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Essays on Social Dilemmas in Networks

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ABSTRACT

ESSAYS ON SOCIAL DILEMMAS IN NETWORKS

By

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The focus of the research is to study mechanisms that can raise the total social welfare in social dilemmas in exogenous networks. The two chapters apply experimental and empirical designs based on an underlying theoretical model which studies the effect of network structure on the group and individual behavior in laboratory settings.

The first chapter studies the efficacy of two cost sharing rules in raising efficiency in a best shot public goods game. The two cost sharing rules align individual incentive with group efficiency. The first is a local cost sharing rule, where individuals who invest receive a transfer from each of their neighbors who do not invest. The second is a global cost sharing rule, where the total cost of investment is equally divided among members who benefit from the public good.

The second chapter studies the effectiveness of two communication architectures in resolving inefficiencies in the provision of local public goods. Communication can help with coordination by lowering strategic uncertainty. The two communication structures I study are the following: (i) global, where everyone in the group can talk, (ii) local, where only neighbors can communicate with each other.

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ACCEPTANCE

This dissertation was prepared under the direction of the candidate's Dissertation Committee. It has been approved and accepted by all members of that committee, and it has been accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Economics in the Andrew Young School of Policy Studies of Georgia State University.

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DEDICATION

To those who need not be named.

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Contents

List of Tables

List of Figures

1 Introduction

Individual decisions are often made within a larger social structure. I am interested in studying the effect of social and geographical structures on individual decisions, especially when actions are substitutable and exhibit local externalities. The overarching theme of my dissertation is to study mechanisms that can raise the total social welfare in social dilemmas in exogenous networks.

The existing literature studying the effect of network structure on public good provision reports a negative relationship between the number of neighbors an individual has and their likelihood of investing. The evidence points to the lack of incentives that individuals in central network positions have to invest in the local public good. The first chapter uses a laboratory experiment to test the relative efficacy of two cost sharing rules in raising efficiency across three network structures in a best shot public goods game. Across the three network structures, I vary the asymmetry in the number of neighbors each position has in the network. The two cost sharing rules are designed to incentivize individuals with more neighbors to invest. The first rule is a local cost sharing, where individuals who invest receive transfers from each of their neighbors who do not invest. The second is a global cost sharing rule, where the total cost of investment is equally divided among individuals who benefit from the public good. Efficiency of provision is the lowest in absence of cost sharing rules. The low efficiency is driven by under-provision of the public good. Introducing the two cost sharing rules increases the provision of the public good. The local cost sharing rule increases efficiency across all three network structures. The effectiveness of the global cost sharing rule in raising efficiency decreases as the asymmetry of the network structure increases.

Communication can be critical in resolving inefficiency in social dilemmas. Communication can help with coordination by reducing strategic uncertainty in a public goods game in networks. The benefit from the public good is constrained by the underlying network structure. However, the actions of unconnected individuals influence equilibrium selection. In the second chapter, I explore the effectiveness of two communication architectures in increasing the efficiency of the provision of public goods in a best-shot game across three network structures. The first communication structure is global, where everyone in the group can talk to each other. The second structure is local, where only members who are connected can communicate with each other. Frequent mis-coordination and underinvestment lead to lower efficiency when groups don't have the option to communicate. Communication increases both the likelihood of coordinating locally between neighbors and on the equilibrium profiles as a group across all network structures.

I conclude the dissertation with a discussion about the efficacy of two mechanisms: cost sharing and communication and their policy implications. I also discuss avenues for future work.

2 Cost Sharing in Public Goods Games in Network[1]

2.1 Introduction

The decisions made by individuals in central positions in social and geographical networks have asymmetric effects on social welfare when actions exhibit local positive externalities Zenou (2016). Costly investment decisions by individuals in central positions benefit a large number of people who are connected to them. These decisions could range from farmers deciding whether to invest in a new crop or farming technique[2] to physicians deciding whether to adopt a new procedure or protocol[3] or R&D decisions (Bramoullé, 2007, Bramoullé et al., 2014). There is no a priori reason to expect central individuals to behave pro-socially. In fact, if actions are substitutable the incentive is to not invest and free-ride on investment decisions of people connected to them[4].

The experimental literature studying the effect of network structure on public good provision finds an inverse relationship between the number of neighbors and the likelihood of making an investment (Charness et al., 2014, Rosenkranz and Weitzel, 2012). There is little empirical evidence on mechanisms that can motivate individuals in central positions to make costly pro-social investment decisions. Dufwenberg and Patel (2017) and Jackson and Wilkie (2005) show that theoretically cost sharing agreements can raise efficiency in public good provision. Dufwenberg and Patel (2017) argues that reciprocity alone is not sufficient but combined with cost sharing can enhance the private provision of public goods.

Therefore, I investigate the efficacy of two cost sharing rules on efficiency in a best shot

[1]I would like to express my sincere gratitude to Vjollca Sadiraj, James Cox, and Tom Mroz for their valuable feedback. Feedback from participants at Fifth and Fourth Network Science and Economics Conference 2019 and 2018, and the Southern Economic Association Annual Meetings in 2018 and 2016. The experiments were funded through the Andrew Young School Dissertation Fellowship.

[2]There is a large body of literature highlighting the importance of social learning in technology adoption and diffusion (Chuang and Schechter, 2015, Foster and Rosenzweig, 2010, Conley and Udry, 2010).

[3]Tasselli (2014) provides an excellent overview of the literature studying the effect of social networks on physician's decisions.

[4]An equilibrium where the maximum number of unlinked agents are investing is stochastically stable in a best-shot public good games (Boncinelli and Pin, 2012, Bramoullé and Kranton, 2007).

public good game[5] (Hirshleifer, 1983) across three network structures in a laboratory experiment. In the *local cost sharing rule* individuals who invest get a transfer of a fixed proportion of the cost from each of their neighbors who don't invest. This rule exploits the number of connections of the individuals to align their incentives with social efficiency, since for a given cost sharing proportion the cost of investing is decreasing as the number of neighbors increases. The *global cost sharing rule* is based on the component-wise egalitarian allocation rule (Jackson, 2005); here, the total cost of provision is equally shared among individuals who benefit from the public good. Payoff for everyone in the group is maximized when everyone in the group benefits from the public good and the least number of individuals are investing.

I vary the number of neighbors that individuals have across the network structures. The Circle network is symmetric, and everyone has two neighbors, whereas the Line and Asymmetric networks are not symmetric. In the Line, individuals in the periphery have one neighbor, and others have two neighbors, and in the Asymmetric network, individuals have either one, two or three neighbors. This asymmetry provides a rich environment to test the relative efficacy of the two cost sharing rules in increasing efficiency across different network structures.

Across all network structures, the efficiency[6] is the lowest in the treatment with no cost sharing rules. The low level of efficiency is driven by under-provision[7] only 72% of the group member has access to a public good compared to 92% when the two cost sharing rules are introduced. Consistent with earlier research (Charness et al., 2014, Rosenkranz and Weitzel, 2012) I find a negative relationship between the number of neighbors an individual has and their likelihood of investing in the non-symmetric networks. This pattern of investment lowers efficiency due to excess investment in the public good. The local cost

[5] See Harrison and Hirshleifer (1989) for experiments on a best-shot game.

[6] Efficiency is defined as the ratio of the realized group profit and maximum possible total profit in each round.

[7] Under-provision is defined as the ratio of the number of subjects who benefit from the public good and the total number of group members.

sharing treatment is successful in increasing efficiency across all network structures by incentivizing individuals with more neighbors to invest. In the global cost sharing rule, as the asymmetry in the network increases, the effectiveness of the rule in raising efficiency decreases. Compared to the baseline the access to public good increases with introducing the global cost sharing rule however, it is mired by over investment.

Comparing across networks, I find the efficiency is highest in the Circle network, which is in line with the previous findings (Fatas et al., 2010, Carpenter et al., 2012, Rosenkranz and Weitzel, 2012, Leibbrandt et al., 2015, Boosey and Isaac, 2016)'.

This chapter contributes to the small literature on public goods game in network[8]. In particular, Rosenkranz and Weitzel (2012) and Charness et al. (2014) find that individuals with more neighbors contribute less than players with fewer neighbors. The closest to my work is Charness et al. (2014) which reports that in a best shot public goods game groups start by coordinating on the efficient equilibria and eventually drift towards the *stable inefficient equilibrium*[9]. There is little evidence pointing at mechanisms that incentivize central individuals to make costly pro-social investments. Caria and Fafchamps (2018) reports results from an artifactual field experiment with farmers in India, where they exploit guilt aversion as the mechanism to induce pro-social behavior. They find that individuals in the center of a star network are more likely to invest once subjects are made aware of the expectations of the individuals in the periphery. I contribute to this literature by offering two cost sharing rules which facilitate groups to coordinate on the efficient equilibrium by incentivizing central individuals to invest in the public good.

In the next section, I present a theoretical analysis and derive testable hypotheses. Section 2.3 presents the experiment design and procedures. I present the empirical results in Section 2.4 and Section 2.5 concludes.

[8](Fatas et al., 2010, Carpenter et al., 2012, Rosenkranz and Weitzel, 2012, Leibbrandt et al., 2015, Charness et al., 2014, Boosey and Isaac, 2016, Caria and Fafchamps, 2018). See Choi et al. (2016) for an excellent overview of laboratory experiments in networks.

[9]In a stochastically stable equilibrium maximum number of agents are investing Boncinelli and Pin (2012).

2.2 Predictions

Consider n agents and let the set of agents be $N = \{1, \ldots, n\}$. Each agent i simultaneously chooses to either invest (1) or not invest (0) in a local public good. Let $\boldsymbol{a} = (a_1, \ldots, a_n)$ denote the action profile of all agents, where $a_i \in \{0, 1\}$ is agent i's action. Agent i's action determines her payoff and affects payoffs of the agents to whom she is linked through positive externalities. Agents are assigned on an undirected graph. Any two agents i and j who share a local public good are represented by a link: $g_{ij} = g_{ji} = 1$. For two agents who are not linked $g_{ij} = g_{ji} = 0$. Let the collection of all links be represented by $n \times n$ matrix $\boldsymbol{G}$. Let N_i denote the set of agents who are directly linked to agent i, called agent i's *neighbors*: $N_i = \{j \in N/i : g_{ij} = 1\}$. Agents i's *neighborhood* is defined as herself and the set of her neighbors; i.e., $\{i\} \cup N_i$.

An agent gets a benefit of *(b)* from the local public good if she or any of her direct neighbors invest. The cost of providing the local public good, c, is positive but smaller than b. Let $\boldsymbol{a_j}$ denote the set of actions of all agents $j \neq i$. An agent i's payoff:

$$u_i(a_i, \boldsymbol{a_j}, \boldsymbol{G}) = b \times \mathbb{1}\left\{\sum_j g_{ij}a_j + a_i \geq 1\right\} - c \times a_i \tag{1}$$

It is straightforward to show that each agent i's best reply is: $a_i = 1$ if no one in the neighborhood invest and (ii) $a_i = 0$, if at least one of her neighbors invest.

I consider three networks of five agents – Line, Asymmetric, and Circle (see Figure 1). Table 1 reports the pure strategy Nash equilibrium for each network structure. One of the central features of this game is the multiplicity of equilibria. Boncinelli and Pin (2012) refine the equilibrium set through stochastic stability, and show that if the source of error affects both investing and not investing agents or agents randomize using a logistic response, then the only stochastically stable states are Nash equilibria with the largest number of unlinked agents investing. Based on the empirical evidence in favor of Boncinelli and Pin (2012) in public good experiments in networks (Charness et al., 2014), I expect that when there is no cost sharing groups are more likely to coordinate on the stochastically stable equilibrium.

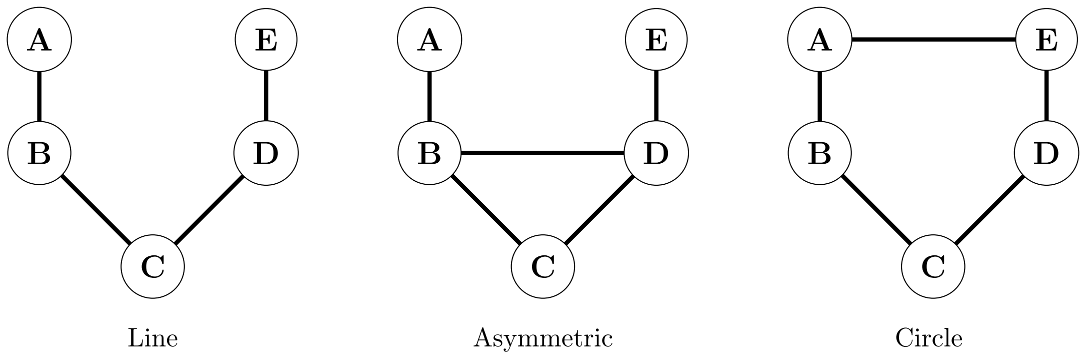


Figure 1: Network structures in the experiment

To analyze the welfare implications of different equilibria, I use a standard utilitarian measure of social welfare, $W(\cdot)$, defined as:

$$W(\boldsymbol{a}, \boldsymbol{G}) = \sum_{i \in N} b \times \mathbb{1}\left\{\sum_{j} g_{ij} a_j + a_i \geq 1\right\} - c \times \sum_{i \in N} a_i$$

Note that groups maximize the total social welfare in any equilibrium when all agents in the network have access to the local public good and the minimum number of agents are investing. Across all the network structures, equilibria with only two unlinked agents investing maximizes total welfare for the group (see Table 1).

Table 1: Pure Strategy Nash Equilibrium

Network (equilibrium)	Investment Choice					$W(\cdot)$
Line	**A**	**B**	**C**	**D**	**E**	
(L1)	1	0	1	0	1	$5b - 3c$
(L2)	0	1	0	1	0	$5b - 2c$
(L3)	0	1	0	0	1	$5b - 2c$
(L4)	1	0	0	1	0	$5b - 2c$
Asymmetric						
(A1)	1	0	1	0	1	$5b - 3c$
(A2)	0	1	0	0	1	$5b - 2c$
(A3)	1	0	0	1	0	$5b - 2c$
Circle						
(C1)	1	0	0	1	0	$5b - 2c$
(C2)	1	0	1	0	0	$5b - 2c$
(C3)	0	1	0	0	1	$5b - 2c$
(C4)	0	0	1	0	1	$5b - 2c$
(C5)	0	1	0	1	0	$5b - 2c$

See Appendix A for proof and mixed strategy Nash equilibrium profiles.

2.2.1 Network Structures

Since investments are substitutes, adding a link has two opposite effects, it increases access to the local public good, but, it also increases incentives to free-ride[10]. Starting with the Line network adding a link between B & D leads to the Asymmetric network. This increases the number of neighbors of B and D has. However, adding the link does not alter the inefficient equilibrium, but it reduces the set of Nash equilibria, which could help with coordination. It is an empirical question whether an additional link leads to efficiency gains.

Adding a link between the agents on the periphery of the Line network results in the Circle network. In the Circle network, theoretically all pure strategy Nash equilibria are efficient, but the pure strategy Nash set is larger, which might lead to coordination problems. Given the two countervailing effects of adding a link, it is unclear a priori if it leads

[10] Galeotti et al. (2010) show that in a symmetric Bayes-Nash equilibria in a best shot public goods game with monotone (threshold) strategies, agents invest only if the number of neighbors they have is below a certain threshold. The threshold decreases as the number of neighbors is increasing.

to efficiency gains.

Hypothesis 1. ***The efficiency is the same in Line and Asymmetric networks and higher in Circle network in the baseline.***

2.2.2 Local Cost Sharing Rule

The investment decision of agents with more neighbors disproportionately affects the total social welfare, since a large number of agents connected to them benefit from their investment. The local cost sharing rule incentivizes individuals in central positions to invest by introducing transfers from each of their neighbors who do not invest.

Definition 1. *The local cost sharing rule is defined as following:*

$$\begin{aligned} u_i(1, \boldsymbol{a_j}, \boldsymbol{G}) &= b - c + c\eta\left(\sum_{j \in N_i}(1 - a_j)\right) \\ u_i(0, \boldsymbol{a_j}, \boldsymbol{G}) &= b \times \mathbb{1}\left\{\sum_{j \in N_i} a_j \geq 1\right\} - c\eta\sum_{j \in N_i} a_j \end{aligned} \tag{2}$$

Where $1 \geq \eta > 0$ *determines the fixed proportion of the cost, an investor receives from each of her neighbors who choose not to invest.*

The local cost sharing incentivizes agents with more neighbors to invest by lowering the cost of investing via transfers. Conversely the transfers incentivize agents with fewer neighbors to free-ride. In the baseline given the parameter values[11], in the inefficient equilibrium, the payoff for agents in positions B and D in the Line and Asymmetric network is 100 (see Table 2). Whereas, with the local cost sharing rule the payoff in the inefficient equilibrium for B and D is 50; they get a payoff of 100 as they have access to the public good and transfer 25 to two neighbors who invest. In the Line network the payoff for all agents in equilibria where either B or D are investing (*L3 and L4 see table 2*), is higher or

[11] $b = 100$, $c = 75$ and $\eta = \frac{1}{3}$.

equal to the payoff in the inefficient equilibrium. In the Asymmetric network, the inefficient equilibrium is Pareto dominated by the equilibria in which either B or D is investing (A2 and A3 see Table 2). In the Asymmetric network the local cost sharing rule creates a competition between B and D to invest, since in equilibria where either B or D are investing, the agent who invests gets back the whole cost of provision as a transfer from three of her neighbors who are not investing, while the agent who is not investing gets a lower payoff of 50. This competition leads to the rise of a fourth equilibrium profile in the Asymmetric network in which only B & D are investing in the group, this equilibrium is efficient but does not Pareto dominate the inefficient equilibrium since the payoff of C is lower.

Proposition 1. *Given the local cost sharing rule and $\eta \leq \frac{1}{3}$, the inefficient equilibrium in the Line and Asymmetric network is Pareto dominated by an efficient equilibrium.*[12]

The local cost sharing rule incentivizes the groups to coordinate away from the inefficient equilibrium to the set of the Pareto dominant efficient equilibria in the Line and Asymmetric network. Note that the local cost sharing rule does not alter the set of efficient equilibria in the Circle network.

Hypothesis 2. ***Introducing the local cost sharing rule will increase efficiency in the Line and Asymmetric networks.***

In comparison to the Circle network, the set of Pareto dominant equilibria is the smaller in the Line and Asymmetric network. The smaller equilibrium set could help to reduce frictions in coordination, which can lead to higher efficiency.

Hypothesis 3. ***Given the local cost sharing rule the efficiency in Line and Asymmetric networks will be higher than in Circle network.***

[12] For proof see Appendix A.3.

2.2.3 Global Cost Sharing Rule

I base the global cost sharing rule on the component-wise egalitarian allocation rule discussed in (Jackson, 2005, Page 150). In the global cost sharing rule, the total cost of investments in the network is divided equally among agents who benefit from the local public goods.

Definition 2. *The global cost sharing rule is defined as the following:*

$$u_i(a_i, a_j, \boldsymbol{G}) = \left[b - \frac{c \times \sum_k^N a_k}{\sum_k^N \mathbb{1}\left\{\sum_{j \in N_k} g_{kj} a_j + a_k \geq 1\right\}} \right] \times \mathbb{1}\left\{\sum_{j \in N_i} g_{ij} a_j + a_i \geq 1\right\} \tag{3}$$

where

1. $\sum_k^N a_k$ – *the total number of agents who chose to invest,*
2. $\sum_k^N \mathbb{1}\left\{\sum_{j \in N_k} g_{kj} a_j + a_k \geq 1\right\}$ – *total number of agents who benefit from the public good.*

The global cost sharing rule aligns an agent's payoff with the maximum group payoff. The rule removes incentives to free-ride as well as over-investments for all group members because the payoff for everyone in the group decreases as the total number of investments increases. I can rank equilibria based on the total group payoffs. The inefficient equilibrium where the maximum number of agents are contributing yields the lowest payoff for all agents in the network, while any efficient equilibria yield a higher payoff (*see, efficiency coloumn Table 2*).

Proposition 2. *Given the global cost sharing rule, the inefficient equilibrium in the Line and Asymmetric network is Pareto dominated by an efficient equilibrium.*[13]

The global cost sharing rule incentivizes groups to coordinate away from the inefficient equilibrium in the Line and Asymmetric network. The global cost sharing rule in the Cir-

[13] For proof see Appendix A.3

cle network by subsidizing the cost of investment reduces the incentive to free-ride compared to the baseline, which can help groups to coordinate and raise efficiency.

Hypothesis 4. ***In comparison to the game without cost-sharing the efficiency is higher across all three network structures.***

The three network structures can be ranked based on the number of Pareto dominant Nash equilibria, a smaller set of equilibrium could help groups to coordinate.

Hypothesis 5. ***With the introduction of the global cost sharing rule, the efficiency will be highest in the Asymmetric network, followed by Line and Circle.***

Both cost sharing rules incentivize agents to coordinate on the set of efficient equilibria across all network structures. However, the global cost sharing rule induces transfers across unconnected agents even though there are no externalities which flow between them. This feature of the global cost sharing rule might lead to coordination failure compared to the local cost sharing rule.

2.3 Experiment Design and Procedures

2.3.1 Experiment Game

Experiment design crosses the three network structures: Line, Asymmetric, and Circle with the baseline and the two cost sharing rules: local cost sharing rule, and the global cost sharing rule. I implement a finitely repeated version of a best-shot game in stages of ten rounds. In each stage, subjects interact in groups of five in one of the three network structures. The subjects know their position in the network. A subject's position and the group remains fixed within a stage. Subjects make simultaneous decisions on whether to invest in the public good. The benefit of the public good is available to everyone in the neighborhood. The benefit from investing is $b = 100$ cents, and the cost of investing is

$c = 75$ cents. The payoff for each round in the baseline game is, therefore:

$$u_i(a_i, \boldsymbol{a_j}, \boldsymbol{G}) = 100 \times \mathbb{1}\left\{\sum_j g_{ij}a_j + a_i \geq 1\right\} - 75 \times a_i \tag{4}$$

In the two cost sharing treatments, I keep the parameter values of b and c fixed at 100 cents and 75 cents. In the *local cost sharing rule* the cost sharing parameter $\eta = \frac{1}{3}$. Thus, each subject who invests gets a transfer of 25 cents from each of her neighbors who did not invest in the local public good. The payoff for the subjects in the local cost sharing rule is given by:

$$\begin{aligned} u_i(1, \boldsymbol{a_j}, \boldsymbol{G}) &= (100 - 75) + 25 \sum_{j \in N_i} (1 - a_j) \\ u_i(0, \boldsymbol{a_j}, \boldsymbol{G}) &= 100 \times \mathbb{1}\left\{\sum_{j \in N_i} a_j \geq 1\right\} - 25 \sum_{j \in N_i} a_j \end{aligned} \tag{5}$$

In the *global cost sharing rule* the total cost of investment is equally divided[14] among subjects who benefit from the local public good. The payoff for the subjects of the global cost sharing rule is given by:

$$u_i(\boldsymbol{a}, \mathbf{G}) = \left[100 - \frac{75 \times \sum_{k=1}^{5} a_k}{\sum_{k=1}^{5} \mathbb{1}\left\{\sum_{j \in N_k} g_{kj}a_j + a_k \geq 1\right\}}\right] \times \mathbb{1}\left\{\sum_{j \in N_i} g_{ij}a_j + a_i \geq 1\right\} \tag{6}$$

Table 2 presents the round payoffs across all pure strategy Nash equilibria.

[14]the cost of one investment is the same as the baseline, 75 cents.

Table 2: Theoretical profits in equilibrium for each round.

Network (equi.)	Baseline					Local Cost Sharing					Global Cost Sharing	Efficiency
	Profit in cents every round											
Line	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**Each Agent**	
(L1)	25	100	25	100	25	50	50	75	50	50	55	0.79
(L2)	100	25	100	25	100	75	75	50	75	75	70	1
(L3)	100	25	100	100	25	75	75	75	75	50	70	1
(L4)	25	100	100	25	100	50	75	75	75	75	70	1
Asymmetric												
(A1)	25	100	25	100	25	50	50	75	50	50	55	0.79
(A2)	100	25	100	100	25	75	100	75	50	50	70	1
(A3)	25	100	100	25	100	50	50	75	100	75	70	1
(A4)*	—	—	—	—	—	75	75	50	75	75	—	1
Circle												
(C1)	25	100	100	25	100	75	75	75	75	50	70	1
(C2)	25	100	25	100	100	75	50	75	75	75	70	1
(C3)	100	25	100	100	25	50	75	75	75	75	70	1
(C4)	100	100	25	100	25	75	75	75	50	75	70	1
(C5)	100	25	100	25	100	75	75	50	75	75	70	1

*In the Asymmetric network A4 is an equilibrium only in the *local cost sharing rule.*

2.3.2 Experiment Procedures

The experiment was conducted at the ExCEN lab at Georgia State University in February - March 2018. A total of 240 subjects participated in the experiment over twelve sessions. The subjects were recruited via email using the ExCEN automated system. Upon arrival at the lab, the subjects reviewed and signed the consent form and were randomly assigned seats in the lab. Throughout the session, subjects were not allowed to communicate with each other[15]. Each session was conducted in three stages, followed by a demographic survey. At the start of each stage, subjects were instructed to read the experimental instruction (*see appendix B*) at their own pace[16]. Before the start of each stage in order to gauge a better understanding of the game, subjects had the option to explore a game simulator at their own pace; they also played a set of practice rounds. Each session[17] lasted for roughly one hour and fifteen minutes.

Subjects only took part in one of the three network structures: Line, Asymmetric, or Circle. Each session consisted of three stages of ten rounds each. At the start of each

[15]To ensure privacy, each computer terminal in the lab is enclosed with dividers.

[16]A summary of instructions was read out loud which was available for subjects to see on their computer screens.

[17]computerized using z-Tree (Fischbacher, 2007).

stage, *su*bjects were randomly matched to form groups of five, and each subject was randomly assigned a network position. The group and the position remained fixed within each stage. Across stages, treatments were introduced. In the first stage, subjects played the baseline game, followed by the two cost sharing rules. Across sessions, the order in which the two cost sharing rules were introduced was randomized.

As explained above, in the baseline treatment, the benefit from an investment in the neighborhood common fund was 100 cents for all individuals in the neighborhood of the investor, and the cost was 75 cents. In the local cost sharing rule, each subject who invests receives a transfer of 25 cents from each neighbor who did not invest. The cost sharing rule was enforced after all subjects made their investment decisions. In the global cost sharing treatment subjects were informed that the benefit of investing was still 100 cents, but all subjects who received a benefit from the neighborhood common fund would equally share the cost of total investment.

At the end of every round, the subjects were provided a summary of the number of the contributing neighbors, their position on the network, their investment decisions and their earnings; this information was available for all the 30 periods. I chose to repeat the stage game for ten rounds[18] to allow for enough time for groups to understand the game and coordinate on an equilibrium.

At the end of each session, each subject answered a questionnaire asking on demographics and some context-specific risk and social preferences questions. Subjects were paid for all 30 periods in cash privately right after the experiment session. The average payoff in the experiment was $14.50 per subject, with a minimum of $ 9.60 and maximum earning of $ 21.60.

[18] Best response dynamics converge to a pure strategy Nash equilibrium within at most 2 x N (Komarovsky et al., 2015, Proposition 2); in our case 10 rounds.

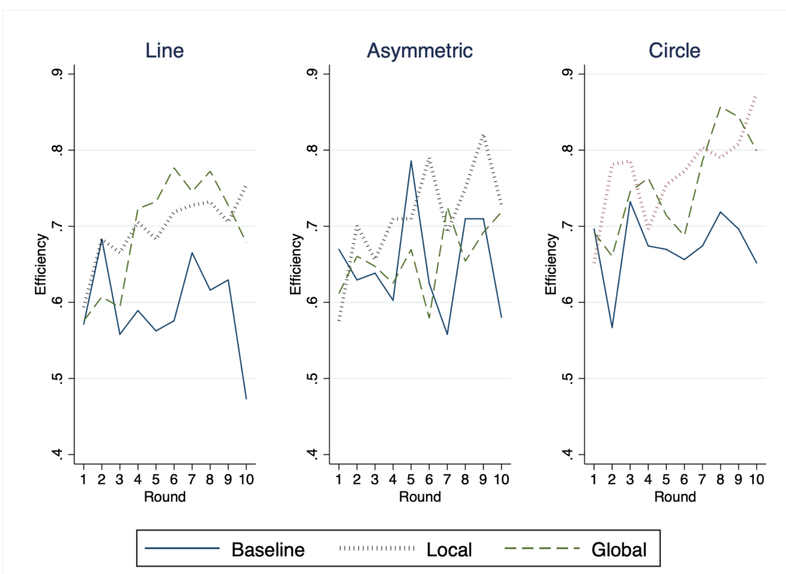
2.4 Results

2.4.1 Efficiency across cost-sharing rules

The two cost sharing rules incentivize groups to coordinate away from the inefficient equilibrium in the Line and Asymmetric networks. Hypotheses 2 and 4 state that compared to the baseline, the two cost sharing rules will increase efficiency in both the network structures. The set of pure strategy Nash equilibria are efficient in the Circle network; the two cost sharing rules subsidize the cost of investing compared to the baseline. The lower cost has two countervailing effects in the Circle network; it could lead to an increase in efficiency because of an increase in the provision of the public good or a loss in efficiency due to over-investment compared to the baseline.

To test the effect of two cost sharing rules on efficiency, first I compute the efficiency for each round using a traditional measure[19]. Figure 2 shows efficiency across the rounds in the baseline and the two cost sharing rules across the three network structures.

Figure 2: Efficiency Across Treatments



Inspecting figure 2 one can observe that in the first round across all the three treat-

[19]Efficiency $= \frac{\text{Realized Payoff}_{\text{round}}}{\text{Theoretical Max. Possible Payoff}}$

ments groups start with similar level of efficiency. In the Line and Circle, compared to the baseline efficiency is higher in the two cost sharing rules. However, in the Asymmetric network, the effect of the two cost sharing rules is not clear. To identify the effect of the two cost sharing rules on the efficiency of provision, I run a linear panel regression model with efficiency as the dependent variable and a categorical variable for baseline and the two cost sharing rules as the variable of interest with a random effect at the group level. To account for learning about the group members due to the repetition of the game, I use round numbers as a control. Table 3[20] reports for each network structure the change in efficiency in the local and the global cost sharing rule compared to the treatment without cost sharing (baseline).

Table 3: OLS Estimates - Efficiency Across Treatment

	Line	Asymmetric	Circle
Local	0.104***	0.0625**	0.0982***
	(0.031)	(0.032)	(0.032)
Global	0.101***	0.00748	0.0813**
	(0.031)	(0.032)	(0.032)
Round	0.00825**	0.00799***	0.0118***
	(0.004)	(0.003)	(0.003)
Observations	480	480	480

Robust standard errors in parentheses
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

In the Line network, the local cost sharing rule increases the efficiency of the play by 17% compared to 59.2% efficiency in the baseline. Compared to the baseline efficiency of 65% in the Asymmetric network, the local cost sharing rule increased efficiency by 9.75%. The local cost sharing rule increases efficiency by 14.5% in the Circle network. I summarize the effect of the local cost sharing rule on efficiency in the following result.

Result 1. ***Compared to the baseline, the local cost sharing rule is successful in raising efficiency across the three network structures.***

[20] I find similar results if I use $1/Round$ as an independent variable, see Appendix A.2

Hypothesis 4 states that the global cost sharing rule would increase efficiency in all three network structures. Compared to the baseline, the global cost sharing rule in the Line network increases efficiency by 17% and by 12% in the Circle network. However, there are no gains in efficiency in the Asymmetric network. The following results summarize the findings for the global cost sharing rule.

Result 2. ***Compared to the baseline, the global cost sharing rule is successful in raising efficiency in the Line and Circle network structure but it has no effect on efficiency for Asymmetric network.***

Both the local and global cost sharing rules align individual incentives with higher group efficiency. Unlike the local cost sharing rule, global cost sharing induces transfers among unlinked agents. The cross-subsidization of investment, even when there is no flow of externalities could lead to coordination failure since choices of subjects outside their neighborhood determine an individual's payoffs. This could lead to lower efficiency in the global cost sharing rule when compared to the local cost sharing rule. To test if there is any difference in efficiency between the local and global cost sharing treatments in each of the network structure, I run a Wald test for equality of the two estimated coefficients. In the Line and Circle, there is no statistically significant difference between efficiency in the local and global cost sharing rules; however, in the Asymmetric network, the local cost sharing rule is successful in raising efficiency compared to the global cost sharing rule ($p = 0.075$).

2.4.2 Efficiency across networks

Hypotheses 1, 3, and 5 state differences in efficiency across network structures in the three treatments: baseline, local cost sharing, and global cost sharing. To test these hypotheses, I run a linear panel regression with efficiency as the dependent variable and a categorical variable for the three network structures as the explanatory variable of interest with random effects at the group level. To account for learning, I use the round number as a control variable. For each treatment: baseline, local cost sharing, and global cost sharing table 4[21] reports the differences in efficiency in Asymmetric and Circle comparison to the Line network.

Table 4: OLS Estimates - Efficiency Across Networks

	Baseline	Local	Global
Baseline (mean)	0.592	0.697	0.693
	(.021)	(0.016)	(0.017)
Asymmetric	0.0585**	0.0165	-0.0349
	(0.028)	(0.034)	(0.030)
Circle	0.0812***	0.0750**	0.0616**
	(0.030)	(0.032)	(0.030)
Round	-0.000974	0.0148***	0.0142***
	(0.004)	(0.003)	(0.003)
Observations	480	480	480

Robust standard errors in parentheses
* $p<0.10$, ** $p<0.05$, *** $p<0.01$

In the baseline, hypothesis 1 states that the efficiency in the Circle will be higher compared to the Line and Asymmetric networks. Comparing between the Line and Asymmetric networks, there should not be any differences in efficiency if groups coordinate on the inefficient equilibrium[22]. However, if a smaller pure strategy Nash equilibrium set can aid with coordination, then in the Asymmetric, the efficiency could be higher because of lower coordination failure. The efficiency in the Asymmetric network is 9.8% higher than the Line network.

The Circle network is 13.7% more efficient compared to the Line network. To compare the difference in efficiency between the Asymmetric to Circle network, I run a Wald test with the null hypothesis that the two regression coefficients are equal. I fail to reject the null hypothesis; there is no statistically significant difference between the efficiency of the Asymmetric and Circle networks.

[21] I find similar results if I use $1/Round$ as an independent variable, see Appendix A.2.

[22] Charness et al. (2014) find that stochastic stability drives equilibrium selection in best shot games in a network.

In the Line and Asymmetric networks, the two cost sharing rules align individual incentives with group efficiency. Recall that all equilibria in Circle network are efficient. However, in both the cost sharing rules compared to the Line and Asymmetric, the set of Pareto dominant Nash equilibria is the larger in the Circle network. If the larger set makes it hard for groups to coordinate on an equilibrium, then one might expect a lower level of efficiency in Circle network, as stated in Hypothesis 3 and 5.

In both the local and global cost sharing rules, the efficiency in Line and Asymmetric networks are not statistically different from each other. Whereas compared to the Line, the Circle network is 10% more efficient in the local cost sharing rule and 8.8% more efficient in the global cost sharing rule. A Wald test of equality of regression coefficient of Asymmetric and Circle network. The Circle is more efficient than the Asymmetric network in local cost sharing ($p = 0.076$) and global cost sharing ($p = 0.0003$). I summarize these observations in the following result.

Result 3. ***The Circle is the most efficient network, with or without the cost sharing of investments.***

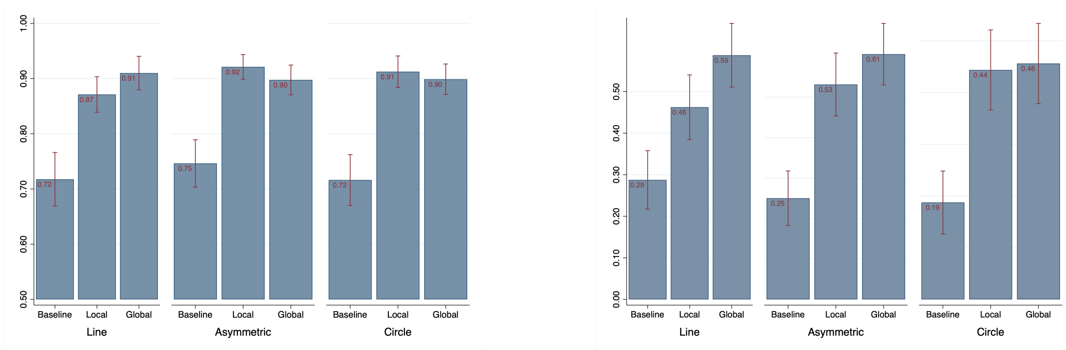
2.4.3 What are the sources of inefficiency?

There are two sources of inefficiency: under-provision and over-provision of the local public good. The welfare loss because of under-provision is higher than overprovision because the benefits from the public good exceed the cost of provision. Under-provision implies a lack of access to the public good. To capture underprovision of the public good, I construct the following measure; *access to public good*, as the ratio between the total number of subjects in the group who receive a benefit from the public good and total group size. An increase in access to the public good could lead to over-investment in a round. To capture over-investment, I define overprovision in a round as a binary variable which takes the value one if all five group members receive a benefit from the public good but there are over two investments in the group.

Figure 3: Sources of Inefficiency

Access to Public Good

Overprovison of Public Good



Inspection of Figures 3a and 3b suggests that the two cost sharing rules increase access to the public good, but they also increase excess investment. Table 5[23] reports results from a linear panel regression with access to public and excess provision as the dependent variable and a categorical variable for the three treatments: baseline, local cost sharing, and global cost sharing as independent variables of interest with random effects at the group level. I use the round as control variables to account for learning. Across all the network structures, the two cost sharing rules increase access to the public good, which improves efficiency. However, greater access comes with overprovision, which lowers efficiency.

Table 5: Access to Public Good and Excess Provision

	Access to Public Good			Over Provision		
	Line	Asymmetric	Circle	Line	Asymmetric	Circle
Local	0.154***	0.175***	0.196***	0.175***	0.281***	0.256***
	(0.029)	(0.025)	(0.028)	(0.058)	(0.039)	(0.051)
Global	0.192***	0.151***	0.182***	0.300***	0.356***	0.269***
	(0.022)	(0.030)	(0.030)	(0.069)	(0.046)	(0.068)
round	0.000379	0.00167	0.00379	-0.00833	-0.00934	-0.0119
	(0.003)	(0.004)	(0.003)	(0.009)	(0.007)	(0.008)
Observations	480	480	480	480	480	480

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

[23]I find similar results if I use $1/Round$ as an independent variable, see Appendix A.2.

Result 4. ***The two cost sharing rules increase the access to public good however that leads to over investment across the three network structures.***

2.4.4 What equilibria are groups more likely to coordinate on?

In this section, I look at equilibrium selection. Figure 4 shows the share of observations consistent with an equilibrium across three network structures. Table 6 reports the percentage of group decisions consistent with equilibrium across three network structures.

Figure 4: Share of Rounds Consistent with Equilibrium

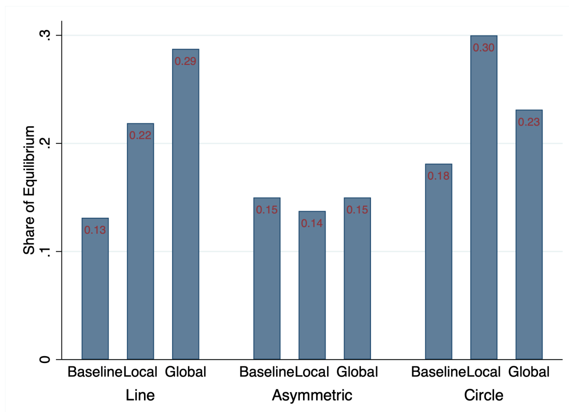


Table 6: Frequency of Equilibrium

Network		**Equilibrium**	**Baseline**	**Local**	**Global**
Line	Equilibrium		13%	22%	29%
	Inefficient	*L1*	29%	23%	35%
	Efficient	*L2*	10%	3%	24%
		L3	10%	9%	22%
		L4	52%	66%	20%
Asymmetric	Equilibrium		15%	14%	15%
	Inefficient	*A1*	46%	0%	79%
	Efficient	*A2*	38%	45%	8%
		A3	17%	5%	13%
		A4	–	50%	–
Circle	Equilibrium		18%	30%	23%
	Efficient	*C1*	21%	35%	14%
		C2	28%	29%	32%
		C3	7%	8%	30%
		C4	24%	13%	22%
		C5	21%	15%	3%

Inspecting figure 4 shows that the two cost sharing rules increase the number of decisions consistent with an equilibrium in the Line and Circle networks. To further investigate the effect the two cost sharing rules have on the likelihood of observing an equilibrium, I run a logistic panel model where the dependent variable in a dummy variable which takes the value one when a group decision is consistent with equilibrium, and zero otherwise. The independent variable of interest is the categorical variable for each of the three treatments: baseline, local cost sharing, and global cost sharing. I also use the round number to account for learning. Table 7[24] reports the marginal effect of the two cost sharing rules compared to the baseline for each of the three network structures.

Table 7: Marginal Effect of Probability of Coordinating on Equilibrium

	Line	Asymmetric	Circle
Baseline	0.132	0.153	0.184
	(0.031)	(0.043)	(0.040)
Local	0.0859*	-0.0212	0.117*
	(0.050)	(0.058)	(0.063)
Global	0.155***	-0.000941	0.0454
	(0.054)	(0.060)	(0.059)
Round	0.0154**	0.0155***	0.0227***
	(0.006)	(0.005)	(0.006)
Observations	480	480	480

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.010

Table 8: Mean Investment by Position

	Baseline					**Local Cost Sharing**					**Global Cost Sharing**				
Network	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**	**A**	**B**	**C**	**D**	**E**
Line	57%	26%	36%	39%	44%	66%	44%	44%	56%	45%	61%	55%	46%	56%	66%
Asymmetric	51%	31%	38%	24%	50%	41%	78%	58%	56%	48%	71%	45%	59%	44%	73%
Circle	36%	29%	39%	26%	34%	70%	46%	42%	54%	36%	53%	38%	53%	43%	60%

[24] I find similar results if I use $1/Round$ as an independent variable, see Appendix A.2

Line

In the baseline, 13% of group decisions are consistent with an equilibrium prediction. Only 29% of the observations are at the inefficient equilibrium. 52% of group decisions consistent with the equilibrium is the efficient equilibrium where subjects in positions A and D are investing. The local cost sharing rule increases the likelihood of coordinating on any equilibrium by 8.6 percentage points (see Table 7). Similar to the baseline in the local cost sharing rule, 66% of equilibrium profiles are ones where subjects in positions A and D are investing. The global cost sharing rule increases the probability of coordinating on equilibrium by 15.5 percentage points, groups are equally likely to coordinate on any of the four pure strategy equilibrium profile[25].

Asymmetric

15% of the group decisions are consistent with an equilibrium prediction in the baseline. The two cost sharing rules do not increase the likelihood of coordinating on an equilibrium (see Table 7). However, the two cost sharing rules influence the equilibrium profile groups to coordinate on. In the baseline, groups are coordinating either on inefficient equilibrium (46%) or on the equilibria where subjects in positions B and E are investing (38%).The local cost sharing rule induces groups to coordinate away from the inefficient equilibrium to either the one where B and E are investing or B and D are investing[26]. In the global cost sharing rule in 79% of the observation consistent with equilibrium, groups coordinate on the inefficient equilibrium where A, C, and E are investing.

[25]Subjects across all nodes are investing on average 57% of rounds (see Table 8).

[26]This is driven by investment behavior of subjects in position B who invest 78% of rounds (see Table 8).

Circle

In the baseline 18% of the group decisions are consistent with equilibrium. Groups are equally likely to coordinate on all equilibria except C3, where B and E are investing[27]. The local cost sharing rule increases the likelihood of equilibrium play by 11.7 percentage points. Groups are more likely to coordinate on the equilibrium where either A and E (C1) are investing, or A and C (C2) are investing[28]. Compared to the baseline, the global cost sharing rule has no effect on the likelihood of equilibrium play; groups are more likely to coordinate on C1, C2 and C3[29].

2.4.5 Effect of cost sharing rule on free-riding behavior

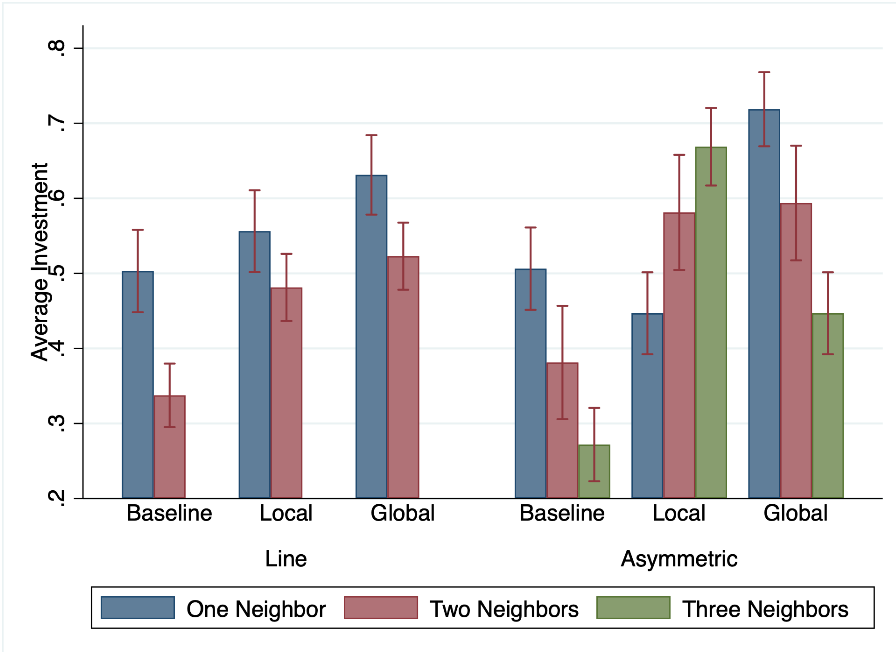
Charness et al. (2014) and Rosenkranz and Weitzel (2012) find a negative relationship between the number of neighbors a subject has and their likelihood of investing in the local public good. Figure 5 for the Asymmetric and Line networks shows the average investment for subjects with one, two, and three neighbors. Examining figure 5 there is evidence of an inverse relationship between the number of neighbors and likelihood of investing in both the Line and Asymmetric networks. The two cost sharing rules in the Line network increase the probability of investment independent of the number of neighbors. In the Asymmetric network, the local cost sharing rule induces subjects with more neighbors to invest more than subjects with fewer neighbors, whereas in the global cost sharing rule one can see the negative relationship between the number of neighbors and their likelihood of investing.

[27]This pattern is consistent with the observation that subjects across all nodes are contributing 33% of the times.

[28]This is driven by the investment behavior of subjects in position A who invest in 70% of the rounds (see Table 8).

[29]Subjects across all positions except on position B are investing 50% of the rounds (Table 8).

Figure 5: Mean Investment by Neighbors



I further investigate the effect of the two cost sharing rules on the likelihood of investing in the Asymmetric network[30]. I run a logistic panel regression where the binary decision to invest is the dependent variable, and the number of neighbors is the primary variable of interest. In addition to the number of neighbors, I take into account the previous period decision, the total investments by the neighbors in the previous period, round, session fixed effect, and demographic variables – gender and race, and as well as random effects at the subject level. I report the estimated marginal effect by the number of neighbors in Asymmetric network in Table 9[31] for the three treatments: baseline, local cost sharing, and global cost sharing.

[30] The results for Line network structure are available on request.

[31] I find similar results if I use $1/Round$ as an independent variable, see Appendix A.2.

Table 9: Marginal Effect of Neighbors on Investment

	Baseline	Local	Global
One Neighbor (mean)	0.499	0.386	0.678
	(.039)	(.049)	(.041)
Two Neighbors	-0.118*	0.209**	-0.0934
	(0.072)	(0.094)	(0.072)
Three Neighbors	-0.222***	0.276***	-0.207***
	(0.054)	(0.077)	(0.077)
# Neighbors invest lag	0.0157	-0.0283	-0.0478*
	(0.031)	(0.037)	(0.027)
Invest lag	-0.116***	-0.0629	-0.0662
	(0.041)	(0.046)	(0.043)
Round	Yes	Yes	Yes
Race	Yes	Yes	Yes
Gender	Yes	Yes	Yes
Session Fixed Effects	Yes	Yes	Yes
Observations	720	720	720

Robust standard errors in parentheses; $p^{*} < 0.10, p^{**} < 0.05, p^{***} < 0.010$

In the baseline, subjects with two neighbors and subjects with three neighbors are 23% and 44% less likely to invest compared to subjects with one neighbor. Comparing subjects with two or three neighbors, I find no statistically significant difference between the likelihood of investing (p = 0.1490).

The local transfer rule incentivizes subjects with more neighbors to invest in the local public good. Subjects with three neighbors are 71% more likely to invest compared to subjects with one neighbor.

The global cost sharing rule aligns individual incentive with total social welfare, but unlike the local cost sharing rule it does not directly induces individuals with more neighbors to invest.. The subsidized cost of investment could lead to over provision of the public good in the network. In global cost sharing, the subjects with three neighbors are 30% less likely to invest compared to subjects with one neighbor.

2.5 Conclusion

In this chapter, I study a repeated best shot public goods game in three network structures. The primary aim of the chapter is to test mechanisms that can raise the total social welfare. I introduce two cost sharing rules and show theoretically that the inefficient equilibrium in the Line, and Asymmetric network is Pareto dominated by an efficient equilibrium. I used a laboratory experiment to test the empirical validity of the theoretical predictions. Compared to the baseline, which is mired by under-provision of the public good, the two cost sharing rules are successful in increasing access to the public good. However, the increase in access leads to over-investment, which leads to a loss in efficiency. The local cost sharing rule increases efficiency across all network structures, whereas global cost sharing is successful in increasing efficiency only in the Line and Circle networks.

These findings have implications for policy interventions that involve costly investment decisions and have local positive externalities. Examples include the adoption of new farming techniques or making expensive time investments to adopt new medical practices. It is imperative not only to identify the central players who can help with diffusion but also provide incentives in the form of cost sharing rules which lower the cost of experimentation and increase take-up of new products and technology. The local cost sharing rule is successful in raising efficiency across the three network structures. To implement the local cost sharing rule, it suffices to know the maximum degree for any network structure to calibrate the cost sharing proportion. There is evidence from field experiments in India that social networks can be effectively used to implement and uphold contracts (Breza and Chandrasekhar, 2019). Implementing the local cost rule in large networks might be procedurally cumbersome. For a larger network structures, the global cost sharing rule might be more effective since it is easy to implement, and it can help with increasing access to local public goods although there is over-investment in the public good.

3 Communication Architectures in Public Goods Games in Network[32]

3.1 Introduction

Geographical boundaries and pre-existing social structures are important determinants of cooperation among individuals. Both field studies and artifactual field experiments find evidence that merely the knowledge of presence of individuals from different social groups in the decision group can lead to lower levels of cooperation (Cardenas, 2000, Hoff and Pandey, 2006, Cox et al., 2018). There is ample evidence which suggests that asymmetries in social structures can lead to persistent under-provision of local public goods, which disproportionately affects individuals in the periphery (Banerjee and Iyer, 2005, Banerjee and Somanathan, 2007, Munshi and Rosenzweig, 2018).

Thus, it is important to study the effect of asymmetries that arise from natural and social constraints on investments in public goods with local externalities. Social network theory provides a rich theoretical framework that allows for studying how different network structures influence equilibrium coordination (Bramoullé and Kranton, 2007, Bramoullé et al., 2014). Multiplicity of equilibria is a central feature of games in networks. One of the key predictions of the theoretical literature is that stable equilibrium profiles often are inefficient because of over-investment in the local public good (Bramoullé and Kranton, 2007, Boncinelli and Pin, 2012). The experimental literature on the effect of network structure on public good provision confirms this result. Charness et al. (2014) and Rosenkranz and Weitzel (2012) find an inverse relationship between the number of neighbors and the likelihood of investing in the public good. Another robust finding is that stochastic stability governs equilibrium selection[33] (Rosenkranz and Weitzel, 2012, Char-

[32] I would like to express my sincere gratitude to Vjollca Sadiraj, James Cox, David J Cooper, and Tom Mroz for their valuable feedback. Feedback from participants at the Fourth and Fifth Network Science and Economics Conference, and the Southern Economic Association Annual Meetings in 2016. The experiments were funded through the Andrew Young School Dissertation Fellowship.

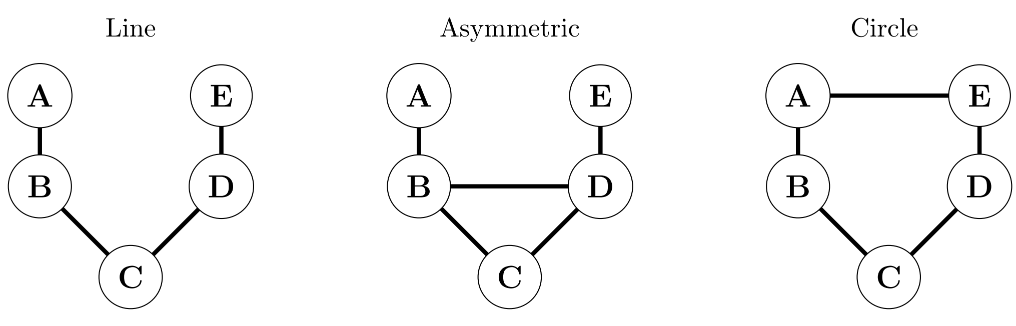
[33] Only 3% of the groups are consistent with a Nash equilibrium (Rosenkranz and Weitzel, 2012).

ness et al., 2014).

Communication between group members could act as a coordination device aiding groups to coordinate away from inefficient provision of local public goods. There is a vast literature that suggests that communication can play a critical role in sustaining cooperation in the provision of public goods game (Ledyard, 1995, Chaudhuri, 2011). There is also evidence that communication networks can enhance efficiency in coordination games (Korkmaz et al., 2018, Choi and Lee, 2014)[34]. Brandts et al. (2019) find that compared to restricted chat unrestricted communication is more effective as a coordination device[35].

In this chapter, I report an experiment designed to test the relative efficacy of two pre-play communication architectures in resolving inefficiencies in a best shot public goods game across three network structures (see Figure 6). Prior to choosing an action in the underlying game, group members engage in an unrestricted text chat in the following two communication structure: the first is a global architecture where all group members can communicate with each other. The second is a local architecture where only connected group members can talk. For example, in the local architecture individual at position A in the Line and Asymmetric network can only communicate with position B, whereas, in the Circle network, she can communicate with B and E.

Figure 6: Network Structures in the Experiment



[34]See Choi et al. (2016) for a review of the literature

[35]Palfrey et al. (2017) presents both theoretical and experimental results that unrestricted text chat is more effective in raising efficiency in threshold public goods games.

There are two sources of inefficiency in the provision of the public good: (i) under-provision, where not all group member receive the benefit from the public good because of underinvestment, and (ii) over-provision, where the public good is provided at excessive cost. Although the commitments made in the pre-play communication are not binding, given the best reply function these are self enforcing[36]. These commitments can help reduce strategic uncertainty and increase efficiency by dissuading both under and overinvestment in the following way. First, it can help gain information about their neighbors' decisions, which can enhance local coordination. Second, Nash equilibrium requires unconnected group members to coordinate their actions. Communication can lead to better group coordination.

I find that introducing pre-play communication increases access to the local public good from 74% in the baseline with no communication to 90% across the three network structures. The increase in the provision of the public good does not come at the cost of overinvestment in the public good; the rate of overinvestment goes down. Comparing across network structures, in the absence of communication I find the Circle network is more efficient which is consistent with the previous research (Fatas et al., 2010, Carpenter et al., 2012, Rosenkranz and Weitzel, 2012, Leibbrandt et al., 2015, Boosey and Isaac, 2016). However with communication these differences dissipate. Consistent with earlier research (Charness et al., 2014, Rosenkranz and Weitzel, 2012) in the baseline I find a negative relationship between the number of neighbors an individual has and their likelihood of investing. Communication is successful is breaking this negative relationship.

This chapter contributes to the experimental literature on pre-play communication, see Crawford (1998), Brandts et al. (2019) for a related survey of the literature. I present evidence regarding the effectiveness of different communication structures on coordination in games of strategic substitutes in networks. To my best knowledge, the focus of both theoretical and experimental research has been on games of strategic complements (Choi et al.,

[36]see Proposition 3

2016). This chapter also contributes to the growing literature studying the effect of network structures on public goods provision [37].

There are few studies of mechanisms that can incentivize individuals in the central positions to invest. Caria and Fafchamps (2018) report results from an artifactual field experiment with farmers in India, where they use expectations of the periphery players as the mechanism to induce pro-social behavior. They find that individuals in the center of a star network reciprocate the expectations of the subjects in the periphery. However, the investment of the center is constrained by the expectation of the periphery players, which could be suboptimal. I contribute to this literature by studying two unstructured communication architectures that can motivate individuals in a central position to make a pro-social investment decision, and the expectations of the periphery do not restrict the choices of subjects. I find that groups in the non-symmetric networks show a preference for both equity and efficiency.

In the next section, I present a theoretical analysis and derive testable hypotheses. Section 3.3 presents the experimental design and procedures. The empirical results are presented in Section 3.4 and Section 3.5 concludes.

3.2 Theoretical Analysis

Let the set of agents be $N = \{1, \ldots, n\}$. Each agent i simultaneously chooses to either invest (1) or not invest (0) in a local public good. Let $\boldsymbol{a} = (a_1, \ldots, a_n)$ denote the action profile of all agents, where $a_i \in \{0, 1\}$ is agent i's action. Agent i's action affects her payoff as well as the payoffs of the agents to whom she is linked through positive externalities. Agents are assigned on a undirected graph. Any two agents i and j who share a local public good are represented by a link: $g_{ij} = g_{ji} = 1$. For two agents who are not linked $g_{ij} = g_{ji} = 0$. Let the collection of all links be represented by $n \times n$ matrix $\boldsymbol{G}$. Let N_i denote the set of agents who are directly linked to agent i, called agent i's *neighbors*:

[37](Fatas et al., 2010, Carpenter et al., 2012, Rosenkranz and Weitzel, 2012, Leibbrandt et al., 2015, Charness et al., 2014, Boosey and Isaac, 2016, Caria and Fafchamps, 2018)

$N_i = \{j \in N/i : g_{ij} = 1\}$. Agents i's *neighborhood* is defined as herself and the set of her neighbors; i.e., $\{i\} \cup N_i$.

An agent gets a benefit of b from the local public good if she or any of her direct neighbors' choose to invest. The cost of providing the local public good, c, is positive but smaller than b. Let $\boldsymbol{a_j}$ denote the set of actions of all agents $j \neq i$. An agent i's payoff is the following:

$$u_i(a_i, \boldsymbol{a_j}, \boldsymbol{G}) = b \times \mathbb{1}\left\{\sum_j g_{ij}a_j + a_i \geq 1\right\} - c \times a_i \tag{7}$$

It is straightforward to show that each agent i's best reply is: $a_i = 1$ if no one in the neighborhood invests and (ii) $a_i = 0$, if at least one of her neighbors invest.

I consider three networks of five agents – Line, Asymmetric, and Circle (see Figure 6). Table 10 reports the pure strategy Nash equilibria for each network structure. One of the central features of this game is the multiplicity of equilibria. Boncinelli and Pin (2012) use the notion of stochastic stability to refine the equilibrium set. Boncinelli and Pin (2012) shows that if both investing and not investing agents randomize or follow a logistic best response, then the only stochastically stable states are Nash equilibria in which the largest number of unlinked agents are investing. Charness et al. (2014) reports evidence in favor of stochastic stability (Boncinelli and Pin, 2012).

Table 10: Pure Strategy Nash Equilibrium

Network (equilibrium)	Investment Choice					$W(\cdot)$
Line	**A**	**B**	**C**	**D**	**E**	
(L1)	1	0	1	0	1	$5b-3c$
(L2)	0	1	0	1	0	$5b-2c$
(L3)	0	1	0	0	1	$5b-2c$
(L4)	1	0	0	1	0	$5b-2c$
Asymmetric						
(A1)	1	0	1	0	1	$5b-3c$
(A2)	0	1	0	0	1	$5b-2c$
(A3)	1	0	0	1	0	$5b-2c$
Circle						
(C1)	1	0	0	1	0	$5b-2c$
(C2)	1	0	1	0	0	$5b-2c$
(C3)	0	1	0	0	1	$5b-2c$
(C4)	0	0	1	0	1	$5b-2c$
(C5)	0	1	0	1	0	$5b-2c$

See appendix B for proof

To analyze the welfare implications of different equilibria, I use a standard utilitarian measure of social welfare, $W(\cdot)$, defined as:

$$W(\boldsymbol{a}, \boldsymbol{G}) = \sum_{i \in N} b \times \mathbb{1}\left\{\sum_j g_{ij} a_j + a_i \geq 1\right\} - c \times \sum_{i \in N} a_i$$

Note that groups maximize the total social welfare when all agents in the network have access to the local public good, and the minimum number of agents are investing. In all the network structures group welfare is maximized when two unlinked agents are investing in equilibrium (see table 10).

Before playing the public goods game, the players engage in pre-play communication, referred to as the communication stage. Pre-play communication is cheap talk in the usual sense that the commitments are not enforceable and payoff-irrelevant. I study the following two communication architectures. First, is a global architecture where all group members can communicate. Second is a local architecture, where only agents connected to each other in the underlying game can communicate with each other.

Although commitments made during the pre-play communication stage are not binding, these commitments are self-enforcing. Suppose agent i commits to invest, then knowing her intentions the best reply for all her neighbors is to not invest. If agent i chooses not to invest, she will earn 0 since her neighbors are not investing. So, she is better off investing and getting $b - c$. Similar arguments can be made for agent i's commitment to not investing.

Proposition 3. ***Commitments made in the communication stage are self-enforcing*[38]*.***

The Nash equilibrium profile is characterized by the maximal independent set[39]. Thus, Nash profiles require coordination on investments of unconnected agents in the network. Since payoffs are determined by an agent's own action, and the action of their direct neighbors, the choices of agents who are not connected are not directly observable, which can lead to coordination failure.

The global communication architecture allows for a complete information network. All agents have the option to gain and verify information about the choices of all group members. This could lead to lower coordination failures, which can lead to an increase in efficiency.

In the local architecture, agents can only communicate with their neighbors. In the three network structures, agents can form coalitions and share information among all group members (Myerson, 1977). At the least, local communication architecture can help with local coordination, which can raise the efficiency of provision.

Hypothesis 6. ***Compared to the baseline, the efficiency in both communication structures will be higher.***

The two communication architectures do not alter the Nash equilibria set. Given the repeated nature of the game, some strategies can raise the efficiency of provision.

[38] Proof in the appendix B

[39] An independent set of a graph is a set of agents such that no two agents who belong to the set are linked. See Theorem 1 Bramoullé and Kranton (2007).

In the Line network, groups can alternate between agents in positions {B,D} and {A,C,E} investing across rounds. If this history is not observed, agents in positions {A,C,E} switch to not invest for the rest of the rounds. In the Asymmetric network, groups can increase efficiency and equity by alternating between the three pure strategies Nash equilibrium. If groups care only about efficiency in both the Line and Asymmetric network across rounds, agents in position {A,D}, and {B,E} can take turns to invest. In the Circle network, all the Nash equilibria are efficient, and alternating between the five pure strategies Nash equilibrium can raise equity while maintaining efficiency.

If all group members use these strategies then any unilateral deviations by agents will yield a lower payoff. The strategy in the Line network where agents in positions {B,D} and {A,C,E} alternate, there is a credible threat by agents in the periphery to enforce the *max-min* payoff of $b - c$ on the central agents by not investing for the rest of the rounds.

Hypothesis 7. ***The two communication architectures will incentivize groups to utilize repeated game strategies across all network structures.***

Comparing across the three network structures, the Circle network has the largest set of Nash equilibria followed by Line and Asymmetric. However, the Line and Asymmetric networks have one stochastically stable Nash equilibrium profile. A larger equilibrium set can lead to a loss in the efficiency of provision because of coordination failure. In the Line and Asymmetric networks, if groups coordinate on the stable equilibrium[40] there should not be any difference in the efficiency across them.

The global architecture has two countervailing effects. On the one hand, it can be more effective, since all agents can communicate and verify information. However, all group members communicating can overwhelm which can lead to coordination failures. Local structure restricts communication between only neighbors; the focused nature of the architecture can help with better local coordination. However, coordination on Nash equilibria requires unconnected agents to coordinate their investment decisions, which is not readily

[40] As observed in Charness et al. (2014).

available in local communication. It is an open empirical question of how these two communication architectures interact with the three network structures.

Hypothesis 8. ***Efficiency is the same in Line and Asymmetric networks and higher in Circle network.***

3.3 Experimental Design and Procedure

I conducted the experiment at the ExCEN lab at Georgia State University from June to November 2018. 180 subjects took part in the experiment over 12 sessions. I recruited the subjects via email using the ExCEN automated system. Upon arrival at the lab, the subjects reviewed and signed the consent form and were randomly assigned seats in the lab. Each session was conducted in three stages, followed by a demographic survey. At the start of each stage, subjects were instructed to read the experimental instruction (*see appendix B*) at their pace[41]. Before the start of each stage, to gauge a better understanding of the game, subjects had the option to explore a game simulator at their own pace; they also played a set of practice rounds. Each session[42] lasted for roughly one hour and fifteen minutes.

Subjects only participated in one of the three network structure: Line, Asymmetric, or Circle. Each session consisted of three stages of ten rounds each. At the start of each stage, subjects were randomly matched to form groups of five, and each subject was randomly assigned a network position. The group members and the position of subjects remained fixed within each stage. Across stages, treatments were introduced. In the first stage, subjects played the game without communication, followed by the two communication architectures. Across sessions, the order in which the two communication architectures were introduced was randomized.

The benefit from an investment in the neighborhood common fund was 100 cents for

[41] A summary of instructions was read out loud which was available for subjects to see on their computer screens.
[42] Computerized using z-Tree (Fischbacher, 2007).

all individuals in the investor's neighborhood, and the cost was 75 cents. In both stages with communication, there was a one-minute communication period before making an investment decision. In global communication treatment, all group members could communicate, whereas in the local communication treatment subjects could communicate with only their neighbors.

At the end of every round, the subjects were provided a summary of the number of the contributing neighbors, their position on the network, their investment decisions and their earnings; this information was available for all 30 periods. I repeated the stage game for ten rounds[43] to allow for enough time for groups to understand the game and coordinate on an equilibrium.

At the end of each session, each subject answered a questionnaire on demographics and some context-specific risk and social preferences questions. Subjects were paid for all the 30 periods in cash privately right after the experiment session. The average payoff in the experiment was \$16.10 per subject, with a minimum of \$9 and maximum earning of \$26.75.

3.4 Results

3.4.1 Efficiency across communication architecture

The two communication architectures do not alter the set of Nash equilibrium. However, communication can reduce strategic uncertainty. The commitments made in the preplay communication stage are self-enforcing. Suppose a subject commits to investing; the best reply for all her neighbors is not to invest. If she reneges on her commitment, she will earn a zero for that round, so she is better off investing. Thus, communication can enhance efficiency by lowering coordination failures.

Hypothesis 6 predicts that compared to the baseline, the two communication treat-

[43]Best response dynamics converge to a pure strategy Nash equilibrium within at most $2 \times N$ (Komarovsky et al., 2015, Proposition 2); in our case 10 rounds.

ments improve the efficiency of public good provision. To test this hypothesis, I define efficiency using a traditional measure[44]. Comparing the distribution of efficiency across treatments for each of the network structures introducing communication enhances efficiency across all network structures[45] (*see Figure 7*).

Figure 7: Cumulative Distribution of Efficiency

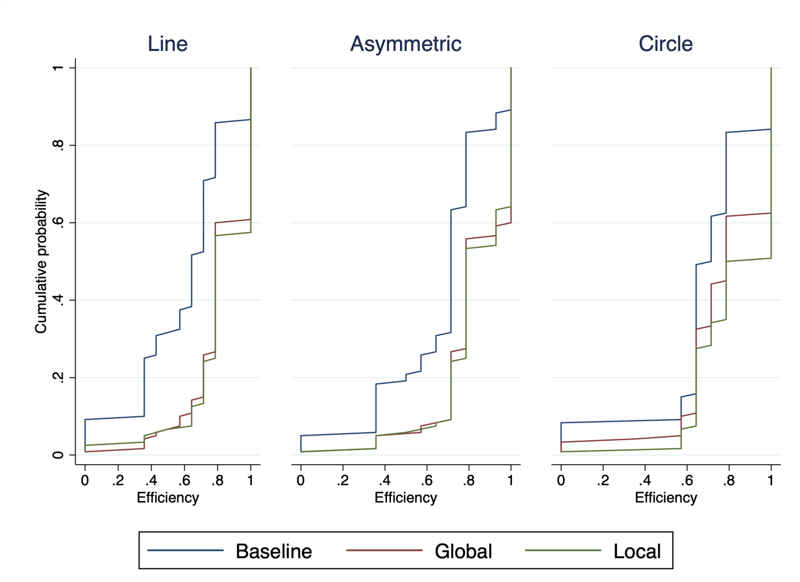
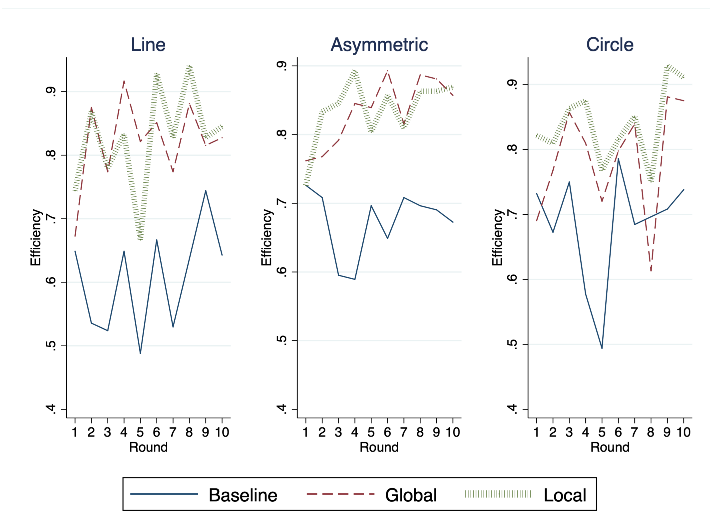


Figure 8: Efficiency Across Rounds



[44] $\text{Efficiency} = \frac{\text{Realized Payoff}_{\text{round}}}{\text{Theoretical Max. Payoff}}$

[45] I conduct am analysis using the 1/round as a dependent variable and in a separate analysis only use periods 5-10 and find the similar results (*please see Appendix B.2.1 and B2.2*).

Given the repeated nature of the game, learning about the group can help with coordination; across the rounds, there are changes in efficiency (*see Figure 8*). To estimate the effect of the two communication architecture on efficiency, I estimate a random effect GLS model. I perform separate estimations for each of the network structures. The model for each network structure is:

$$E_{it} = \sum_{k=1}^{3} \beta_k C^k + \kappa Round + \varepsilon_{it} \tag{8}$$

where E_{it} is the group i's efficiency in period t, C^K indicates the communication treatment variable, where C^1 is the no communication treatment, C^2 is the global architecture, and C^3 is the local architecture. I use the round number as a control for learning. Table 11[46] reports changes in efficiency with respect to the C^1, the treatment without communication.

Table 11: Efficiency Across Treatment

	Line	Asymmetric	Circle
Global	0.214***	0.161***	0.101***
	(0.041)	(0.036)	(0.027)
Local	0.220***	0.163***	0.155***
	(0.040)	(0.036)	(0.034)
Round	0.00924**	0.00744**	0.00625**
	(0.005)	(0.004)	(0.003)
Observations	360	360	360

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

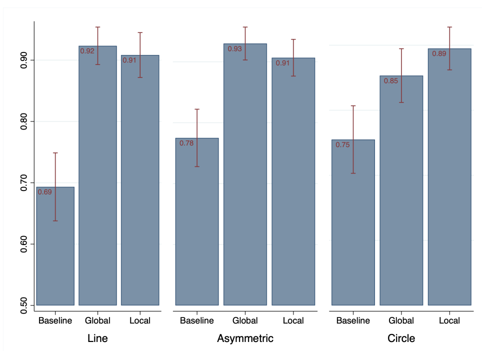
Across the three network structures compared to the baseline, both the global and local communication structures lead to an increase in efficiency. However, when comparing the between the two communication architectures, I find no statistically significant dif-

[46] I conduct am analysis using the 1/round as a dependent variable and in a separate analysis only use periods 5-10 and find the similar results (*please see Appendix B.2.1 and B2.2*).

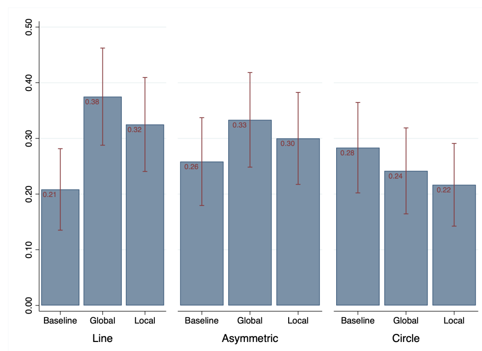
ferences[47]. An increase in access[48] can drive the gain in efficiency. At the same time, an increase in access could lead to overprovision[49] of the public good which impedes efficiency. Introducing the communication architectures increases access to the public good from 75% to 90% across the network structure. Increase in access is not coupled with overinvestment. In fact, local communication lowers excess investment in Circle network (*see figure 9a and 9b*).

Figure 9: Sources of Inefficiency

Access to Public Good



Overprovison of Public Good



Result 5. *The two communication architectures enhance efficiency across all network structures by increasing access to the local public good.*

Individuals with more neighbors get the highest payoff in the inefficient equilibrium. If subjects care only about maximizing their payoffs, then individuals in positions B and D will commit to not investing in the communication stage. Since commitments are self-enforcing, the efficiency in the Line and Asymmetric network would be lower compared to the Circle where all Nash equilibria are efficient. Hypothesis 8 predicts the Circle network to be more efficient. To estimate the effect of the network structure has on efficiency, similar to specification (8), I estimate a random effect GLS model for each of the treatments.

[47] I fail to reject the null hypothesis of the Wald test of equality of the coefficients.

[48] I measure access to the public good as the ratio between the total number of subjects in the group who receive a benefit and total group size.

[49] I define overprovision in a round as a binary variable which takes the value one if all five group members receive a benefit from the public good but there are over two investments in the group.

The model for each treatment is:

$$E_{it} = \sum_{k=1}^{3} \beta_k N^k + \kappa Round + \varepsilon_{it} \tag{9}$$

where E_{it} is the group i's efficiency in period t, N^K indicates the network treatment variable, where N^1 is the Line, N^2 is the Asymmetric, and N^3 is the Circle network. I control for *learning* by using the round number as a measure. The results in Table 12[50] report changes in the efficiency with respect to the N^1 the line network.

Table 12: Efficiency Across Network

	Baseline	Local	Global
Line (mean)	0.606	0.821	0.826
	(0.025)	(0.017)	(.019)
Asymmetric	0.0667*	0.0131	0.0101
	(0.037)	(0.035)	(0.034)
Circle	0.0774**	-0.0357	0.0131
	(0.037)	(0.039)	(0.031)
Round	0.00535	0.00930***	0.00829***
	(0.004)	(0.004)	(0.003)
Observations	360	360	360

Robust standard errors in parentheses; $p^* < 0.10, p^{**} < 0.05, p^{***} < 0.010$

In the baseline treatment compared to Line, both the Asymmetric and Circle networks are more efficient. However, with communication, I find no statistically significant difference between the three network structures. In Line and Asymmetric networks, groups achieve 83% efficiency across both the communication architectures, which is higher that the efficiency of coordinating on the inefficient equilibrium[51]. This suggest that subjects' when making their decision have both efficiency and equity[52] concerns. Compared to the

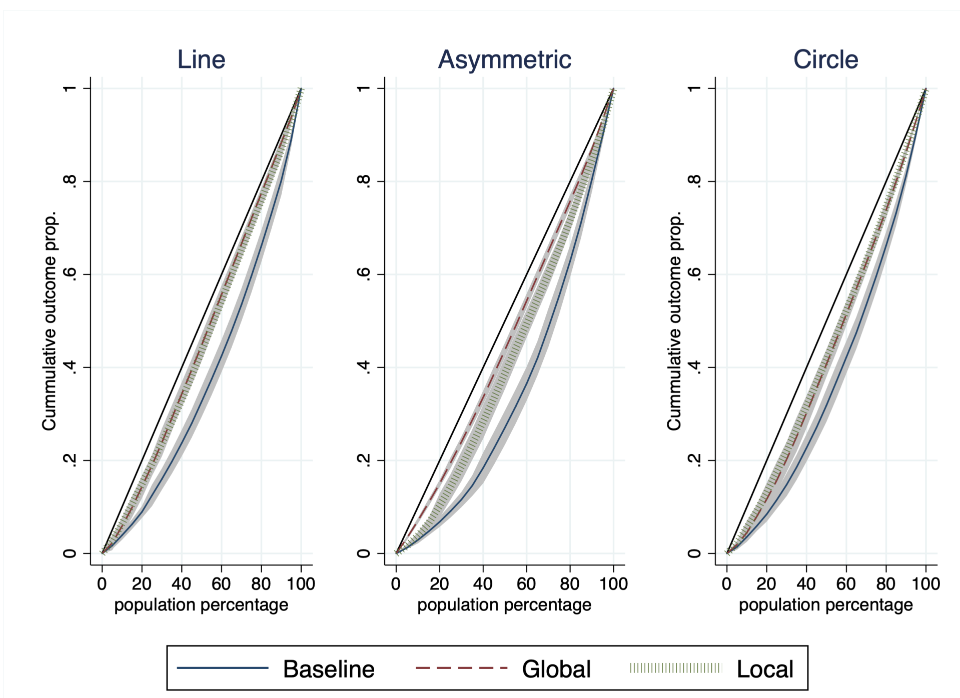
[50] I conduct am analysis using the 1/round as a dependent variable and in a separate analysis only use periods 5-10 and find the similar results (*please see Appendix B.2.1 and B2.2*).
[51] $\frac{5\times100-3\times75}{5\times100-2\times75} \approx 79\%$
[52] I use Gini as a measure of inequality

baseline, communication across all network structures lead to an increase in both total group payoff and lead to a more equitable distribution of earnings among subjects (*see Figure 10 and Table 13*). Across the three network structure the efficient equilibrium profiles are the ones in which two unconnected neighbors are investing and everyone in the group receive a benefit from the public good. If groups learn to alternate between them, this can increase both efficiency and equity. I explore equilibrium selection in the next section.

Table 13: Total Profit – By Type

	Line			**Asymmetric**			**Circle**		
Position	**Baseline**	**Global**	**Local**	**Baseline**	**Global**	**Local**	**Baseline**	**Global**	**Local**
A	337.5	556.2	558.3	264.6	518.8	464.6	639.6	545.8	589.6
B	466.7	612.5	600.0	750.0	614.6	677.1	356.2	568.8	597.9
C	479.2	597.9	625.0	431.2	625.0	681.2	437.5	577.1	618.8
D	497.9	579.2	600.0	587.5	618.8	602.1	575.0	502.1	545.8
E	341.7	527.1	508.3	322.9	541.7	502.1	385.4	554.2	585.4
Total	**2123.0**	**2872.9**	**2891.6**	**2356.2**	**2918.9**	**2927.1**	**2393.7**	**2748.0**	**2937.5**

Figure 10: Lorenz Curve



Result 6. *Communication aids groups towards more equitable and efficient payoffs and mitigates differences in efficiency across the three network structures.*

3.4.2 Equilibrium Selection

Table 14[53] reports the share of observations consistent with a pure strategy Nash equilibrium predictions[54].

Table 14: Frequency of Equilibrium

		Baseline	Global	Local
Line	Not an equilbria	79%	31%	30%
	L1 - A, C, & E	7%	29%	27%
	L2 - B & D	4%	35%	30%
	L3 - B & E	3%	3%	8%
	L4 - A & E	7%	3%	6%
Asymmetric	Not an equilbria	85%	63% (46%)	61% (52%)
	A1 - A, C, & E	5%	13% (13%)	12% (12%)
	A2 - B & E	5%	10% (10%)	13% (13%)
	A3 - A & D	5%	13% (13%)	14% (14%)
	A4* - B & D	0%	(18%)	(9%)
Circle	Not an equilbria	83%	62%	50%
	C1 - A & D	3%	8%	12%
	C2 - A & C	0%	8%	9%
	C3 - B & E	8%	8%	10
	C4 - C & E	3%	6%	11%
	C5 - B & D	3%	8%	8%

*Behavioral Equilibrium - B & D invest

The commitments made in the pre-play communication stage are non-binding and have no direct effect on the payoff. However, they add to the information available to subjects before they decide. The global structure has two countervailing effects. On the one hand, it can be more effective in reinforcing a common prior among all group members aiding coordination. But on the other hand, all group members communicating can be overwhelming, which can lead to coordinate failures. In the local structure there is more

[53] The equilibrium coordination in periods 5 - 10 and find the similar results (*please see Appendix B.2.2*)

[54] Note that in the Asymmetric network B and D investing although is not a Nash equilibrium but groups consistently coordinate on this action profile

focused communication among neighbors, which can help with better coordination. However, group members are not aware of the decision of other group members. Since coordination depends on the actions of the unconnected subjects in the group, the lack of information can lead to failure to achieve a Nash equilibrium. It is an open empirical question, which one would lead to better coordination.

In the baseline, with no communication across all network structures, only 17.5% of the observations are consistent with an equilibrium prediction. The two communication architecture across the three network structures lead to an increase in the likelihood of coordinating on a Nash equilibrium profile. The rate of coordination on an equilibrium increases over two-and-a-half times in the Line and Asymmetric network, and over one and half times in the Circle network (*see Table 26 in Appendix B2*). However, there is no statistically significant difference between the two communication architectures[55].

Comparing the three network structures, in the Line and Asymmetric network if individuals care only about their payoffs, subjects in position B and D would commit to not invest which maximize their payoff. As a result groups could be more likely to coordinate on the inefficient equilibrium. In the Circle network, although all Nash equilibria are efficient, the set is the larger. A larger set might lead to mis-coordination.

Groups in the Line network across both the communication architectures are more successful in coordinating on a pure strategy Nash profile. In the global architecture groups compared to Line, groups in the Asymmetric and Circle networks, are 50% less likely to coordinate on an equilibrium profile. However, in contrast to the global, the local communication helps with coordination in the Circle network. In comparison to the Line network, the groups in the Asymmetric and Circle network are 42% and 28% less likely to coordinate on an equilibrium see Table 27).

Across the three network structures and treatments, groups coordinate on several equilibrium profiles (see Figure 11). Consistent with hypothesis 7 the communication architec-

[55]I fail to reject the null hypothesis of the Wald test of equality of the coefficients.

tures lead to a discernible pattern of investment across rounds in the Line and Asymmetric networks, suggesting a repeated game dynamic. These dynamics vary across the three network structures.

Figure 11: Equilibrium

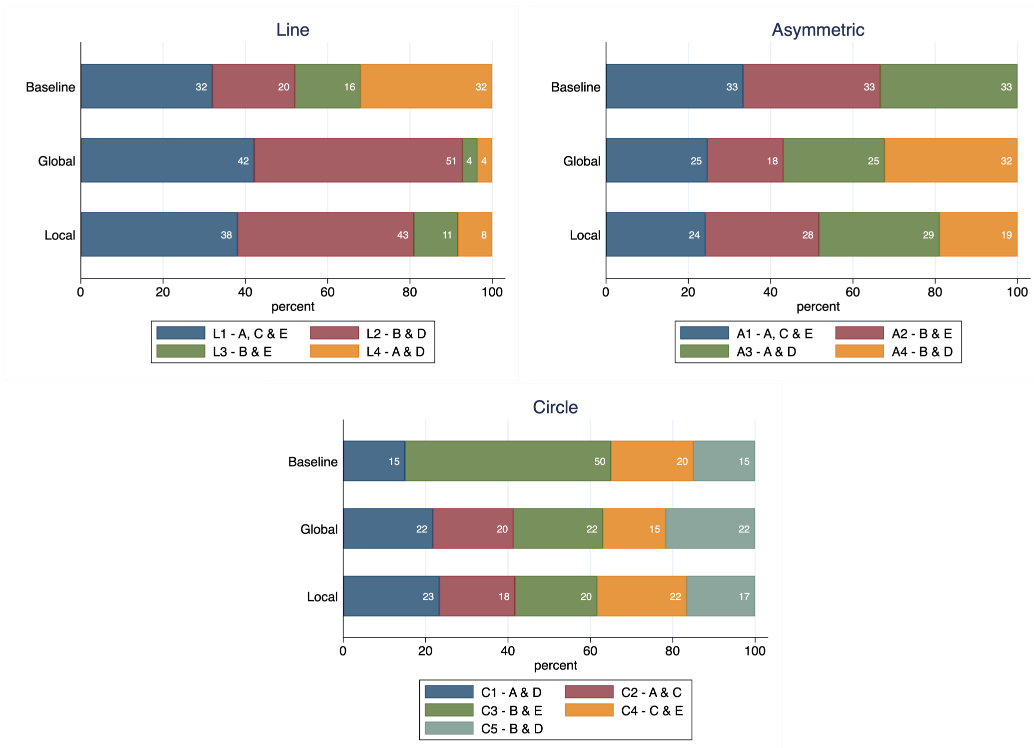


Table 15: Markov Transition Matrix – Between Equilibrium Profiles

	Baseline						**Global Communication**						**Local Communication**					
							Line											
	No	L1	L2	L3	L4		No	L1	L2	L3	L4		No	L1	L2	L3	L4	
No	0.77	0.07	0.06	0.04	0.07		0.54	0.13	0.26	0.03	0.05		0.41	0.13	0.28	0.08	0.10	
L1	0.78	0.00	0.00	0.00	0.22		0.06	0.00	0.94	0.00	0.00		0.15	0.03	0.76	0.03	0.03	
L2	0.91	0.09	0.00	0.00	0.00		0.21	0.77	0.00	0.00	0.03		0.28	0.72	0.00	0.00	0.00	
L3	0.67	0.33	0.00	0.00	0.00		0.80	0.00	0.20	0.00	0.00		0.50	0.25	0.00	0.00	0.25	
L4	1.00	0.00	0.00	0.00	0.00		0.50	0.00	0.00	0.50	0.00		0.25	0.13	0.00	0.63	0.00	
							Asymmetric											
	No	A1	A2	A3	A4		No	A1	A2	A3	A4		No	A1	A2	A3	A4	
No	0.86	0.04	0.04	0.05			0.48	0.08	0.08	0.18	0.17		0.50	0.08	0.21	0.13	0.08	
A1	0.67	0.33	0.00	0.00			0.19	0.00	0.00	0.13	0.69		0.57	0.00	0.00	0.07	0.36	
A2	1.00	0.00	0.00	0.00			0.45	0.18	0.09	0.27	0.00		0.64	0.07	0.00	0.29	0.00	
A3	0.71	0.00	0.29	0.00			0.69	0.00	0.31	0.00	0.00		0.63	0.00	0.19	0.19	0.00	
A4	0.00	0.00	0.00	1.00			0.41	0.53	0.06	0.00	0.00		0.29	0.57	0.00	0.07	0.07	
							Circle											
	No	C1	C2	C3	C4	C5	No	C1	C2	C3	C4	C5	No	C1	C2	C3	C4	C5
No	0.82	0.03		0.10	0.02	0.03	0.67	0.07	0.08	0.05	0.05	0.08	0.50	0.14	0.09	0.08	0.13	0.06
C1	1.00	0.00		0.00	0.00	0.00	0.56	0.00	0.00	0.22	0.11	0.11	0.50	0.00	0.00	0.33	0.08	0.08
C2							0.33	0.00	0.00	0.44	0.00	0.22	0.36	0.00	0.00	0.27	0.00	0.36
C3	0.75	0.00		0.00	0.25	0.00	0.80	0.20	0.00	0.00	0.00	0.00	0.64	0.00	0.21	0.00	0.07	0.07
C4	1.00	0.00		0.00	0.00	0.00	0.63	0.25	0.00	0.00	0.00	0.13	0.64	0.36	0.00	0.00	0.00	0.00
C5	0.86	0.00		0.14	0.00	0.00	0.25	0.13	0.38	0.00	0.25	0.00	0.25	0.13	0.25	0.00	0.38	0.00

Line

With global architecture, 83% of the groups learn to alternate between equilibrium profiles where: (i) subjects in positions A, C, and E (L1) invest and (ii) subjects in positions B, and D (L2) invest. Coordination on L1 and L2 make up 93% of the observations consistent with an equilibrium. 94% of the observations which start off in L1 transition to L2, and, 77% of the observations which start off in L2 transition to L1 (see Table 15 and Figure 25). The switching between L1 and L2 equilibrium addresses concerns of equity and efficiency. In all other efficient equilibrium profiles, the subjects in position C always free rides on the investment of B and D. If subjects care about inequality then coordinating between L2, L3, L4 profiles although is efficient, favors the payoff of C. Coordinating on the stochastically stable profile, L1, would lead to greater levels of inequity in the group since subjects in positions B and D receive the highest payoffs. The global communication subjects in positions A, C, and E form a majority and together can change the status quo of the stochastic stable equilibrium by deciding to not invest which forces B and D to invest. Alternating between L1 and L2 is an $\alpha - stable$ allocation[56] if subjects in the group make network-based relative income comparisons (Cheng and Xing, 2018).

Similar to the pattern in global architecture, in the local communication groups coordinate on L1 and L2 (see Table 15). Over 72% of the observations start at L1 transition to L2 and vice versa (see Table 15). Local architecture gives subjects at C a central position in the communication network. C acts as an information bridge between B and D, which is critical for coordination on any efficient equilibrium profiles. Two groups where C exploits their central position consistently alternate between two equilibrium profiles, where B and E invest (L3) and A and B invest (L4) (see Figure 25).

[56]An allocation is stable if it is not revoked under α-majority voting; that is, there exists no alternative allocation, such that a fraction of at least α of the population have their rankings strictly improved under the alternative. In this case, $\alpha = 0.5$.

Asymmetric

In the global communication, in addition to the three pure strategy Nash equilibrium profiles, 18% of group decisions are consistent with an action profile where B and D are investing (A4). Four out of twelve groups consistently alternate between A, C, and E (A1) investing and A4 (see Figure 26). One group[57] learns to alternate between the two efficient equilibria, where in one round A and D invests (A2) and the next round B and E invest (A3). One group[58] is successful in rotating between the three pure strategy Nash equilibrium profiles. Unlike, the Line network groups in the Asymmetric network groups do not have access to a clear focal strategy to alternate between two Nash equilibria which can address both efficiency and equity concerns. A4 is not enforceable since subjects in B and D can make the same payoff by taking turns among themselves. Alternating between the two efficient equilibrium (A2 and A3) renders higher payoff to subjects in position C. In this network, it is harder for groups to address both efficiency and equity concerns which leads to frequent mis-coordinations.

With local communication, the number of observations consistent with A4 falls in half to 9%. Only two groups consistently alternate between A1 and A4. Groups value overall efficiency as reflected in frequent coordination on A2 and A4 (see Figure 11 and Table 15).

Circle

The circle network has the largest pure strategy Nash equilibrium set, which can overwhelm groups negotiating to coordinate on across the ten rounds. In global communication, only half of the groups were successful in alternating or successively coordinating on an equilibrium. In contrast, local architecture leads to higher levels of coordination, suggesting that restricted communication helps with coordination on any equilibrium. There is substantial heterogeneity among groups to discern a common pattern. The groups suc-

[57]Group 3 see Figure 26

[58]Group 12 see Figure 26

cessful in coordinating on equilibria were equally likely to coordinate on any of the five pure strategy equilibrium (see Table 15).

Result 7. *Both communication architectures lead to a higher rate of coordination on the set of pure strategy Nash equilibria. However, there is substantial heterogeneity across the three network structures on equilibrium profiles groups coordinate on.*

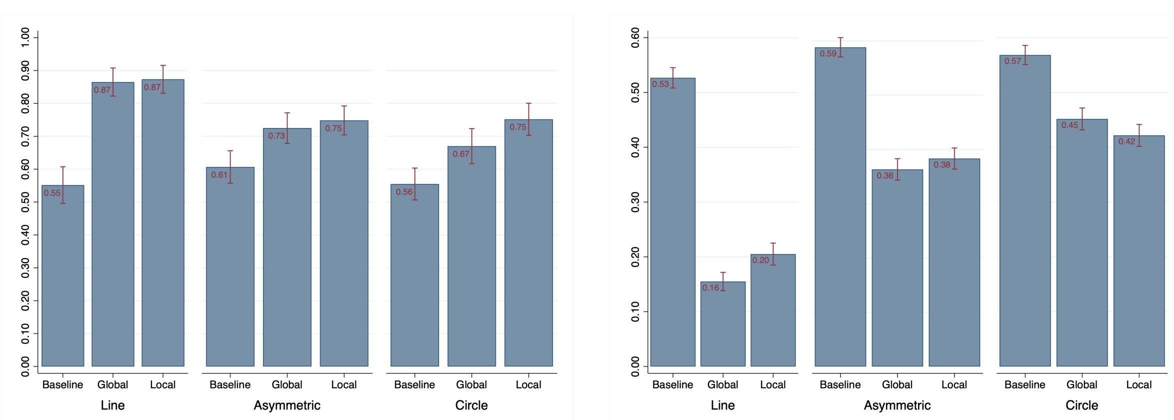
3.4.3 Do subjects learn from their neighbors?

Equilibrium coordination depends on the actions of unconnected agents. Communication can help with easing coordination failure. The average best reply increases with implementation of the two communication structures (see Figure 12, consistent belief). Absent communication, across all network structures more than half of the subjects based their decisions on their neighbor's action in the previous round. The proportion of groups giving myopic best reply falls after introducing communication (see Figure 12, myopic best reply).

Figure 12: Group Best Reply Rate

Consistent Belief

Myopic Best Reply



Recall, the best reply is to invest if no one in the neighborhood invests and to not invest if at least one of her neighbors invests. To estimate the effect of the two communication architecture on how subjects in the game respond, I estimate a random effect GLS model. I perform separate estimations for subjects grouped according to their position[59] in the network. The model for each group is:

$$invest_{it} = \sum_{k=1}^{3} \beta_k C^k + \delta \mathbb{1}\{\sum_{j \in N_i} a_j \geq 1\} + \sum_{k=1}^{3} \zeta_k C^k \times \mathbb{1}\{\sum_{j \in N_i} a_j \geq 1\} + \eta X_i + \varepsilon_{it} \tag{10}$$

where $invest_{it}$ is the investment decision of subject i in period t, C^K indicates the communication treatment variable, where C^1 is the no communication treatment, C^2 is the global architecture, and C^3 is the local architecture. $\mathbb{1}\{\sum_{j \in N_i} a_j \geq 1\}$ is an indicator function which takes the value one if at least one of subject i's neighbors invest. X_i includes controls for last period decision, round , session fixed effect, and demographic variables – gender and race.

Compared to the baseline, subjects on average are investing more in the two communication structures across all network structures (see Table 16[60]. The low level of investment in the treatment without communication is consistent with the conclusion that underprovision of the public good leads to lower efficiency without communication. In the absence of strategic uncertainty, all subjects give the best reply to their neighbors across the baseline and the two communication architectures, which implies $\delta = -1$ therefore $\zeta_k = 0$. A negative coefficient of ζ implies that communication helps in reducing strategic uncertainty. I find that subjects compared to the baseline are less likely to invest when at least one of their neighbors invest in the two communication treatments (see Table 16). These findings suggest that the consistency of belief about neighbors' play increases with communication.

[59]In the Line and Asymmetric network, there are three groups: A & E, C, and, B &D.

[60]I conduct a similar analysis using the 1/round as a dependent variable and find the similar results (*please see Appendix B.2.1*)

Table 16: Effect of Communication on Investment Decision

	Line			Asymmetric			Circle
	A & E	C	B & D	A & E	C	B & D	All
Global	0.270***	0.459***	0.426***	0.243***	-0.0310	0.579***	0.107
	(0.094)	(0.145)	(0.081)	(0.076)	(0.154)	(0.134)	(0.067)
Local	0.215**	0.443***	0.393***	0.148*	0.0397	0.558***	0.215***
	(0.102)	(0.130)	(0.075)	(0.086)	(0.131)	(0.123)	(0.067)
Atleast one neighbor invests	-0.0937	-0.0666	-0.0599	-0.132	-0.131*	-0.0625	-0.0871*
	(0.065)	(0.108)	(0.073)	(0.082)	(0.080)	(0.063)	(0.051)
Atleast one neighbor invests x Global	-0.463***	-0.603***	-0.608***	-0.379***	-0.213	-0.324***	-0.191***
	(0.102)	(0.144)	(0.107)	(0.096)	(0.146)	(0.109)	(0.073)
Atleast one neighbor invests x Local	-0.470***	-0.688***	-0.625***	-0.315***	-0.333**	-0.426***	-0.357***
	(0.091)	(0.124)	(0.093)	(0.106)	(0.166)	(0.110)	(0.071)
Invest lag	-0.253***	-0.0672	-0.151***	-0.237***	-0.175***	-0.324***	-0.190***
	(0.039)	(0.049)	(0.055)	(0.034)	(0.066)	(0.060)	(0.030)
Round	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Experience	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Race	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Session	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	696	348	696	696	348	696	1740

Robust standard errors in parentheses; $p^{*} < 0.10, p^{**} < 0.05, p^{***} < 0.010$

Across the two communication structures, there are differences in the information available to the subjects. In the global architecture, subjects can incorporate the decisions of everyone in the group, whereas in the local structure, information is readily available about their direct neighbors but not of member further away. To identify what information applies to subjects, I estimate a random effect GLS model. I perform separate estimations for each position in the network and across all treatment. The model specification:

$$invest_{it}^{I} = \sum_{k=1}^{4} \beta_k invest_{jt}^{k} + \eta X_i + \varepsilon_{it} \quad \text{for } i \neq j \tag{11}$$

Where $invest_{it}^{I}$ is the investment decision of subject i in position I in period t. $invest_{jt}^{K}$ represents the investment decision of subject j in position K[61] in period t. X_i includes control for round , session fixed effect, and demographic variables – gender and race. Table 17 and 18[62] report results from Baseline , and the two communication structures.

[61] $K \neq I$

[62] I conduct am analysis using the 1/round as a dependent variable and find the similar results (*please*

Table 17: Baseline – Effect of Other's Decision on Your Decision

	Line					Asymmetric					Circle				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
Invest A		-0.126***	-0.0499	-0.0404	0.0386		-0.0692**	-0.215***	0.0767**	-0.133***		0.00650	0.203***	0.103**	-0.161***
		(0.021)	(0.047)	(0.047)	(0.033)		(0.030)	(0.038)	(0.038)	(0.050)		(0.049)	(0.071)	(0.043)	(0.028)
Invest B	-0.133***		0.121***	0.0390	-0.0538	-0.0938**		-0.0819	0.0253	0.109***	0.00381		0.151***	-0.0568**	0.142***
	(0.025)		(0.040)	(0.047)	(0.046)	(0.041)		(0.050)	(0.037)	(0.037)	(0.029)		(0.043)	(0.028)	(0.040)
Invest C	-0.0583	0.136***		-0.222***	0.174***	-0.269***	-0.0718		0.140***	0.156***	0.120***	0.151***		0.0304	-0.0576
	(0.055)	(0.045)		(0.037)	(0.046)	(0.047)	(0.044)		(0.036)	(0.050)	(0.045)	(0.042)		(0.036)	(0.051)
Invest D	-0.0417	0.0415	-0.209***		-0.0769	0.0904**	0.0101	0.130***		-0.129**	0.0665**	-0.0626**	0.0334		-0.0371
	(0.049)	(0.047)	(0.033)		(0.049)	(0.045)	(0.031)	(0.037)		(0.061)	(0.028)	(0.031)	(0.039)		(0.054)
Invest E	0.0369	-0.0483	0.142***	-0.0600		-0.122**	0.0779***	0.116***	-0.104**		-0.115***	0.174***	-0.0702	-0.0412	
	(0.031)	(0.042)	(0.038)	(0.044)		(0.048)	(0.026)	(0.039)	(0.050)		(0.018)	(0.053)	(0.064)	(0.058)	
Round	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Race	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Session	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Baseline

In the Line network, the actions of the subjects on the periphery, A and E, have an inverse relation with their neighbors. Unlike subject at position D whose actions are consistent with a best reply to both her neighbors, subjects at positions B and C give a best reply to only one of their two neighbors. There is a positive relationship between the actions of subjects B and C, which leads to overprovision.

Without communication subjects in the periphery (A and E) in Asymmetric network, take actions consistent with the best reply function. Subjects in positions B and D replicate this pattern in the actions with their neighbors in the periphery. However, the actions of subjects B, C, and D between them contradict the best response, which leads to overprovision. In the absence of communication, subjects across all positions end up miscoordinating their actions with at least one of their neighbors in the Circle network.

see Appendix B.2.1).

Table 18: Communication – Effect of Other's Decision on Your Decision

	Line					Asymmetric					Circle				
	A	B	C	D	E	A	B	C	D	E	A	B	C	D	E
								Global Communication							
Invest A		-0.479***	0.255***	-0.280***	0.105***		-0.615***	-0.0476	0.134***	0.127***		-0.366***	-0.0000278	-0.00856	-0.0988**
		(0.071)	(0.035)	(0.033)	(0.037)		(0.030)	(0.058)	(0.041)	(0.046)		(0.048)	(0.056)	(0.051)	(0.042)
Invest B	-0.476***		-0.374***	0.131***	-0.0912***	-0.647***		-0.271***	0.0562	0.0223	-0.382***		-0.270***	0.0488	0.0719
	(0.085)		(0.054)	(0.045)	(0.034)	(0.030)		(0.046)	(0.037)	(0.036)	(0.056)		(0.050)	(0.042)	(0.047)
Invest C	0.204***	-0.301***		-0.0836*	0.191***	-0.0367	-0.198***		-0.0742*	0.101***	-0.0000272	-0.254***		-0.0986*	0.154***
	(0.040)	(0.043)		(0.045)	(0.034)	(0.045)	(0.037)		(0.039)	(0.039)	(0.055)	(0.043)		(0.051)	(0.047)
Invest D	-0.212***	0.0999**	-0.0794*		-0.451***	0.152***	0.0607	-0.109*		-0.669***	-0.00748	0.0409	-0.0880**		-0.129***
	(0.039)	(0.046)	(0.042)		(0.052)	(0.049)	(0.039)	(0.064)		(0.032)	(0.045)	(0.034)	(0.043)		(0.036)
Invest E	0.0674**	-0.0590**	0.154***	-0.382***		0.148***	0.0247	0.154***	-0.688***		-0.0861**	0.0601	0.137***	-0.129***	
	(0.027)	(0.029)	(0.041)	(0.044)		(0.050)	(0.040)	(0.054)	(0.027)		(0.035)	(0.040)	(0.038)	(0.035)	
								Local Communication							
Invest A		-0.616***	0.238***	-0.0770	0.167***		-0.468***	-0.126**	-0.125***	-0.0108		-0.293***	-0.0273	0.0865**	-0.324***
		(0.086)	(0.071)	(0.058)	(0.058)		(0.040)	(0.053)	(0.025)	(0.033)		(0.042)	(0.052)	(0.041)	(0.037)
Invest B	-0.619***		-0.276***	0.205***	0.226***	-0.646***		-0.475***	-0.316***	-0.0321	-0.298***		-0.408***	0.0700*	0.148***
	(0.062)		(0.057)	(0.074)	(0.058)	(0.034)		(0.054)	(0.049)	(0.054)	(0.051)		(0.043)	(0.039)	(0.037)
Invest C	0.190***	-0.218***		-0.298***	0.109**	-0.132**	-0.360***		-0.308***	0.000367	-0.0286	-0.420***		-0.250***	0.143***
	(0.043)	(0.069)		(0.058)	(0.053)	(0.054)	(0.046)		(0.054)	(0.052)	(0.054)	(0.033)		(0.054)	(0.035)
Invest D	-0.0597	0.158**	-0.303***		-0.572***	-0.141***	-0.257***	-0.331***		-0.538***	0.0743**	0.0590*	-0.205***		-0.214***
	(0.043)	(0.064)	(0.039)		(0.052)	(0.023)	(0.043)	(0.050)		(0.064)	(0.036)	(0.034)	(0.044)		(0.049)
Invest E	0.0891**	0.120***	0.0663*	-0.394***		-0.0108	-0.0234	0.000352	-0.481***		-0.301***	0.134***	0.125***	-0.228***	
	(0.041)	(0.035)	(0.035)	(0.051)		(0.033)	(0.039)	(0.050)	(0.056)		(0.032)	(0.033)	(0.034)	(0.049)	
Round	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Race	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Session	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Communication Architectures

In both communication architectures in the Line network, subjects across all positions coordinate their action with all group members. As predicted by the best reply function, subjects' action is negatively related to their direct neighbors. There is a positive relationship between the actions of unconnected group members, as predicted by the Nash equilibrium profile. Across all positions, subjects take into account the choices of all group members in their decision-making process in global structure in Asymmetric network, whereas in the local architecture subjects give weight to the action of subjects directly connected to them and their neighbors. I find a positive relationship between the actions of B and D, corroborating the coordination on the behavioral equilibrium (A4). In the Circle network subjects are successful in giving best replies to their neighbors and but fail to coordinate with subjects unconnected to them in the global structure, which explains the lower rates of corresponds to the observation that groups were less likely to coordinate on an equilibrium vis-à-vis Line and the Asymmetric network. With the local structure, subjects are not only successful in giving best replies to their neighbors but also coordinate with subjects in their maximal independent set.

Result 8. *Without communication there are frequent mis-coordinations in action; communication architecture leads to better coordination both with direct and indirect neighbors across all network structures.*

Effect of number of neighbors on investment decision

The literature studying the effect of network structure on public goods provision finds a negative relationship between the number of neighbors and their probability of investing. To test this hypothesis, I estimate a logistic panel model with the number of neighbors as the main variable of interest. I perform separate estimations for three treatments. The model for each treatment is:

$$invest_{it} = \sum_{k=1}^{3} \beta_k degree_i^K + \zeta X + \varepsilon_{it} \tag{12}$$

where $invest_{it}$ is the investment decision of subject i in period t. $degree^K$ shows the number of neighbors subject i has, $degree^1$ indicates one neighbor, $degree^2$ indicates two neighbors, and $degree^3$ indicates three neighbors. X_i includes control for number of neighbors who invested in the current period and last period, last period decision, round , session fixed effect, and demographic variables – gender and race.

Table 19: Number of Neighbors and Investments

	Baseline		Global		Local	
	Line	Asymmetric	Line	Asymmetric	Line	Asymmetric
One neighbor (mean)	0.364	0.515	0.449	0.429	0.409	0.371
	(0.040)	(0.044)	(0.021)	(0.034)	(0.025)	(0.032)
Two neighbors	-0.00344	-0.0362	0.0497	-0.122*	0.0533	-0.0294
	(0.059)	(0.102)	(0.038)	(0.063)	(0.034)	(0.052)
Three neighbors		-0.254***		0.147***		0.189***
		(0.070)		(0.050)		(0.058)
# Neighbor invests	-0.0442	-0.0104	-0.234***	-0.227***	-0.257***	-0.281***
	(0.034)	(0.022)	(0.024)	(0.029)	(0.020)	(0.028)
Invest lag	-0.180***	-0.190***	-0.258***	-0.398***	-0.295***	-0.316***
	(0.041)	(0.042)	(0.067)	(0.052)	(0.054)	(0.054)
Round	Yes	Yes	Yes	Yes	Yes	Yes
Race	Yes	Yes	Yes	Yes	Yes	Yes
Gender	Yes	Yes	Yes	Yes	Yes	Yes
Session	Yes	Yes	Yes	Yes	Yes	Yes
Observations	540	540	540	540	540	540

Robust standard errors in parentheses; $p^{*} < 0.10, p^{**} < 0.05, p^{***} < 0.010$

The effect of the number of neighbors on the likelihood of investing is more pronounced in the Asymmetric network. In the baseline, compared to subjects with one neighbor, subjects with three neighbors are 49% less likely to invest. This effect is reversed in the global and local communication architectures. In fact, in the global architecture subjects with three neighbors are 34% more likely to invest and with local communication subjects with three neighbors 50% more likely to invest than subjects with one neighbor (see Table 19[63]. In the Line, the pattern of alternating investments between subjects with one and two neighbors leads to no statistically significant differences between the likelihood of investing. Introducing the two communication structures, subjects pay attention to the actions of neighbors, which is reflected by a negative relationship between a subject's and their neighbors' investment decisions. A negative estimate between current and last round's decision is consistent with play alternating among Nash equilibria.

[63] I conduct a similar analysis using the 1/round as a dependent variable and find the similar results (*please see Appendix B.2.1*)

Result 9. *Both the communication architectures nudge subjects with more neighbors to invest.*

3.5 Conclusion

In this chapter, I study the effect of communication in a repeated best shot public goods game across three network structures. The research question I set out to study is the efficacy of communication as a coordination device. I explore the effect of two communication architectures: global and local. Compared to the baseline, communication is successful in raising efficiency across the three network structures. Groups in Line and Asymmetric networks consistently alternate between equilibrium profiles where two and three group members are investing. This pattern of investment suggests that groups prefer both efficiency and equity. Groups in Circle network with the global communication were less successful in negotiating on strategies they could coordinate across the rounds. This highlights the difficulties of having a larger Nash set, which leads to mis-coordination. Local communication constrained by the externalities network performs better across all network structures.

These findings have implications for policy interventions that involve situations where actions are locally substitutable and exhibit externalities. These decisions could range from an investment decision in a technology by farmers[64] to doctors adopting a new practice protocols[65]. Communication can be used as a device to resolve inefficiencies in the provision of the local public goods. Depending on the underlying network structure, the global or local structure can be implemented. Local communication is more natural to implement in a network setting where individuals are more likely to communicate with their neighbors.

[64] There is a large body of literature highlighting the importance of social interaction in technology adoption and diffusion (Chuang and Schechter, 2015, Foster and Rosenzweig, 2010, Conley and Udry, 2010).

[65] Tasselli (2014) provides an excellent overview of the literature studying the effect of social networks on physician's decisions.

4 Conclusion

The two chapters in this dissertation present evidence that both pecuniary and non-pecuniary mechanisms can be effective in resolving the inefficiency of the provision of local public goods. In the absence of these mechanisms, there is underinvestment in the public goods, the individuals in the periphery are severely affected by lack of access to the public good. Both cost sharing and communication help increase access to public goods. However, there is heterogeneity in the effect of each mechanism across the three network structures. Policymakers should be cognizant of the underlying network structure when implementing policies.

The first chapter finds that a tax-subsidy regime based on the number of neighbors is successful in raising efficiency across both homogenous and heterogeneous networks. Although global cost sharing has nice normative properties, it is unsuccessful in raising efficiency in non-symmetric networks. The uniform payoff generated by the global cost sharing rule for all individuals in the network does not incentivize central individuals to invest in the public good. It is crucial to identify the properties of the network when designing policies..

The second chapter finds that both global communication and communication constrained by the underlying externalities network are successful in raising efficiency and equity across all network structures. Although the efficiency is comparable between the global and local structure in the Line and Asymmetric network, the difference in the properties of the two structure leads to differences in patterns of equilibrium selection. Local communication is effective even when the set of Nash equilibrium profiles is large and it might be more difficult for individuals to negotiate on a set of strategies.

Based on the two chapters and the empirical evidence pointing at the efficacy of endogenously occurring social norms in sustaining cooperation in social dilemmas (Ostrom, 2014). In future research, allowing groups to communicate and decide on a cost-sharing agreement can help in raising the overall efficiency of provision of local public goods. The results from the study allow an empirical test of the cooperative game theory solutions proposed in Myerson (1977) and Jackson (2005). Data are informative about the effect of network structure and individual position on the sharing rules agreed upon.

Experimental methods allow for a clear identification of the network structure on individual and group decision making. The social, economic, and infrastructure networks outside the laboratory are large. However, a major limitation of my studying network in the laboratory is that the size of the network is restricted by the seats available in the lab. The results from the three stylized network present evidence in favor of the efficacy of cost sharing and communication. However, generalizing these results for policy requires testing of these mechanisms over larger networks in an online experiment or field settings. There is evidence of biases in individuals recalling information about network structure, which bears out both in a controlled laboratory experiment and in two friendship networks from a Silicon Valley firm (Dessi et al., 2016). These biases might affect the efficacy of the mechanism presented in this dissertation.

A Appendix Chapter 1

A.1 Instructions - Cost Sharing

WELCOME!

No Talking Allowed
Once the experiment begins, we request that you do not to talk until the end of the experiment. If you have any questions, please raise your hand.

Three Stages
There are 3 stages in this experiment. Each stage consists of 10 rounds. So, there are a total of 30 rounds in this experiment. At the beginning of each stage, you will be:

1. Randomly matched with four other individuals in the room. Group composition remains fixed within each stage but differs across stages.

2. At the end of each round, you will be provided a summary of your earnings in the experiment.

Payment
You will earn in cents for the decisions you make in each round of the experiment. At the end of the experiment, you will be paid in cash your total earnings from all the 30 rounds.

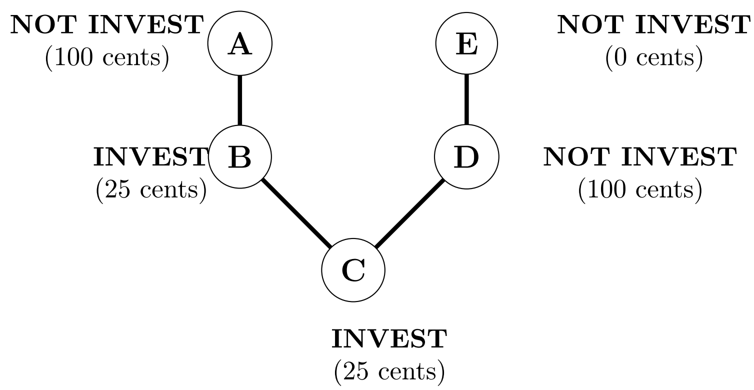
Decision Environment
Members of each group are randomly assigned to one of the five positions, {A, B, C, D or E}, as shown, in Figure 1, below at the beginning of each stage. Assigned positions remains fixed within each stage but differs across stages.
Your assigned position determines which members of the group you are connected to. A connection between two positions is represented by a line. For example, in Figure 1, if your position is at C, then you are connected to two of your group members, the ones assigned to positions B and D. We will call B and D **your neighbors** and {B, C, D} **your neighborhood**.

Decision Task and Payoffs
Stage 1:
There is a neighborhood common fund that you share with your neighbors. At the beginning of each round, everyone is asked to make a decision on whether to INVEST in the neighborhood common fund at a cost of 75 cents. If there is at least one investment in the neighborhood common fund then the individual who invested, as well as each of his neighbors, earns 100 cents.

Line

1. You earn 25 cents: 100 cents (from the neighborhood common fund) minus 75 cents (the cost of investing).
2. Your neighbor at D earns 100 cents: 100 cents (from the neighborhood common fund as you and B invested).
3. Your neighbor at B earns 25 cents: 100 cents (from neighborhood common fund) minus 75 cents (the cost of investing)

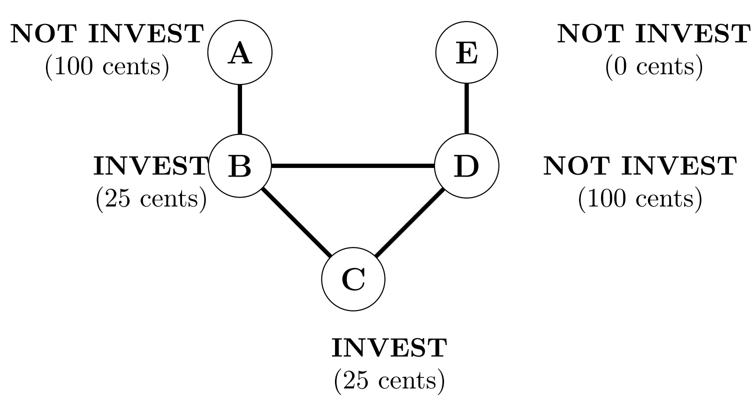
Figure 13: Stage 1 - Instruction - Line



Asymmetric

1. You earn 25 cents: 100 cents (from the neighborhood common fund) minus 75 cents (the cost of investing).
2. Your neighbor at D earns 100 cents: 100 cents (from the neighborhood common fund as you and B invested).
3. Your neighbor at B earns 25 cents: 100 cents (from neighborhood common fund) minus 75 cents (the cost of investing)

Figure 14: Stage 1 - Instruction - Asymmetric



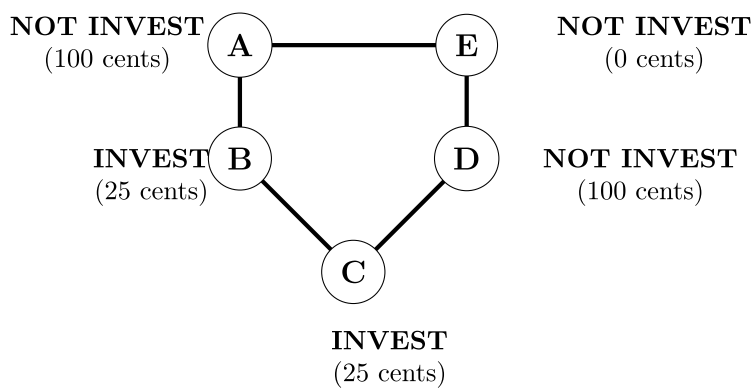
Circle

1. You earn 25 cents: 100 cents (from the neighborhood common fund) minus 75 cents (the cost of investing).

2. Your neighbor at D earns 100 cents: 100 cents (from the neighborhood common fund as you and B invested).

3. Your neighbor at B earns 25 cents: 100 cents (from neighborhood common fund) minus 75 cents (the cost of investing)

Figure 15: Stage 1 - Instruction - Circle



Stage 2:

Transfers are introduced in stage 2: Individuals who invest receive a transfer of 25 cents from each neighbor who does not invest. Decision tasks are the same as in Stage 1.

Example: Suppose your position is C. If C (you), and B invest but A, D, and E do not invest, then both you and B receive a transfer of 25 cents from D, in addition B receives a transfer of 25 cents from A. Payoffs (Figure 2) are:

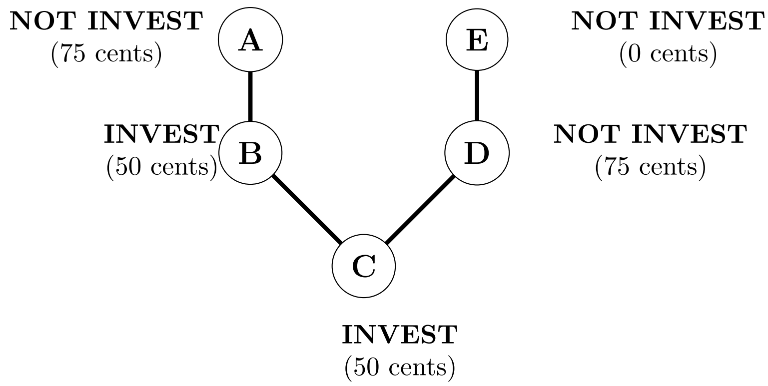
Line

1. You earn 50 cents: 100 cents (from neighborhood common fund), minus 75 cents (the cost of investing) plus 25 cents (25 cents transfer from D your neighbor who did not invest).

2. Your neighbor at D earns 75 cents: 100 cents (from the neighborhood common fund as you invested) minus 25 cents (D's transfer to you).

3. Your neighbor at B earns 50 cents: 100 cents (from neighborhood common fund), minus 75 cents (the cost of investing) plus 25 cents (25 cents transfer from A, B's neighbors who did not invest).

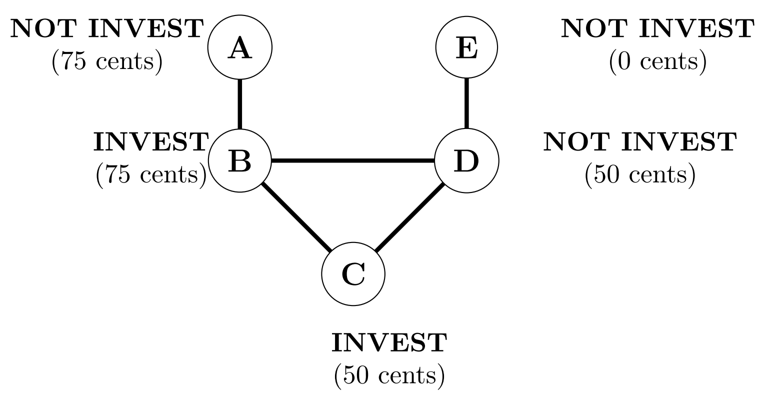
Figure 16: Local Cost Sharing - Instruction - Line



Asymmetric

1. You earn 50 cents: 100 cents (from neighborhood common fund), minus 75 cents (the cost of investing) plus 25 cents (25 cents transfer from D your neighbor who did not invest).
2. Your neighbor at D earns 50 cents: 100 cents (from the neighborhood common fund as you invested) minus 50 cents (D's transfers to you and B).
3. Your neighbor at B earns 75 cents: 100 cents (from neighborhood common fund), minus 75 cents (the cost of investing) plus 50 cents (25 cents transfers from A and D, B's neighbors who did not invest).

Figure 17: Local Cost Sharing - Instruction - Asymmetric



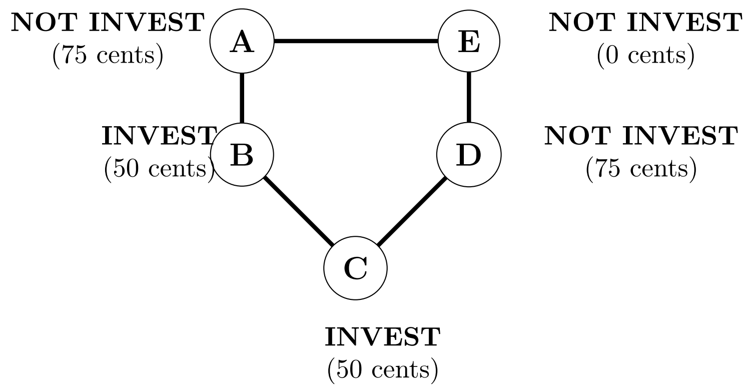
Circle

1. You earn 50 cents: 100 cents (from neighborhood common fund), minus 75 cents (the cost of investing) plus 25 cents (25 cents transfers from D your neighbor who did not invest).

2. Your neighbor at D earns 75 cents: 100 cents (from the neighborhood common fund as you invested) minus 25 cents (D's transfer to you).

3. Your neighbor at B earns 50 cents: 100 cents (from neighborhood common fund), minus 75 cents (the cost of investing) plus 25 cents (25 cents transfers from A, B's neighbors who did not invest).

Figure 18: Local Cost Sharing - Instruction - Circle



Stage 3:

Cost sharing is introduced in stage 3: The total cost of investments for the group is equally shared by individuals who benefit from the common fund. Decision tasks are the same as in Stage 1.

Example: Suppose your position is C. Suppose C (you) invest but A, B, D, and E do not invest. Then the total cost of investment is 75 cents. C (you), B and D benefit from the common fund and each pay 25 cents (= 75/3). Then payoffs (Figure 3) are:

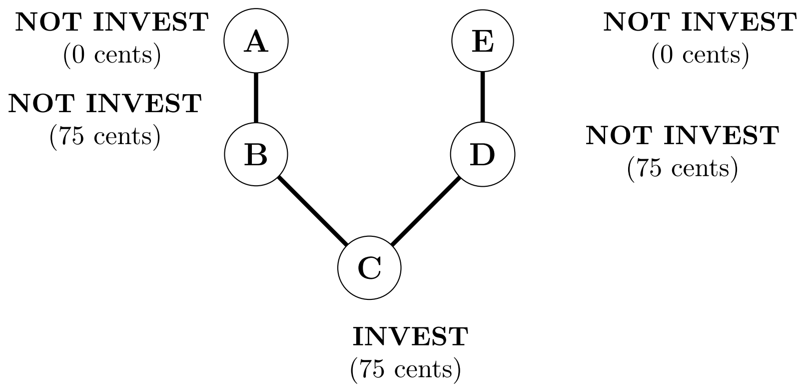
Line

1. You earn 75 cents: 100 cents (from the neighborhood common fund) minus 25 cents (the cost of investing).

2. Your neighbor at D earns 75 cents: 100 cents (from the neighborhood common fund) minus 25 cents (the cost of investing).

3. Your neighbor at B earns 75 cents: 100 cents (from the neighborhood common fund) minus 25 cents (the cost of investing).

Figure 19: Global Cost Sharing - Instruction - Line



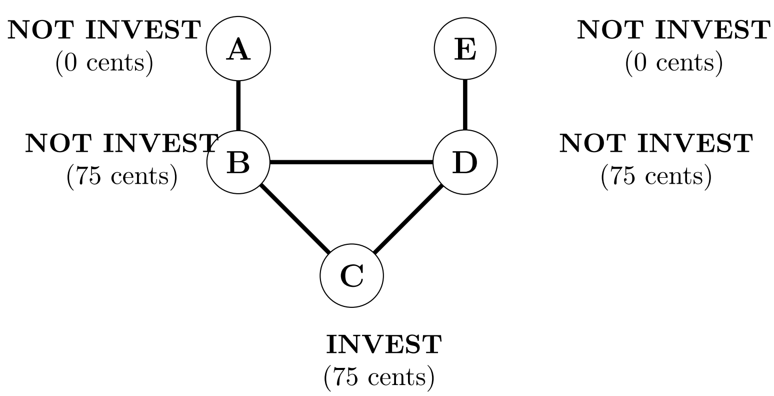
Asymmetric

1. You earn 75 cents: 100 cents (from the neighborhood common fund) minus 25 cents (the cost of investing).

2. Your neighbor at D earns 75 cents: 100 cents (from the neighborhood common fund) minus 25 cents (the cost of investing).

3. Your neighbor at B earns 75 cents: 100 cents (from the neighborhood common fund) minus 25 cents (the cost of investing).

Figure 20: Global Cost Sharing - Instruction - Asymmetric



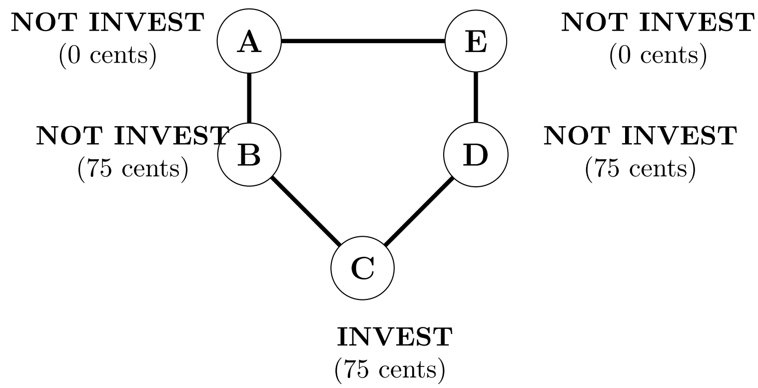
Circle

1. You earn 75 cents: 100 cents (from the neighborhood common fund) minus 25 cents (the cost of investing).

2. Your neighbor at D earns 75 cents: 100 cents (from the neighborhood common fund) minus 25 cents (the cost of investing).

3. Your neighbor at B earns 75 cents: 100 cents (from the neighborhood common fund) minus 25 cents (the cost of investing).

Figure 21: Global Cost Sharing - Instruction - Circle



A.2 Extra Tables

Table 20: OLS Estimates - Efficiency Across Treatments (1/Rounds)

	Line	Asymmetric	Circle
Local	0.104***	0.0625*	0.0982***
	(0.024)	(0.033)	(0.032)
Global	0.101***	0.00748	0.0813***
	(0.025)	(0.037)	(0.031)
$1/Round$	-0.115***	-0.0859***	-0.106***
	(0.038)	(0.026)	(0.040)
Observations	480	480	480

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 21: OLS Estimates - Efficiency Across Network (1/Rounds)

	Baseline	Local	Global
Asymmetric	0.0585**	0.0165	-0.0349
	(0.028)	(0.034)	(0.030)
Circle	0.0812***	0.0750**	0.0616**
	(0.030)	(0.032)	(0.030)
$1/Round$	0.00401	-0.169***	-0.141***
	(0.040)	(0.030)	(0.030)
Observations	480	480	480

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 22: Access to Public Good and Excess Provision (1/Rounds)

	Access to Public Good			Excess Provision		
	Line	Asymmetric	Circle	Line	Asymmetric	Circle
Local	0.154***	0.175***	0.196***	0.0963**	0.271***	0.163***
	(0.029)	(0.025)	(0.028)	(0.041)	(0.038)	(0.041)
Global	0.192***	0.151***	0.182***	0.150***	0.224***	0.174***
	(0.022)	(0.030)	(0.030)	(0.055)	(0.032)	(0.049)
$1/Round$	0.00614	0.0210	-0.00322	0.193***	0.156***	0.195***
	(0.036)	(0.033)	(0.037)	(0.030)	(0.043)	(0.047)
Observations	480	480	480	480	480	480

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 23: Marginal Effect of Probability of Coordinating on Equilibrium (1/Rounds)

	Line	Asymmetric	Circle
Baseline (mean)	0.131***	0.150***	0.181***
	(0.028)	(0.028)	(0.036)
Local	0.0875**	-0.0125	0.119**
	(0.042)	(0.039)	(0.046)
Global	0.156***	0	0.0500
	(0.045)	(0.040)	(0.044)
$1/Round$	-0.156*	-0.202**	-0.253***
	(0.080)	(0.086)	(0.089)
Observations	480	480	480

Robust standard errors in parentheses

* p<0.10, ** p<0.05, *** p<0.010

Table 24: Marginal Effect of Neighbors on Investment (1/Rounds)

	Baseline	Local	Global
One neighbor	0.500	0.385	0.679
	(0.039)	(0.050)	(0.041)
Two neighbors	-0.118*	0.210**	-0.0941
	(0.072)	(0.094)	(0.072)
Three neighbors	-0.222***	0.279***	-0.208***
	(0.054)	(0.077)	(0.077)
# neighbors invest lag	0.0157	-0.0303	-0.0465*
	(0.031)	(0.037)	(0.027)
Invest lag	-0.116***	-0.0659	-0.0660
	(0.041)	(0.045)	(0.043)
$1/Round$	Yes	Yes	Yes
Race	Yes	Yes	Yes
Gender	Yes	Yes	Yes
Session	Yes	Yes	Yes
Observations	720	720	720

Robust standard errors in parentheses

* p<0.10, ** p<0.05, *** p<0.01

A.3 Proof – Proposition

Lemma 1. *In the baseline game without cost sharing rules, in the Line network, the pure strategy Nash equilibria are (1,0,1,0,1), (0,1,0,1,0), (1,0,0,1,0), and (0,1,0,0,1). In the Asymmetric network, the pure-strategy Nash equilibria are (1,0,1,0,1), (1,0,0,1,0), and (0,1,0,0,1). In the Circle network, the pure strategy Nash equilibria are (1,0,0,1,0), (1,0,1,0,0), (0,1,0,0,1), (0,0,1,0,1) and (0,1,0,1,0)*

Proof. In a Nash equilibrium, we show that:

1. $a_i = 1$ if and only if $\forall j \in N_i$, $a_j = 0$
2. $a_i = 0$ if and only if $\exists j \in N_i$ s.t. $a_j = 1$

Let's consider the first condition, consider a profile of actions, a_j such that, $\forall j \in N_i$, $a_j = 0$. Then the best reply for agent i is $a_i = 1$ because $u_i(0, \boldsymbol{a_j}, G) = 0$ and $u_i(1, \boldsymbol{a_j}, G) = b - c$, $u_i(1, \boldsymbol{a_j}, G) > u_i(0, \boldsymbol{a_j}, G)$ since $b > c > 0$. Consider a profile of actions , a_j such that, $\exists j \in N_i$ s.t. $a_j = 1$, then the best reply of agent i is $a_i = 0$ because $u_i(0, \boldsymbol{a_j}, G) = b$ and $u_i(1, \boldsymbol{a_j}, G) = b - c$ and $u_i(0, \boldsymbol{a_j}, G) > u_i(1, \boldsymbol{a_j}, G)$ since $b > b - c$. Assume a Nash equilibrium $a_i = 0$ and $\forall j \in N_i$, $a_j = 0$, then the best reply for agent i is $a_i = 1$ because $u_i(0, \boldsymbol{a_j}, G) = 0$ and $u_i(1, \boldsymbol{a_j}, G) = b - c$, a contradiction. Assume a Nash equilibrium $a_i = 1$ and $\exists j \in N_i$ s.t. $a_j = 1$, then the best reply for agent i is $a_i = 0$ because $u_i(0, \boldsymbol{a_j}, G) = b$ and $u_i(1, \boldsymbol{a_j}, G) = b - c$, a contradiction. Based on the best reply it is straightforward to verify that the pure strategy Nash equilibria listed are the set of all possible Nash equilibria ■

Proposition 4. *Suppose* $\eta \leq \frac{1}{\max_G\{N_k\}}$*:*

1. *If it is optimal for an agent to invest in the baseline, then it is optimal for the agent to invest in the game with local cost sharing.*
2. *If it is optimal for an agent to not invest in the baseline, then it is optimal for the agent to not invest in the game with local cost sharing.*
3. *Inefficient equilibrium in the Line and Asymmetric network is Pareto dominated by an efficient equilibrium.*

Proof. The following are the proofs for the three claims in Proposition 1.

Part 1: From Lemma 1 we know that in the baseline game without cost sharing, $a_i = 1$ if and only if $\forall j \in N_i$, $a_j = 0$. The best reply is the same in the game with local cost sharing. In the game with local cost sharing rule, consider a profile of action, a_j such that, $\forall j \in N_i$, $a_j = 0$. Then the best reply for player i is $a_i = 1$ because $u_i(0, \boldsymbol{a_j}, G) = 0$ and $u_i(1, \boldsymbol{a_j}, G) = b - c + N_i \eta c$, $u_i(1, \boldsymbol{a_j}, G) > u_i(0, \boldsymbol{a_j}, G)$ since $b - c > 0$ and $N_i \eta c > 0$.

Part 2: From Lemma 1 we know that in the baseline game without cost sharing, $a_i = 0$ if and only if $\exists j \in N_i$ s.t. $a_j = 1$. In the game with local cost sharing rule, consider the following two cases:

Case 1: For $\eta < \frac{1}{\max_G\{N_k\}}$ the best reply in the game with local cost sharing is the same as in the baseline. Assume a Nash equilibrium where, r agents in agent i's neighborhood are investing, then the best reply of agent i is $a_i = 0$ because $u_i(0, \boldsymbol{a_j}, G) = b - r\eta c$ and $u_i(1, \boldsymbol{a_j}, G) = b - c + (N_i - r)\eta c$, $u_i(0, \boldsymbol{a_j}, G) > u_i(1, \boldsymbol{a_j}, G)$ since $\eta < \frac{1}{\max_G\{N_k\}}$.

Case 2: For $\eta = \frac{1}{\max_G\{N_k\}}$, if it is optimal for an agent to not invest in the baseline, it is optimal for the agent to not invest in the game with local cost sharing. In the baseline, agent i best reply is $a_i = 0$ if and only if $\exists j \in N_i$ s.t. $a_j = 1$. Assume a Nash equilibrium, r agents in agent i's neighborhood are investing, then the best reply of agent i is $a_i = 0$ because $u_i(0, \boldsymbol{a_j}, G) = b - r\eta c$ and $u_i(1, \boldsymbol{a_j}, G) = b - c + (N_i - r)\eta c$, $u_i(0, \boldsymbol{a_j}, G) < u_i(1, \boldsymbol{a_j}, G)$ if $N_i < \max_G N_i N_k$ and $u_i(0, \boldsymbol{a_j}, G) = u_i(1, \boldsymbol{a_j}, G)$ for $N_i = N_k$. Therefore, agents with the maximum number of neighbors will be indifferent between investing or not investing when there are r investments in their neighborhood. Therefore if it was optimal for an agent to not invest in the baseline, it still will be weakly optimal for them to invest in the game with local cost sharing rule.

Applying Parts 1 and 2 it can be verified that pure strategy Nash equilibrium that in the Line network are: (1,0,1,0,1), (0,1,0,1,0), (1,0,0,1,0), and (0,1,0,1,0). In the Asymmetric network, the pure-strategy Nash equilibria are (1,0,1,0,1), (1,0,0,1,0), and (0,1,0,0,1). In the Circle network, the pure strategy Nash equilibria are (1,0,0,1,0), (1,0,1,0,0), (0,1,0,0,1), (0,0,1,0,1) and (0,1,0,1,0).

Part 3: For Line $\max_G\{N_k\} = 2$ and Asymmetric $\max_G\{N_k\} = 3$, so for η[66] used in the experiment satisfies $\eta \leq \frac{1}{\max_G\{N_i\}}$. Table 25 reports the pure strategy Nash equilibria in Line and Asymmetric networks and the corresponding payoffs.

Table 25: Equilibrium Profits

		Investment Decision						Theoretical Profits				
		A	B	C	D	E		A	B	C	D	E
Line	(L1)	1	0	1	0	1		$b-(1-\eta)c$	$b-2\eta c$	$b-(1-2\eta)c$	$b-2\eta c$	$b-(1-\eta)c$
	(L2)	0	1	0	1	0		$b-\eta c$	$b-(1-2\eta)c$	$b-\eta c$	$b-(1-2\eta)c$	$b-\eta c$
	(L3)	0	1	0	0	1		$b-\eta c$	$b-(1-2\eta)c$	$b-\eta c$	$b-\eta c$	$b-(1-\eta)c$
	(L4)	1	0	0	1	0		$b-(1-\eta)c$	$b-\eta c$	$b-\eta c$	$b-(1-2\eta)c$	$b-\eta c$
Asymmetric	(A1)		1	0	1	0	1	$b-(1-\eta)c$	$b-2\eta c$	$b-(1-2\eta)c$	$b-2\eta c$	$b-(1-\eta)c$
	(A2)	0	1	0	0	1		$b-\eta c$	$b-(1-3\eta)c$	$b-\eta c$	$b-2\eta c$	$b-(1-\eta)c$
	(A3)	1	0	0	1	0		$b-(1-\eta)c$	$b-2\eta c$	$b-\eta c$	$b-(1-3\eta)c$	$b-\eta c$
	(A4)	0	1	0	1	0		$b-\eta c$	$b-(1-2\eta)c$	$b-\eta c$	$b-(1-2\eta)c$	$b-\eta c$

In the Line network, the payoff of each agent in pure strategy Nash equilibria: L3 and L4 either remains the same or increases in comparison to L1 (inefficient equilibrium). Similarly in the Asymmetric network, the payoff for each agent in pure strategy Nash equilibria: A2 and A3 either remains the same or increases in comparison to A1 (inefficient equilibrium,).

[66] $\eta = \frac{1}{3}$

■

Proposition 5. *In the game with the global cost sharing rule and a given strategy profile for a_j such that everyone in the network has access to the public good then :*

1. *If it is optimal for agent i to invest in the baseline, then it is optimal for agent i to invest in the game with global cost sharing rule.*
2. *If it is optimal for agent i to not invest in the baseline, then it is optimal for agent i to not invest in the game with global cost sharing in the Line, Asymmetric and Circle networks.*
3. *Inefficient equilibrium is Pareto dominated by the efficient equilibrium.*

Proof. The following are the proofs for the three claims in Proposition 2.

Part 1 If agent i invest in the baseline then no one in her neighborhood is investing (see *Lemma 1*). If so then her decision with global cost shairng remains optimal because of investing with global cost sharing is less than or equal to the cost of investing, c, in the baseline.

Part 2 If agent i does not invest in the baseline then it must be the case that is there is at least one of her neighbors investing (see *Lemma 1*). If agent i invests then the benefit remains the same but the total cost of provision increases since there is an additional investment which generates no new benefits.

Part 3 Consider an inefficient equilibrium profile, α, where there are c_0 investments in the network,and an efficient equilibrium profile, β, where there are c_1 investments in the network. The payoff of agent i is:

$$u_i(\alpha) = b - \frac{c \times c_0}{N}$$
$$u_i(\beta) = b - \frac{c \times c_1}{N}$$

Since $c_0 > c_1$ it implies that

$$u_i(\beta) > u_i(\alpha)$$

■

Mixed Strategy Nash Equilibrium

The decision whether to invest or not depends on the evaluation of the following condition:

$$b - c \geq \left(1 - \prod_{i=1}^{N_i}(1 - p_i)\right) b$$

$$\left(\prod_{i=1}^{N_i}(1 - p_i)\right) \geq \frac{c}{b}$$

Where p_i be the probability of investing for agent i in a network.

Line Network

To solve for the mixed strategy Nash equilibrium we look for values of p_i for $i \in \{A, B, C, D, E\}$ such that the following conditions are satisfied implying that each player is indifferent between investing and not investing.

$$\text{Player A}: \quad (1 - p_B) = \frac{c}{b} \tag{13}$$

$$\text{Player B}: \quad (1 - p_A)(1 - p_C) = \frac{c}{b} \tag{14}$$

$$\text{Player C}: \quad (1 - p_B)(1 - p_D) = \frac{c}{b} \tag{15}$$

$$\text{Player D}: \quad (1 - p_C)(1 - p_E) = \frac{c}{b} \tag{16}$$

$$\text{Player E}: \quad (1 - p_D) = \frac{c}{b} \tag{17}$$

Case 1: We start with $p_B = 1 - \frac{c}{b}$ (see condition in equation 14). Substituting $p_B = 1 - \frac{c}{b}$ in equation 15 we derive that $p_D = 0$, which implies $p_E = 1$. To solve for p_A and p_C the condition in equation 14 simplifies to:

$$(1 - p_A)(1 - p_C) = \frac{c}{b}$$

$$\implies p_A = 1 - \frac{c}{b(1 - p_C)}$$

There are many values of $p_C \in (0, 1 - \frac{c}{b}]$ as long $p_A \in (0, 1 - \frac{c}{b}]$. So a mixed strategy Nash equilibria: $\left(p_A, 1 - \frac{c}{b}, 1 - \frac{c}{b(1-p_A)}, 0, 1\right)$ and by symmetry we have $1, \left(1, 0, 1 - \frac{c}{b(1-p_E)}, 0.5, p_E\right)$. For $p_A = 1 - \frac{c}{b}$, equation 14 implies that $p_C = 0$. Hence $(1 - \frac{c}{b}, 1 - \frac{c}{b}, 0, 1 - \frac{c}{b}, 1 - \frac{c}{b})$, $(1 - \frac{c}{b}, 1 - \frac{c}{b}, 0, 1, 0)$, and $(1 - \frac{c}{b}, 1 - \frac{c}{b}, 0, 0, 1)$ are Nash equilibria. By symmetry, $(0, 1, 0, 1 - \frac{c}{b}, v)$ and $(1, 0, 0, 1 - \frac{c}{b}, 1 - \frac{c}{b})$ are also Nash equilibria.

Case2: For $p_B = 1 - \frac{c}{b}$ and lets assume $p_A = 0$, we know from equation 15, $p_D = 0$ which implies $p_E = 1$. From equation 14 we know $p_C = 1 - \frac{c}{b}$. Hence, $(0, 1 - \frac{c}{b}, 1 - \frac{c}{b}, 0, 1)$ is a Nash equilibrium. By symmetry, $(1, 0, 1-\frac{c}{b}, 1-\frac{c}{b}0)$is also an equilibrium.

Asymmetric Network

To solve for the mixed strategy Nash equilibrium we look for values of p_i for $i \in \{A, B, C, D, E\}$ such that the following conditions are satisfied implying that each player is indifferent between investing and not investing.

$$\text{Player A}: \quad (1-p_B) = \frac{c}{b} \tag{18}$$

$$\text{Player B}: \quad (1-p_A)(1-p_C)(1-p_D) = \frac{c}{b} \tag{19}$$

$$\text{Player C}: \quad (1-p_B)(1-p_D) = \frac{c}{b} \tag{20}$$

$$\text{Player D}: \quad (1-p_B)(1-p_C)(1-p_E) = \frac{c}{b} \tag{21}$$

$$\text{Player E}: \quad (1-p_D) = \frac{c}{b} \tag{22}$$

Case 1: We start with $p_B = 1-\frac{c}{b}$ (see condition in equation 18). Substituting $p_B = 1-\frac{c}{b}$ in equation 20 we derive that $p_D = 0$, which implies $p_E = 1$. To solve for p_A and p_C the condition in equation 19 simplifies to:

$$(1-p_A)(1-p_C) = \frac{c}{b}$$
$$\implies p_C = 1 - \frac{c}{b(1-p_A)}$$

There are many values of $p_C \in (0, 1-\frac{c}{b}]$ as long $p_A \in (0, 1-\frac{c}{b}$. The following are the mixed strategy Nash equilibria: $\left(p_A, 1-\frac{c}{b}, 1-\frac{c}{b(1-p_A)}, 0, 1\right)$ and by symmetry we have $\left(1, 0, 1-\frac{c}{b(1-p_E)}, 1-\frac{c}{b}, p_E\right)$.

Case 2: For $p_B = 1-\frac{c}{b}$ we know from equation 20, $p_D = 0$ which implies $p_E = 1$. Lets assume $p_A = 0$, according to equation 19, $p_C = 1-\frac{c}{b}$. We have a mixed strategy Nash equilibrium $(0, 1-\frac{c}{b}, 1-\frac{c}{b}, 0.1)$. By symmetry we have $(1, 0, 1-\frac{c}{b}, 1-\frac{c}{b}, 0)$ as a mixed strategy Nash equilibrium. Assume, $p_B = p_D = 1-\frac{c}{b}$, based equation 20 we have $p_C = 0$, $(0, 1-\frac{c}{b}, 0, 1-\frac{c}{b}, 0)$ is a mixed strategy Nash equilibrium.

Circle Network

To solve for the mixed strategy Nash equilibrium we look for values of p_i for $i \in \{A, B, C, D, E\}$ such that the following conditions are satisfied implying that each player is indifferent between investing and not investing.

$$\text{Player A}: \quad (1-p_E)(1-p_B) = \frac{c}{b} \tag{23}$$

$$\text{Player B}: \quad (1-p_A)(1-p_C) = \frac{c}{b} \tag{24}$$

$$\text{Player C}: \quad (1-p_B)(1-p_D) = \frac{c}{b} \tag{25}$$

$$\text{Player D}: \quad (1-p_C)(1-p_E) = \frac{c}{b} \tag{26}$$

$$\text{Player E}: \quad (1-p_A)(1-p_D) = \frac{c}{b} \tag{27}$$

Case 1: Symmetric mixed strategy Nash equilibrium, lets assume $p_i = p \ \forall i \in \{A, B, C, D, E\}$ in that case any of the equation 23 - 27 simplifies to

$$(1-p)^2 = \frac{c}{b}$$

$$p = 1 - \sqrt{\frac{c}{b}}$$

Symmetric mixed strategy Nash equilibrium, $\left(1 - \sqrt{\frac{c}{b}}, 1 - \sqrt{\frac{c}{b}}, 1 - \sqrt{\frac{c}{b}}, 1 - \sqrt{\frac{c}{b}}, 1 - \sqrt{\frac{c}{b}}\right)$

Case 2: Lets assume $p_C = p_E = 0$, equation 26 would imply $p_D = 1$, solving equation23 we get $p_B = 1 - \frac{c}{b}$ and solving equation 24 we get $p_A = 1 - \frac{c}{b}$, therefore $(1 - \frac{c}{b}, 1 - \frac{c}{b}, 0, 1, 0)$. Similarly $(0, 1, 0, 1 - \frac{c}{b}, 1 - \frac{c}{b})$, $(0, 1 - \frac{c}{b}, 1 - \frac{c}{b}, 0, 1)$, $(1 - \frac{c}{b}, 0, 1, 0, 1 - \frac{c}{b})$, $(1, 0, 1 - \frac{c}{b}, 1 - \frac{c}{b}, 0)$ are mixed strategy Nash equilibria.

B Appendix Chapter 2

B.1 Instructions - Communication

Welcome!

No Talking Allowed
Once the experiment begins, we request that you do not to talk until the end of the experiment. If you have any questions, please raise your hand.

Three Stages
There are 3 stages in this experiment. Each stage consists of 10 rounds. So, there are a total of 30 rounds in this experiment. At the beginning of each stage, you will be:

1. Randomly matched with four other individuals in the room. Group composition remains fixed within each stage but differs across stages.

2. At the end of each round, you will be provided a summary of your earnings in the experiment.

Payment

You will earn in cents for the decisions you make in each round of the experiment. At the end of the experiment, you will be paid in cash your total earnings from all the 30 rounds.

Decision Environment

Members of each group are randomly assigned to one of the five positions, {A, B, C, D or E}, as shown, in Figure 1, below at the beginning of each stage. Assigned positions remains fixed within each stage but differs across stages.
Your assigned position determines which members of the group you are connected to. A connection between two positions is represented by a line. For example, in Figure 1, if your position is at C, then you are connected to two of your group members, the ones assigned to positions B and D. We will call B and D **your neighbors** and {B, C, D} **your neighborhood**.

Decision Task and Payoffs

Stage 1:

There is a neighborhood common fund that you share with your neighbors. At the beginning of each round, everyone is asked to make a decision on whether to INVEST in the neighborhood common fund at a cost of 75 cents. If there is at least one investment in the neighborhood common fund then the individual who invested, as well as each of his neighbors, earns 100 cents.

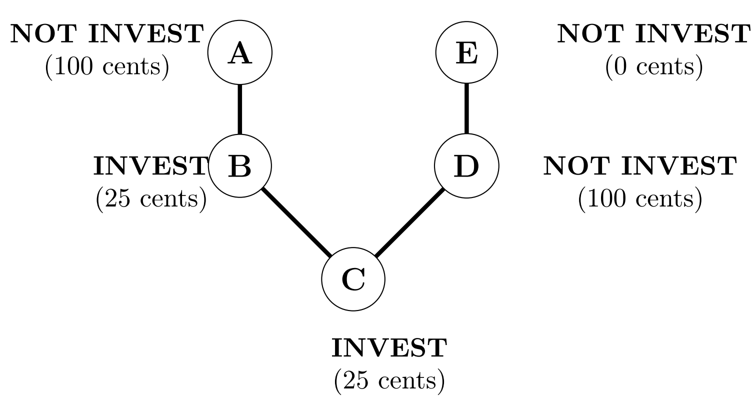
Line

1. You earn 25 cents: 100 cents (from the neighborhood common fund) minus 75 cents (the cost of investing).

2. Your neighbor at D earns 100 cents: 100 cents (from the neighborhood common fund as you and B invested).

3. Your neighbor at B earns 25 cents: 100 cents (from neighborhood common fund) minus 75 cents (the cost of investing)

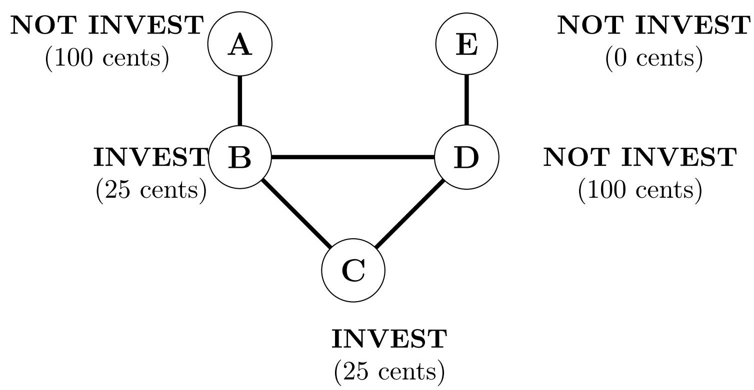
Figure 22: Stage 1 - Instruction - Line



Asymmetric

1. You earn 25 cents: 100 cents (from the neighborhood common fund) minus 75 cents (the cost of investing).
2. Your neighbor at D earns 100 cents: 100 cents (from the neighborhood common fund as you and B invested).
3. Your neighbor at B earns 25 cents: 100 cents (from neighborhood common fund) minus 75 cents (the cost of investing)

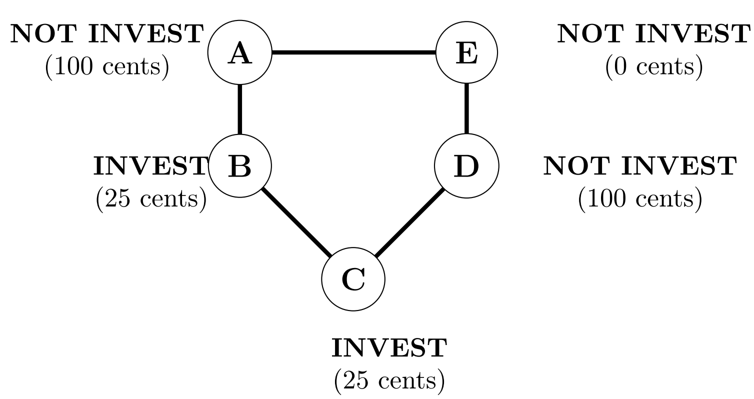
Figure 23: Stage 1 - Instruction - Asymmetric



Circle

1. You earn 25 cents: 100 cents (from the neighborhood common fund) minus 75 cents (the cost of investing).
2. Your neighbor at D earns 100 cents: 100 cents (from the neighborhood common fund as you and B invested).
3. Your neighbor at B earns 25 cents: 100 cents (from neighborhood common fund) minus 75 cents (the cost of investing)

Figure 24: Stage 1 - Instruction - Circle



Stage 2:

In stage 2, at the beginning of each round, the group can communicate via a group chat window for 1 minute. The decision task is the same as in Stage 1.
Please focus your communication on the following two points:

1. Your investment decision, and

2. Who in the group should invest.

Stage 3:

In stage 3, at the beginning of each round, you and your neighbors can communicate via a chat window for 1 minute. The decision task is the same as in Stage 1.
Please focus your communication on the following two points:

1. Your investment decision, and

2. Who in the neighborhood should invest.

B.2 Supplemental Regression, Tables and Figures

- In order to estimate effect of the two communication architectures on the likelihood of coordinating on a equilibrium. For each of the network structure, I estimate the following panel logistic regression model with random effects at the group level.

$$Equilibrium_{it} = \sum_{k=1}^{3} \beta_k C^k + \kappa Round + \varepsilon_{it} \tag{28}$$

Where $Equilibrium_{it}$ is an indicator function which takes the value 1 if the groups coordinate on any equilibrium profile for group i in period t,, C^K indicates the communication treatment variable, where C^1 is the no communication treatment, C^2 is the global architecture, and C^3 is the local architecture. I control for l*earning* using the round number as a measure. Table 26 reports changes in efficiency with respect to the C^1 the treatment without communication.

Table 26: Equilibrium Coordination Across Treatments

	Line	Asymmetric	Circle
Baseline (mean)	0.201	0.118	0.159
	(0.045)	(0.028)	(0.033)
Global	0.495***	0.286***	0.232***
	(0.114)	(0.087)	(0.077)
Local	0.503***	0.312***	0.350***
	(0.101)	(0.052)	(0.057)
Round	0.0216**	0.0333***	0.0203***
	(0.009)	(0.008)	(0.007)
Observations	360	360	360

Marginal effects; Standard errors in parentheses;
$p^{*} < 0.10, p^{**} < 0.05, p^{***} < 0.010$

- In order to estimate the effect of the network structure on the likelihood of coordinating on an equilibrium. For each of the communication architectures, I estimate the following panel logistic regression model with random effects at the group level.

$$Equilibrium_{it} = \sum_{k=1}^{3} \beta_k N^k + \kappa Round_t + \varepsilon_{it} \tag{29}$$

Where $Equilibrium_{it}$ is an indicator function which takes the value 1 if the groups coordinate on any equilibrium profile for group i in period t, N^K indicates the network treatment variable, where N^1 is the Line, N^2 is the Asymmetric, and N^3 is the circle network. I control for *learning* by using the round number as a measure. The results in table 27 reports changes in efficiency with respect to the N^1 to the line network.

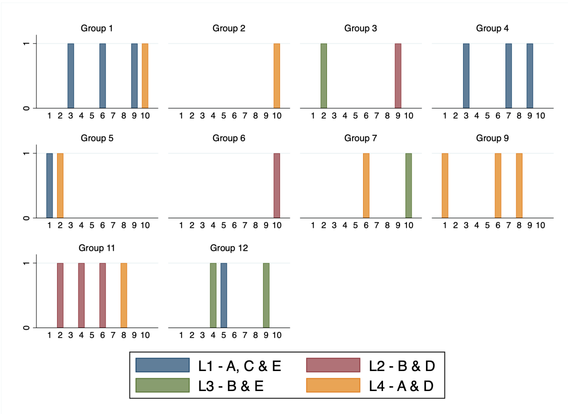
Table 27: Equilibrium Coordination Across Networks

	Baseline	Global	Local
Line (mean)	0.208	0.693	0.701
	(0.039)	(0.070)	(0.059)
Asymmetric	-0.0583	-0.318***	-0.309***
	(0.052)	(0.103)	(0.073)
Circle	-0.0417	-0.313***	-0.202**
	(0.050)	(0.109)	(0.083)
Round	0.0110*	0.0263***	0.0275***
	(0.006)	(0.007)	(0.008)
Observations	360	360	360

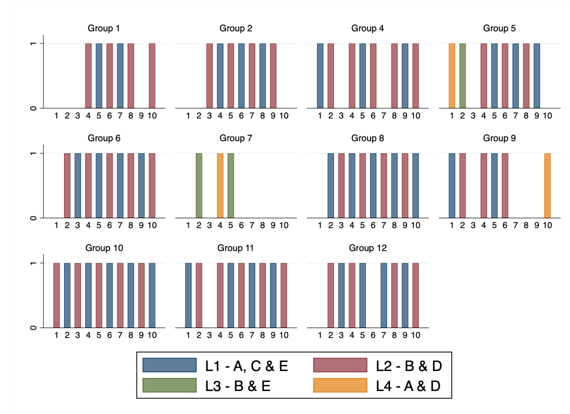
Marginal effects; Standard errors in parentheses;
$p^{*} < 0.10, p^{**} < 0.05, p^{***} < 0.010$

Figure 25: Equilibrium Across Rounds – Line

Baseline



Global



Local

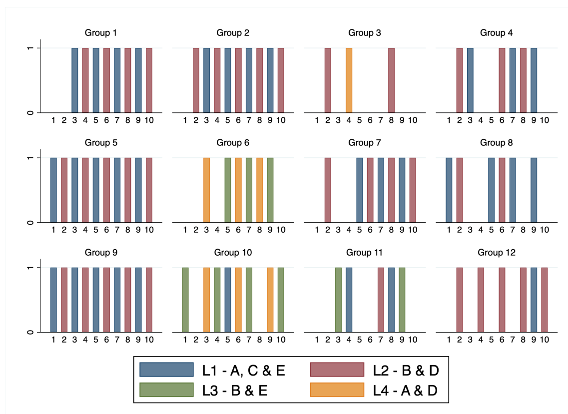
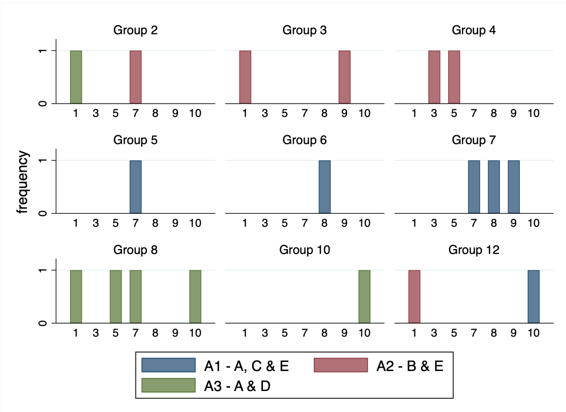
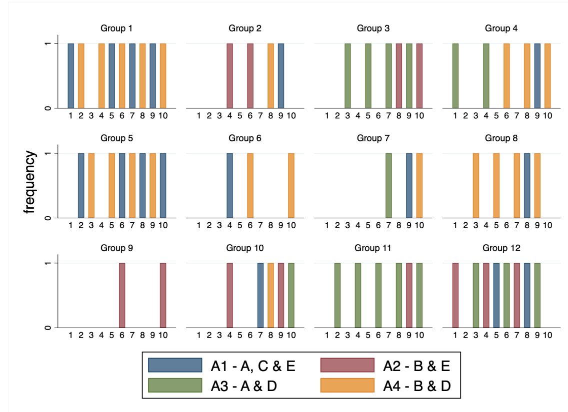


Figure 26: Equilibrium Across Rounds – Asymmetric

Baseline



Global



Local

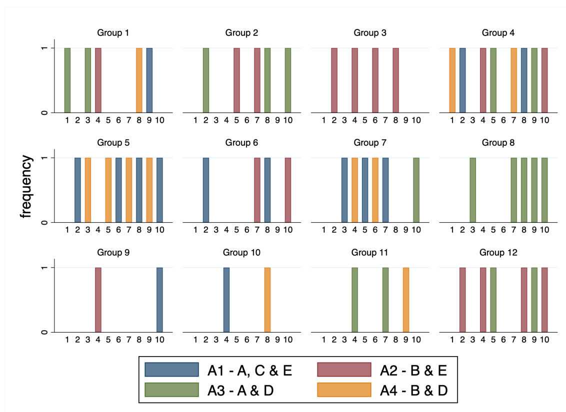
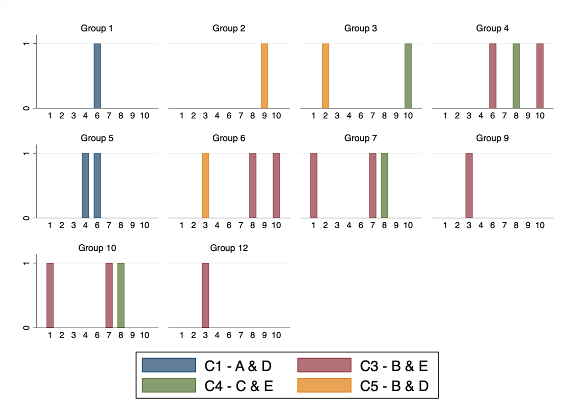
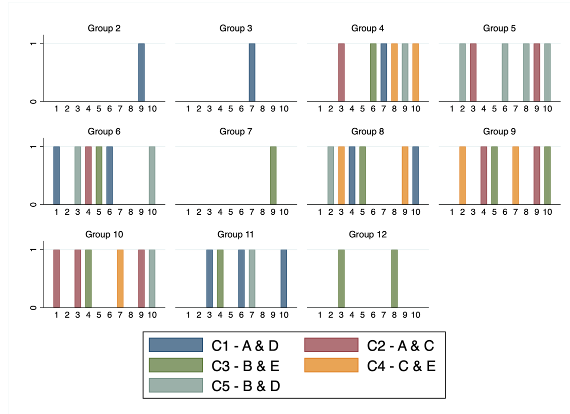


Figure 27: Equilibrium Across Rounds – Circle

Baseline



Global



Local

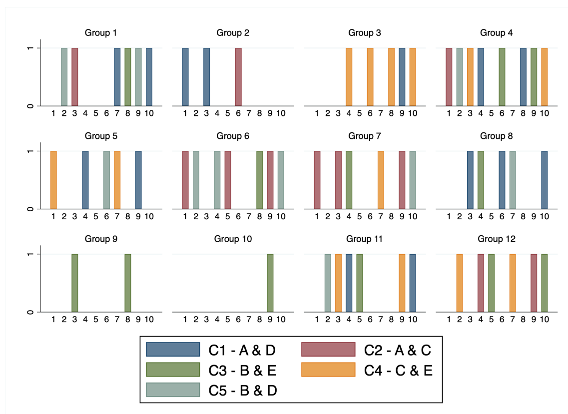
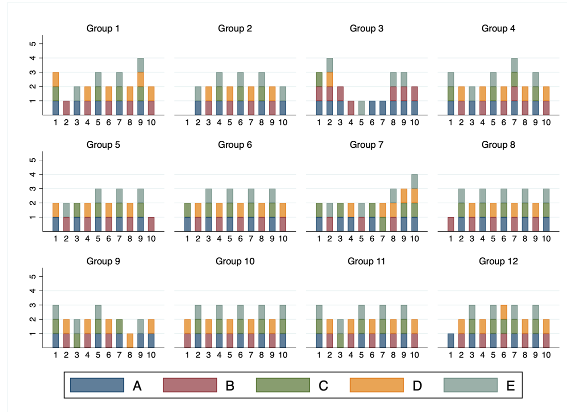


Figure 28: Line Group Investment

Baseline

Global



Local

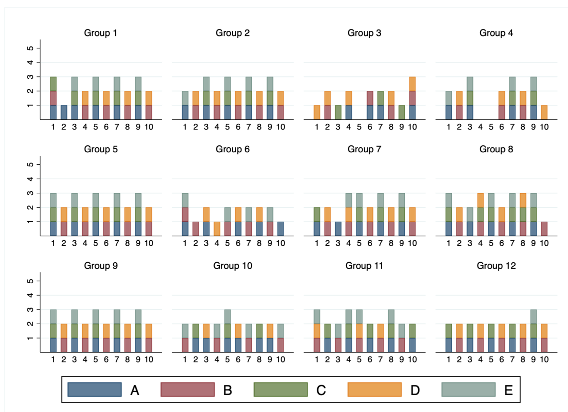


Figure 29: Asymmetric Group Investment

Baseline

Global

Local

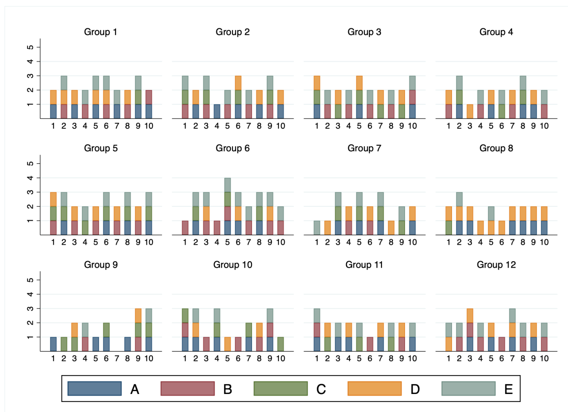
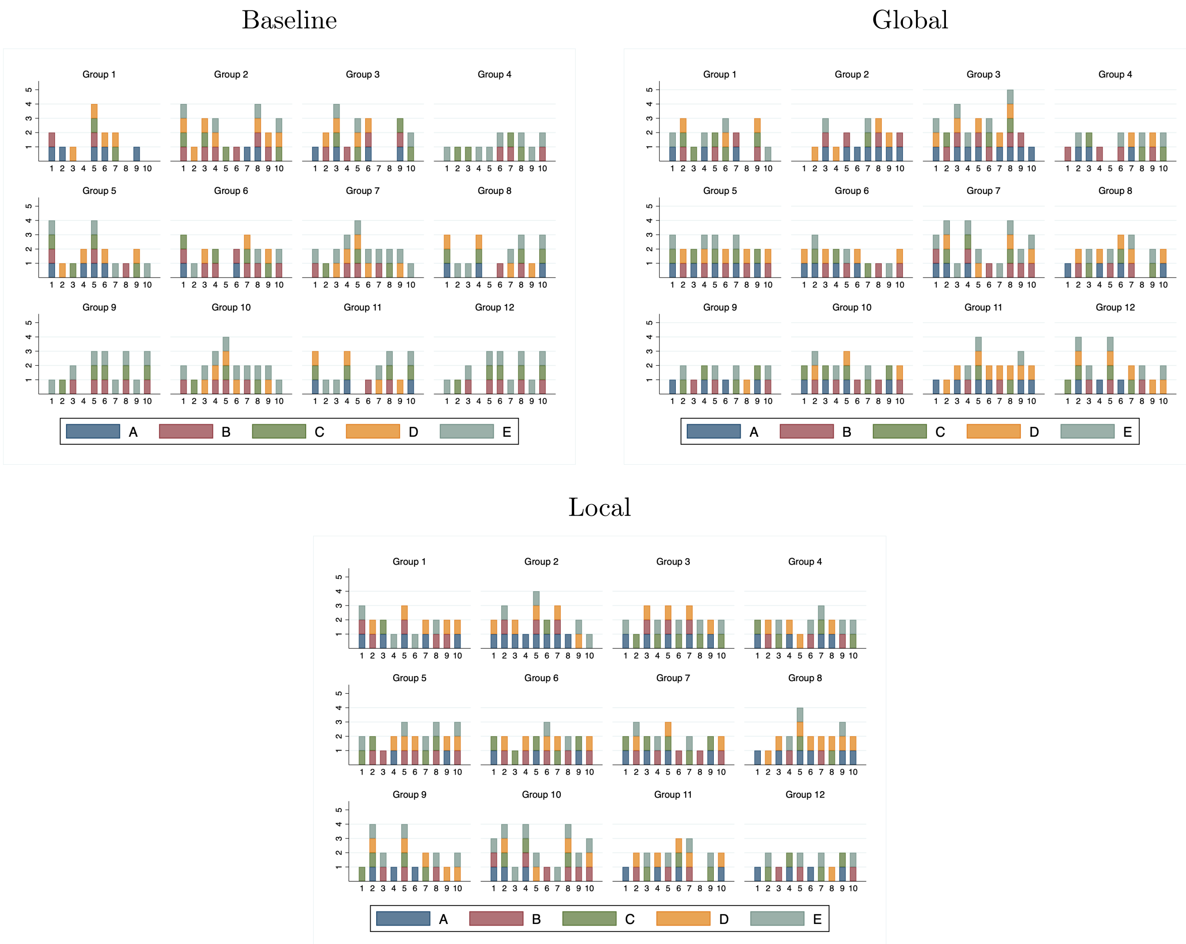


Figure 30: Circle Group Investment



B.2.1 Results for 1/Round

Table 28: Effect Across Treatment (1/Round)

	Line	Asymmetric	Circle
Global	0.214***	0.161***	0.101***
	(0.041)	(0.036)	(0.027)
Local	0.220***	0.163***	0.155***
	(0.040)	(0.036)	(0.034)
$1/Round$	-0.0923*	-0.0731	-0.0376
	(0.054)	(0.053)	(0.036)
Observations	360	360	360

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 29: Efficiency Across Network (1/Round)

	Baseline	Local	Global
Asymmetric	0.0667*	0.0131	0.0101
	(0.037)	(0.035)	(0.034)
Circle	0.0774**	-0.0357	0.0131
	(0.037)	(0.039)	(0.031)
$1/Round$	0.0234	-0.134***	-0.0921***
	(0.040)	(0.046)	(0.031)
Observations	360	360	360

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 30: Effect of Communication on Investment Decision (1/Round)

	A & E	C	D & E	A & E	C	D & E	All
Atleast one neighbor invest	-0.0975	-0.0664	-0.0621	-0.126	-0.125	-0.0583	-0.0893*
	(0.066)	(0.109)	(0.072)	(0.085)	(0.078)	(0.064)	(0.052)
Global	0.305***	0.501***	0.414***	0.236***	-0.0362	0.589***	0.111
	(0.094)	(0.155)	(0.090)	(0.080)	(0.147)	(0.124)	(0.073)
Local	0.208**	0.495***	0.358***	0.136	0.0766	0.574***	0.206***
	(0.101)	(0.138)	(0.078)	(0.087)	(0.144)	(0.119)	(0.073)
Atleast one neighbor invest x Global	-0.468***	-0.635***	-0.611***	-0.417***	-0.228	-0.344***	-0.210***
	(0.102)	(0.146)	(0.112)	(0.110)	(0.144)	(0.108)	(0.073)
Atleast one neighbor invest x Local	-0.452***	-0.720***	-0.621***	-0.343***	-0.408**	-0.466***	-0.361***
	(0.088)	(0.132)	(0.098)	(0.107)	(0.168)	(0.111)	(0.074)
Invest Lag	-0.284***	-0.0611	-0.170***	-0.249***	-0.170**	-0.338***	-0.198***
	(0.043)	(0.057)	(0.058)	(0.038)	(0.069)	(0.064)	(0.031)
Constant	0.575***	0.290	0.544***	0.515***	0.494**	0.200*	0.583***
	(0.111)	(0.198)	(0.090)	(0.094)	(0.197)	(0.107)	(0.066)
1/*Round*	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Experience	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Race	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Session	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	648	324	648	648	324	648	1620

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 31: Effect of Communication – Line (1/Round)

	(1) Invest A	(2) Invest B	(3) Invest C	(4) Invest D	(5) Invest E	(6) Invest A	(7) Invest B	(8) Invest C	(9) Invest D	(10) Invest E	(11) Invest A	(12) Invest B	(13) Invest C	(14) Invest D	(15) Invest E
Invest A		-0.123***	-0.0496	-0.0368	0.0413		-0.472***	0.256***	-0.249***	0.129***		-0.623***	0.249***	-0.0642	0.165***
		(0.021)	(0.048)	(0.047)	(0.032)		(0.068)	(0.035)	(0.033)	(0.032)		(0.088)	(0.074)	(0.056)	(0.056)
Invest B	-0.130***		0.118***	0.0478	-0.0455	-0.473***		-0.375***	0.130***	-0.0970***	-0.619***		-0.263***	0.213***	0.226***
	(0.025)		(0.039)	(0.046)	(0.047)	(0.083)		(0.054)	(0.041)	(0.033)	(0.063)		(0.061)	(0.071)	(0.056)
Invest C	-0.0581	0.133***		-0.228***	0.175***	0.206***	-0.302***		-0.0872*	0.176***	0.197***	-0.209***		-0.302***	0.111**
	(0.055)	(0.043)		(0.035)	(0.047)	(0.038)	(0.043)		(0.047)	(0.033)	(0.044)	(0.071)		(0.058)	(0.052)
Invest D	-0.0376	0.0493	-0.210***		-0.0676	-0.189***	0.0982**	-0.0822*		-0.452***	-0.0495	0.165***	-0.308***		-0.570***
	(0.048)	(0.046)	(0.031)		(0.048)	(0.038)	(0.044)	(0.045)		(0.052)	(0.042)	(0.062)	(0.039)		(0.052)
Invest E	0.0393	-0.0406	0.142***	-0.0530		0.0882***	-0.0661**	0.150***	-0.407***		0.0871**	0.120***	0.0677**	-0.389***	
	(0.030)	(0.043)	(0.038)	(0.043)		(0.026)	(0.030)	(0.039)	(0.047)		(0.040)	(0.035)	(0.034)	(0.049)	
1/*Round*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Race	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Session	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 32: Effect of Communication – Asymmetric (1/Round)

	(1) Invest A	(2) Invest B	(3) Invest C	(4) Invest D	(5) Invest E	(6) Invest A	(7) Invest B	(8) Invest C	(9) Invest D	(10) Invest E	(11) Invest A	(12) Invest B	(13) Invest C	(14) Invest D	(15) Invest E
Invest A		-0.0702**	-0.214***	0.0750*	-0.134***		-0.617***	-0.0494	0.148***	0.139***		-0.464***	-0.129**	-0.131***	-0.0119
		(0.031)	(0.038)	(0.038)	(0.050)		(0.032)	(0.059)	(0.041)	(0.047)		(0.039)	(0.055)	(0.027)	(0.035)
Invest B	-0.0950**		-0.0804*	0.0235	0.106***	-0.653***		-0.276***	0.0774**	0.0439	-0.649***		-0.480***	-0.321***	-0.0294
	(0.043)		(0.049)	(0.037)	(0.038)	(0.033)		(0.049)	(0.035)	(0.033)	(0.034)		(0.056)	(0.051)	(0.055)
Invest C	-0.267***	-0.0704		0.141***	0.157***	-0.0371	-0.196***		-0.0598	0.106***	-0.138**	-0.366***		-0.310***	0.00563
	(0.048)	(0.043)		(0.036)	(0.049)	(0.044)	(0.037)		(0.039)	(0.036)	(0.057)	(0.047)		(0.056)	(0.052)
Invest D	0.0885**	0.00853	0.131***		-0.131**	0.170***	0.0839**	-0.0913		-0.674***	-0.148***	-0.260***	-0.329***		-0.535***
	(0.045)	(0.031)	(0.036)		(0.060)	(0.050)	(0.037)	(0.064)		(0.033)	(0.026)	(0.044)	(0.050)		(0.064)
Invest E	-0.123***	0.0763***	0.118***	-0.105**		0.166***	0.0496	0.168***	-0.702***		-0.0120	-0.0213	0.00536	-0.480***	
	(0.048)	(0.026)	(0.039)	(0.050)		(0.053)	(0.035)	(0.051)	(0.028)		(0.035)	(0.040)	(0.049)	(0.056)	
1/*Round*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Race	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Session	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 33: Effect of Communication – Circle (1/Round)

	(1) Invest A	(2) Invest B	(3) Invest C	(4) Invest D	(5) Invest E	(6) Invest A	(7) Invest B	(8) Invest C	(9) Invest D	(10) Invest E	(11) Invest A	(12) Invest B	(13) Invest C	(14) Invest D	(15) Invest E
Invest A		0.00994	0.203***	0.125***	-0.177***		-0.353***	0.0134	-0.00678	-0.0921**		-0.280***	-0.0137	0.107**	-0.331***
		(0.048)	(0.073)	(0.044)	(0.024)		(0.046)	(0.056)	(0.051)	(0.041)		(0.045)	(0.052)	(0.043)	(0.040)
Invest B	0.00561		0.149***	-0.0554*	0.142***	-0.371***		-0.275***	0.0374	0.0709	-0.277***		-0.402***	0.0510	0.139***
	(0.027)		(0.043)	(0.029)	(0.040)	(0.054)		(0.049)	(0.043)	(0.046)	(0.053)		(0.043)	(0.036)	(0.036)
Invest C	0.115***	0.150***		0.0272	-0.0519	0.0132	-0.257***		-0.111**	0.154***	-0.0140	-0.416***		-0.259***	0.136***
	(0.043)	(0.042)		(0.036)	(0.053)	(0.055)	(0.043)		(0.050)	(0.045)	(0.053)	(0.034)		(0.052)	(0.035)
Invest D	0.0777***	-0.0612*	0.0301		-0.0502	-0.00594	0.0312	-0.0987**		-0.134***	0.0926**	0.0447	-0.219***		-0.211***
	(0.027)	(0.032)	(0.039)		(0.052)	(0.045)	(0.035)	(0.042)		(0.037)	(0.039)	(0.033)	(0.044)		(0.050)
Invest E	-0.117***	0.167***	-0.0610	-0.0535		-0.0802**	0.0587	0.137***	-0.133***		-0.300***	0.126***	0.118***	-0.219***	
	(0.015)	(0.049)	(0.064)	(0.053)		(0.034)	(0.038)	(0.036)	(0.036)		(0.034)	(0.033)	(0.034)	(0.048)	
1/*Round*	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Race	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Gender	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Session	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 34: Number of Neighbors and Investments (1/Round)

	Baseline		Global		Local	
	Line	Asymmetric	Line	Asymmetric	Line	Asymmetric
Two neighbors	-0.00216	-0.0358	0.0503	-0.123**	0.0557*	-0.0289
	(0.059)	(0.102)	(0.038)	(0.063)	(0.034)	(0.052)
Three neighbors		-0.252***		0.146***		0.189***
		(0.070)		(0.051)		(0.058)
# neighbors invest	-0.0472	-0.0129	-0.233***	-0.227***	-0.258***	-0.283***
	(0.033)	(0.022)	(0.024)	(0.030)	(0.020)	(0.028)
Invest Lag	-0.180***	-0.191***	-0.252***	-0.397***	-0.289***	-0.316***
	(0.041)	(0.041)	(0.068)	(0.053)	(0.053)	(0.054)
1/*Round*	Yes	Yes	Yes	Yes	Yes	Yes
Race	Yes	Yes	Yes	Yes	Yes	Yes
Gender	Yes	Yes	Yes	Yes	Yes	Yes
Session	Yes	Yes	Yes	Yes	Yes	Yes
Observations	540	540	540	540	540	540

Robust standard errors in parentheses

* p<0.10, ** p<0.05, *** p<0.01

B.2.2 Results for Periods 5-10

Figure 31: Efficiency Across Periods 5-10

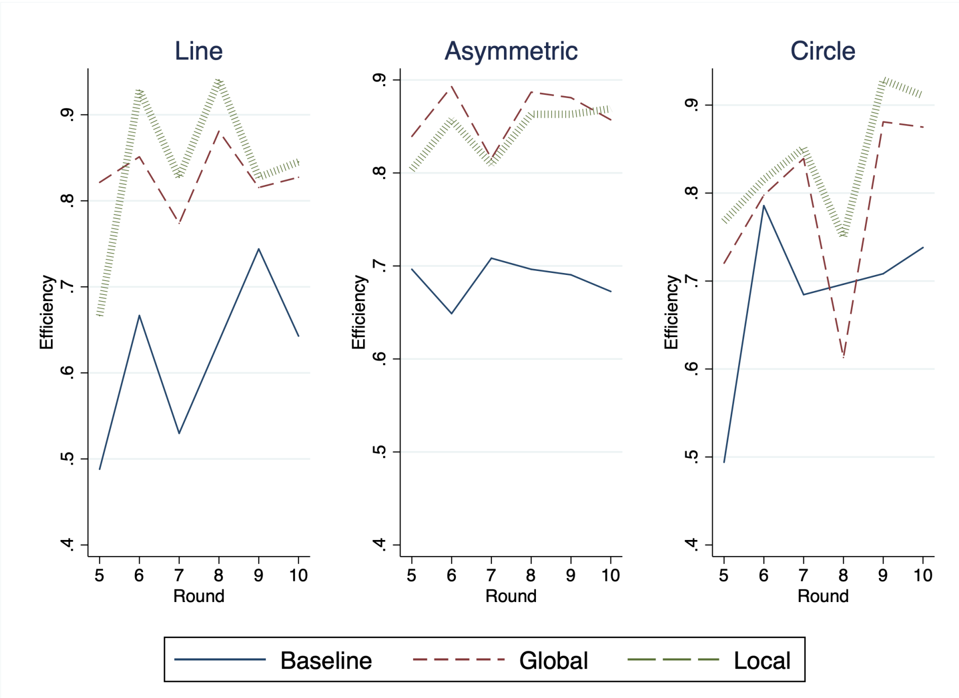


Figure 32: Efficiency Across Periods 5-10 – Bar

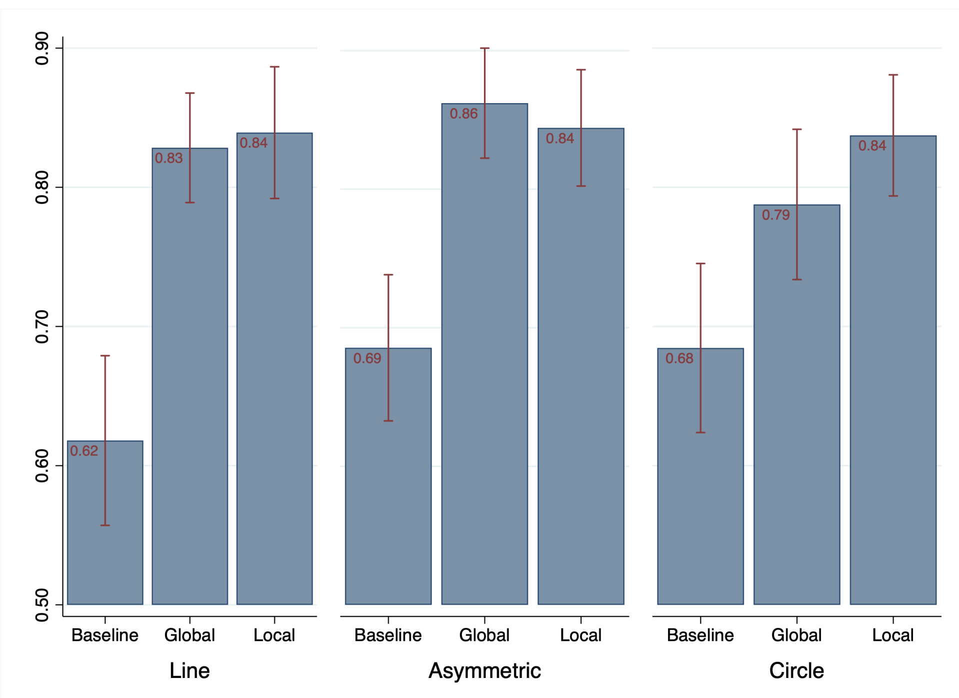


Table 35: Effect of Treatment – Periods 5-10

	Line	Asymmetric	Circle
Global	0.210***	0.177***	0.103***
	(0.042)	(0.043)	(0.027)
Local	0.221***	0.159***	0.153***
	(0.046)	(0.044)	(0.043)
Round	0.0176*	0.00493	0.0262***
	(0.009)	(0.007)	(0.008)
Observations	216	216	216

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 36: Effect of Network – Periods 5-10

	Line	Asymmetric	Circle
Asymmetric	0.0675	0.0337	0.00496
	(0.047)	(0.036)	(0.044)
Circle	0.0665	-0.0407	-0.00198
	(0.047)	(0.039)	(0.036)
Round	0.0201**	0.00907	0.0196***
	(0.010)	(0.007)	(0.007)
Observations	216	216	216

Robust standard errors in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Table 37: Frequency of Equilibrium – Periods 5-10

		Baseline	Global	Local
Line	Not an equilibria	78%	26%	22%
	L1 - A, C & E	7%	35%	32%
	L2 - B & D	4%	36%	32%
	L3 - B & E	3%	1%	8%
	L4 - A & D	8%	1%	6%
Asymmetric	Not an equilibria	82%	33%	47%
	A1 - A, C & E	8%	18%	13%
	A2 - B & E	4%	11%	13%
	A3 - A & D	6%	14%	17%
	A4 - B & D	0%	24%	11%
Circle	Not an equilibria	82%	60%	51%
	C1 - A & D	3%	10%	11%
	C2 - A & C	0%	4%	7%
	C3 - B & E	8%	10%	13%
	C4 - C & E	6%	7%	11%
	C5 - B & D	1%	10%	7%

B.3 Proof – Proposition

Lemma 2. *In the baseline game without cost sharing rules, in the Line network, the pure strategy Nash equilibria are (1,0,1,0,1), (0,1,0,1,0), (1,0,0,1,0), and (0,1,0,0,1). In the Asymmetric network, the pure-strategy Nash equilibria are (1,0,1,0,1), (1,0,0,1,0), and (0,1,0,0,1). In the Circle network, the pure strategy Nash equilibria are (1,0,0,1,0), (1,0,1,0,0), (0,1,0,0,1), (0,0,1,0,1) and (0,1,0,1,0)*

Proof. *See Lemma 1* ■

Proposition 6. ***Commitments made in the communication stage are self-enforcing.***

Proof. Suppose agent i commits to invest. Based on Lemma 2 the best reply for all her neighbors is to not invest. Agent i gets a higher payoff of $u_i(1, \boldsymbol{a_j}, G) = b - c$, by following through on her commitment since deviating from her commitment yeilds a lower payoff $u_i(0, \boldsymbol{a_j}, G) = 0$. Similarly, suppose agent i commits to not invest, based on Lemma 2 the best reply for at least one of her neighbors is to invest. Agent i gets a higher payoff of $u_i(0, \boldsymbol{a_j}, G) = b$, by following through on her commitment since deviating from her commitment yeilds a lower payoff $u_i(1, \boldsymbol{a_j}, G) = b - c$. ■

References

Banerjee, A. and Iyer, L. (2005). History, institutions, and economic performance: The legacy of colonial land tenure systems in india. *The American Economic Review*, 95(4):1190–1213. 29

Banerjee, A. and Somanathan, R. (2007). The political economy of public goods: some evidence from india. *Journal of Development Economics*, 82(2):287–314. 29

Boncinelli, L. and Pin, P. (2012). Stochastic stability in best shot network games. *Games and Economic Behavior*, 75(2):538–554. 3, 5, 6, 29, 33

Boosey, L. and Isaac, R. M. (2016). Asymmetric network monitoring and punishment in public goods experiments. *Journal of Economic Behavior & Organization*, 132:26–41. 5, 31, 32

Bramoullé, Y. (2007). Anti-coordination and social interactions. *Games and Economic Behavior*, 58(1):30–49. 3

Bramoullé, Y. and Kranton, R. (2007). Public goods in networks. *Journal of Economic Theory*, 135(1):478–494. 3, 29, 35

Bramoullé, Y., Kranton, R., and D'Amours, M. (2014). Strategic interaction and networks. *The American Economic Review*, 104(3):898–930. 3, 29

Brandts, J., Cooper, D. J., and Rott, C. (2019). Communication in laboratory experiments. Edward Elgar Publishing. 30, 31

Breza, E. and Chandrasekhar, A. G. (2019). Social networks, reputation, and commitment: Evidence from a savings monitors experiment. *Econometrica*, 87(1):175–216. 28

Cardenas, J.-C. (2000). How do groups solve local commons dilemmas? lessons from experimental economics in the field. *Environment, Development and Sustainability*, 2(3-4):305–322. 29

Caria, A. S. and Fafchamps, M. (2018). Expectations, network centrality, and public good contributions: Experimental evidence from india. *Journal of Economic Behavior & Organization*. 5, 32

Carpenter, J., Kariv, S., and Schotter, A. (2012). Network architecture, cooperation and punishment in public good experiments. *Review of Economic Design*, 16(2-3):93–118. 5, 31, 32

Charness, G., Feri, F., Meléndez-Jiménez, M. A., and Sutter, M. (2014). Experimental games on networks: Underpinnings of behavior and equilibrium selection. *Econometrica*, 82(5):1615–1670. 3, 4, 5, 6, 19, 25, 29, 31, 32, 33, 36

Chaudhuri, A. (2011). Sustaining cooperation in laboratory public goods experiments: a selective survey of the literature. *Experimental Economics*, 14(1):47–83. 30

Cheng, C. and Xing, Y. (2018). Stable allocations with network-based comparisons. *Available at SSRN 3307723*. 47

Choi, S., Gallo, E., and Kariv, S. (2016). Networks in the laboratory. *Oxford Handbook on the Economics of Networks*. 5, 30, 31

Choi, S. and Lee, J. (2014). Communication, coordination, and networks. *Journal of the European Economic Association*, 12(1):223–247. 30

Chuang, Y. and Schechter, L. (2015). Social networks in developing countries. *Annual Review of Resource Economics*, 7(1):451–472. 3, 56

Conley, T. G. and Udry, C. R. (2010). Learning about a new technology: Pineapple in ghana. *The American Economic Review*, pages 35–69. 3, 56

Cox, J. C., Sadiraj, V., and Sen, U. (2018). Cultural identities and resolution of social dilemmas. *Economic Inquiry*. 29

Crawford, V. (1998). A survey of experiments on communication via cheap talk. *Journal of Economic Theory*, 78(2):286–298. 31

Dessi, R., Gallo, E., and Goyal, S. (2016). Network cognition. *Journal of Economic Behavior & Organization*, 123:78–96. 58

Dufwenberg, M. and Patel, A. (2017). Reciprocity networks and the participation problem. *Games and Economic Behavior*, 101:260–272. 3

Fatas, E., Meléndez-Jiménez, M. A., and Solaz, H. (2010). An experimental analysis of team production in networks. *Experimental Economics*, 13(4):399–411. 5, 31, 32

Fischbacher, U. (2007). z-tree: Zurich toolbox for ready-made economic experiments. *Experimental Economics*, 10(2):171–178. 14, 37

Foster, A. D. and Rosenzweig, M. R. (2010). Microeconomics of technology adoption. *Annual Review of Economics*, 2(1):395–424. 3, 56

Galeotti, A., Goyal, S., Jackson, M. O., Vega-Redondo, F., and Yariv, L. (2010). Network games. *The Review of Economic Studies*, 77(1):218–244. 8

Harrison, G. W. and Hirshleifer, J. (1989). An experimental evaluation of weakest link/best shot models of public goods. *Journal of Political Economy*, 97(1):201–225. 4

Hirshleifer, J. (1983). From weakest-link to best-shot: The voluntary provision of public goods. *Public choice*, 41(3):371–386. 4

Hoff, K. and Pandey, P. (2006). Discrimination, social identity, and durable inequalities. *The American Economic Review*, 96(2):206–211. 29

Jackson, M. O. (2005). Allocation rules for network games. *Games and Economic Behavior*, 51(1):128–154. 4, 11, 58

Jackson, M. O. and Wilkie, S. (2005). Endogenous games and mechanisms: Side payments among players. *The Review of Economic Studies*, 72(2):543–566. 3

Komarovsky, Z., Levit, V., Grinshpoun, T., and Meisels, A. (2015). Efficient equilibria in a public goods game. In *Web Intelligence and Intelligent Agent Technology (WI-IAT), 2015 IEEE/WIC/ACM International Conference on*, volume 2, pages 214–219. IEEE. 15, 38

Korkmaz, G., Capra, M., Kraig, A., Lakkaraju, K., Kuhlman, C., and Vega-Redondo, F. (2018). Coordination and collective action on communication networks. Technical report, Sandia National Lab.(SNL-NM), Albuquerque, NM (United States). 30

Ledyard, J. O. (1995). Public goods: A survey of experimental research,. In *Handbook of Experimental Economics*. Princeton University Press. 30

Leibbrandt, A., Ramalingam, A., Sääksvuori, L., and Walker, J. M. (2015). Incomplete punishment networks in public goods games: experimental evidence. *Experimental Economics*, 18(1):15–37. 5, 31, 32

Munshi, K. and Rosenzweig, M. (2018). Ethnic politics, group size, and the under-supply of local public goods. 29

Myerson, R. B. (1977). Graphs and cooperation in games. *Mathematics of operations research*, 2(3):225–229. 35, 58

Ostrom, E. (2014). Collective action and the evolution of social norms. *Journal of Natural Resources Policy Research*, 6(4):235–252. 57

Palfrey, T., Rosenthal, H., and Roy, N. (2017). How cheap talk enhances efficiency in threshold public goods games. *Games and Economic Behavior*, 101:234–259. 30

Rosenkranz, S. and Weitzel, U. (2012). Network structure and strategic investments: An experimental analysis. *Games and Economic Behavior*, 75(2):898–920. 3, 4, 5, 25, 29, 31, 32

Tasselli, S. (2014). Social networks of professionals in health care organizations a review. *Medical Care Research and Review*, 71(6):619–660. 3, 56

Zenou, Y. (2016). Key players. *Oxford Handbook on the Economics of Networks, Oxford: Oxford University Press.* 3

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