0.0179)	(0.0233)
Fixed effect	no	yes	yes	yes
Woman	no	no	yes	yes
Risk Averse	no	no	no	yes
Constant	0.279***	0.201***	0.203**	0.234***
	(0.0156)	(0.0659)	(0.0686)	(0.0700)
Observations	1920	1920	1920	1920
R-squared	0.033	0.200	0.200	0.200

Table 6: Equilibrium Convergence : δ

Network	$\lvert\lambda_{min}\rvert$	δ	Equilibrium profile	Characterization	N	Convergence(%)
Turtle	2	0.35	(1,1,1,1,1,1)	Unique	240	80(33.3%)
Turtle	2	0.75	(1,1,1,1,1,1)		240	48(20%)
			(2,1,0,2,1,0)	Specialized		15(6.6%)
Wheel	3	0.35	(1,1,1,1,1,1)		240	72(30%)
			(2,0,2,0,2,0)	Specialized		6(2.5%)
Wheel	3	0.75	(1,1,1,1,1,1)		240	35(14.5%)
			(2,0,2,0,2,0)	Specialized		14(6.4%)
Circle	2	0.35	(1,1,1,1,1,1)	Unique	240	96(40%)
Circle	2	0.75	(1,1,1,1,1,1)		240	71(29.5%)
			(2,0,2,0,2,0)	Specialized		8(3.3%)

Table 7: Equilibrium Convergence

Network	$\lvert\lambda_{min}\rvert$	δ	Equilibrium profile	Characterization	N	Convergence(%)
Turtle	2	0.75	(1,1,1,1,1,1)		240	48(20%)
			(2,1,0,2,1,0)	Specialized		15(6.6%)
Core-periphery	2	0.75	(1,1,1,1,1,1)		240	0(0%)
			(2,0,2,0,2,0)	Specialized		62(25.8%)

Table 8: Regression for the specialized equilibrium

	(1)	(2)
Core-periphery	0.184***	0.171***
	(0.0380)	(0.0387)
Fixed effect	no	yes
Woman	no	yes
Risk averse	no	yes
Constant	0.0668***	0.0644
	(0.0156)	(0.0659)
Observations	480	480
R-squared	0.014	0.104

Table 9: Regression for the specialized actions.

	(1)	(2)	(3)	(4)
Core-periphery	0.323***	0.323***	0.322***	0.330****
	(0.0238)	(0.0240)	(0.0226)	(0.0235)
Fixed effect	no	yes	yes	yes
Woman	no	no	yes	yes
Risk Averse	no	no	no	yes
Constant	0.446***	0.505***	0.504***	0.449***
	(0.0164)	(0.0687)	(0.0707)	(0.0845)
Observations	1920	1920	1920	1920
R-squared	0.109	0.151	0.151	0.152

Table 10: Equilibrium Convergence

Network	AvgDegree	$\lvert\lambda_{min}\rvert$	δ	Equilibrium	Character	N	Converge(%)
Circle	2	2	0.35	(1,1,1,1,1,1)	Unique	240	96(40%)
Turtle	3	2	0.35	(1,1,1,1,1,1)	Unique	240	80(33.3%)
Circle	2	2	0.75	(1,1,1,1,1,1) (2,0,2,0,2,0)	Specialized	240	71(29.5%) 8(3.3%)
Turtle	3	2	0.75	(1,1,1,1,1,1) (2,1,0,2,1,0)	Specialized	240	48(20%) 15(6.6%)

Table 11: Regression for the specialized actions.

	(1)	(2)	(3)	(4)
Turtle	0.323***	0.323***	0.322***	0.330****
	(0.0238)	(0.0240)	(0.0226)	(0.0235)
Fixed effect	no	yes	yes	yes
Woman	no	no	yes	yes
Risk Averse	no	no	no	yes
Constant	0.446***	0.505***	0.504***	0.449***
	(0.0164)	(0.0687)	(0.0707)	(0.0845)
Observations	1920	1920	1920	1920
R-squared	0.109	0.151	0.151	0.152

Figure 1: Treatments

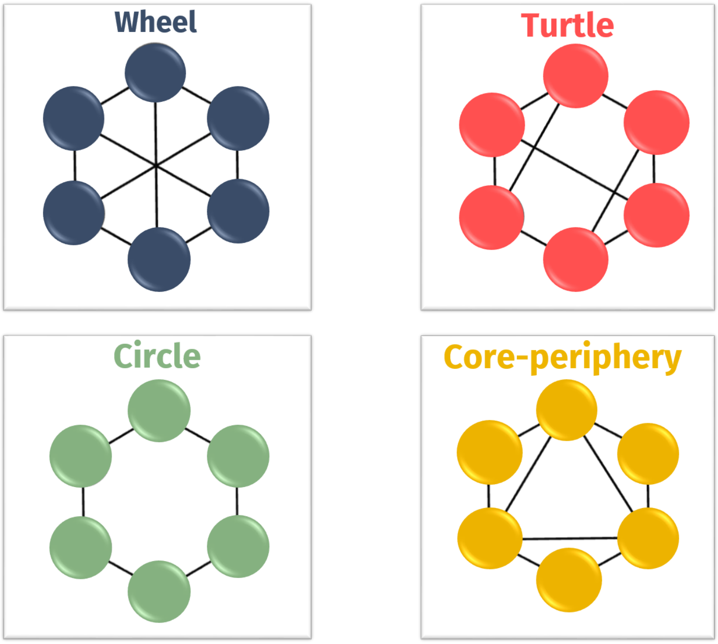

Figure 2: Equilibrium convergence : across periods

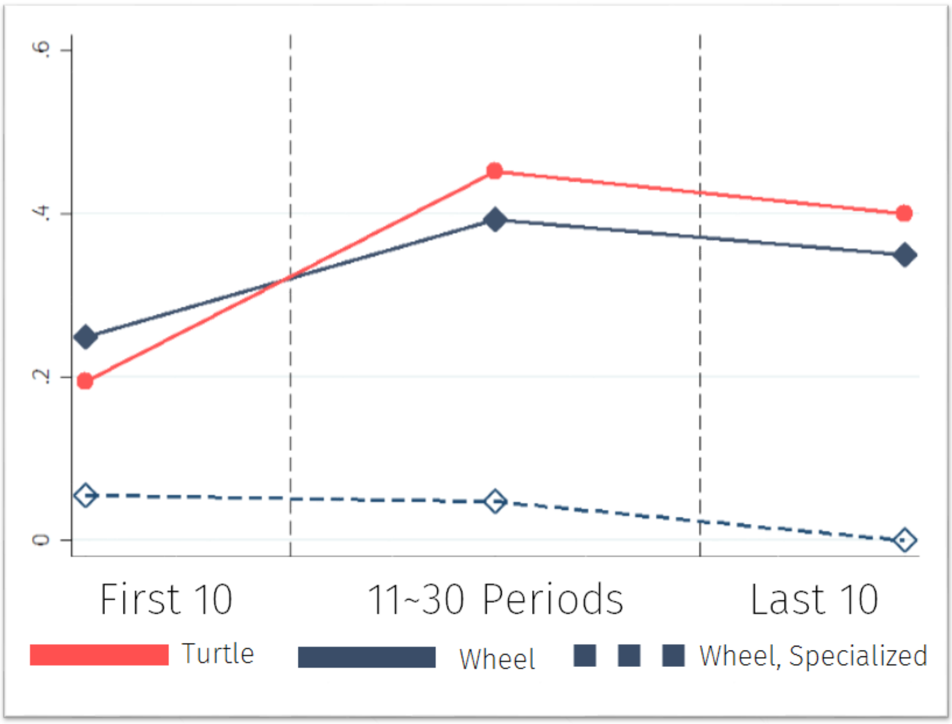

Figure 3: Contribution across treatments

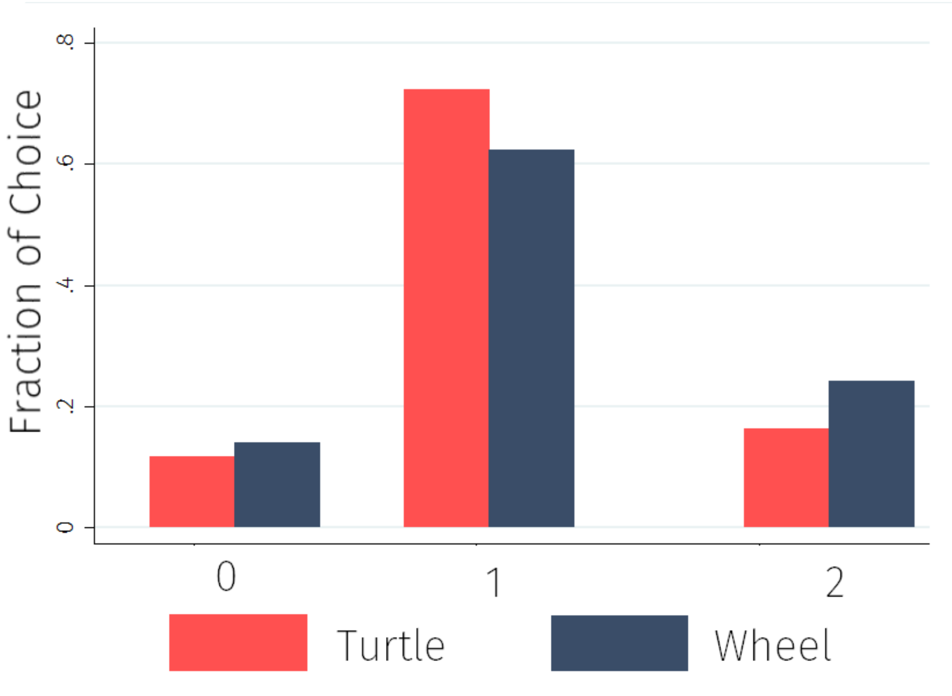

Figure 4: Contribution across treatments

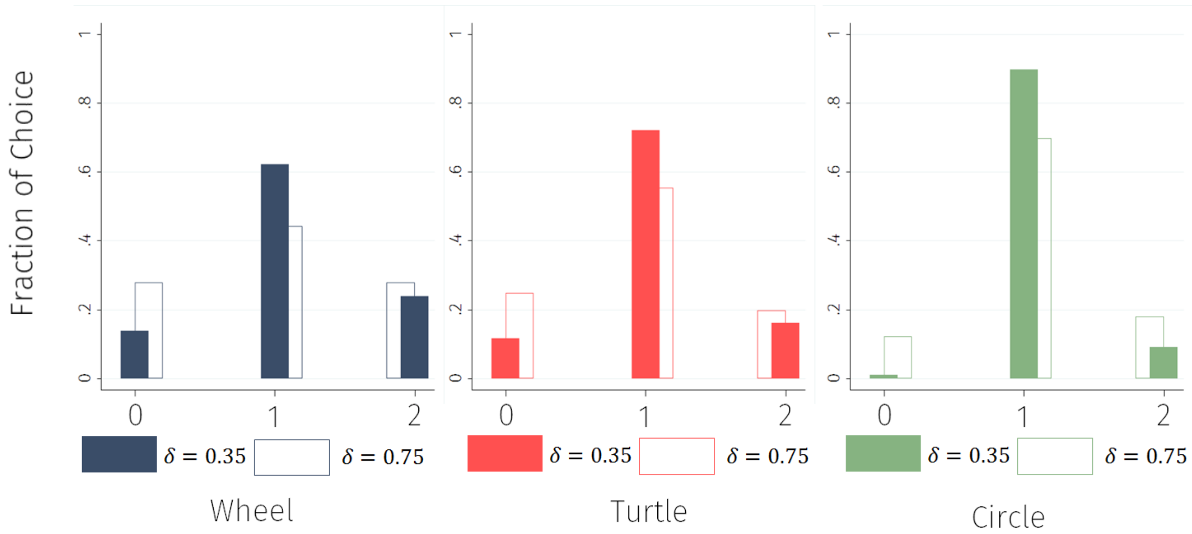

Figure 5: Specialized equilibrium selection across period

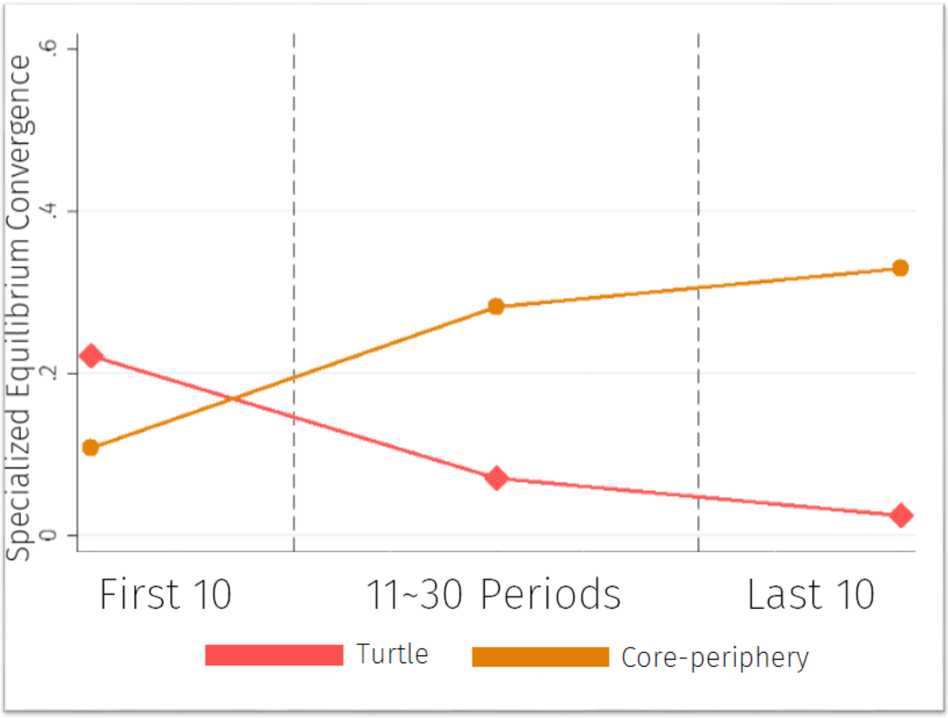

Figure 6: Contribution across treatments

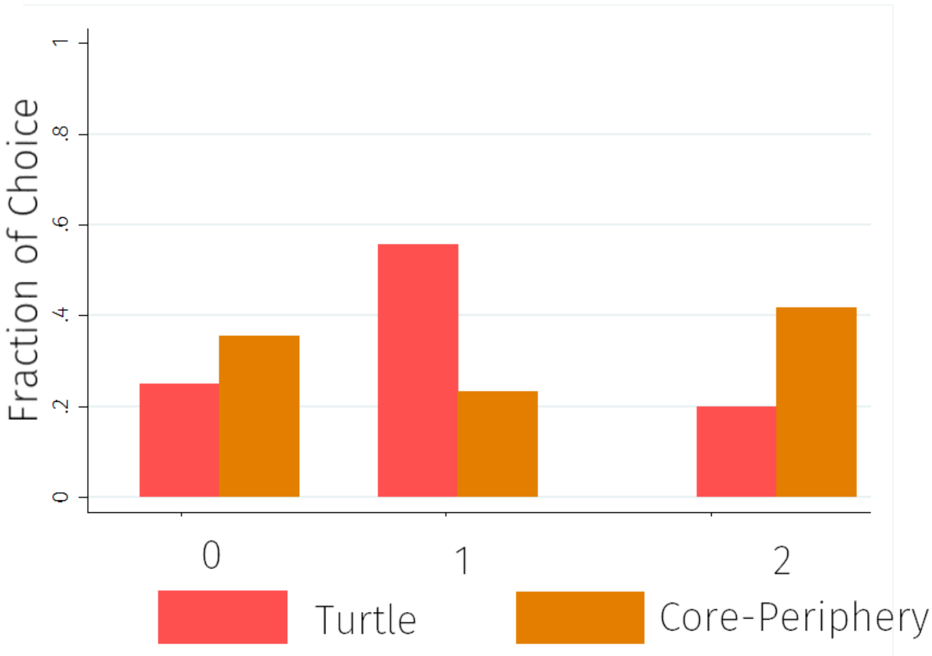

Figure 7: Contribution across core and periphery position