Can we talk our way to efficiency?

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Abstract

Does the local nature of information in a networked environment impede coordination and cooperation? How does the communication structure affect the actions the group coordinates on? This paper explores the interplay between two communication structures and decisions in a best-shot public good game across three five-person networks. The network determines which group members share a local public good. Across the networks, the number of neighbors each person has is varied. In the Line network, an individual can have either one or two neighbors. In the Asymmetric network, an individual can have one, two, or three neighbors. Lastly, the Circle network is symmetric, and everyone has two neighbors. I then introduce two communication structures. The first is global, where all group members can communicate. The second is local, where only neighbors can communicate. Unlike global, the local structure overlays the communication structure on the underlying network. In the baseline treatment without communication, efficiency is low due to a lack of access to the public good. In the Line and Asymmetric network, the access to the public is lower for individuals with fewer neighbors. Both global and local communication structures successfully increase efficiency in Line and Asymmetric networks. Global communication enables groups to coordinate across equilibrium profiles by taking turns to invest, reducing payoff disparities. Local communication, while also improving efficiency, reinforces the strategic advantage of individuals with more neighbors in the Line and Asymmetric network. In the Circle network, only local communication successfully raises efficiency by improving coordination on Nash equilibria. Global communication does not significantly improve efficiency or equilibrium coordination in the Circle network. The Circle network sees improved equilibrium coordination and efficiency with local communication.

JEL-Codes: C72, C92, D70, D83, H41.
Keywords: Strategic substitutes, Social and economic networks, Communication, Repeated games.

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1 Introduction and motivation

The structure of the social fabric that weaves our economic and social relationships is critical in determining how the social surplus is generated and divided among those in the group. The geographical and social structure restricts the flow of information across different parts of the network. This local nature of information can impede coordination and often obscure the understanding of one's actions on others to whom they are indirectly linked. For example, in social structures such as the caste system in India, Munshi and Rosenzweig (2018) and Banerjee and Somanathan (2007) find that an increase in social fragmentation leads to an under-supply of public goods, especially for those who are on the periphery in these social structures. Even in artifactual field experiments, simply being aware of the presence of individuals from different social groups leads to lower levels of cooperation (Cardenas, 2000, Hoff and Pandey, 2006, Cox et al., 2018). Many of these decisions can have long-term consequences, such as the persistence of inequalities, and they impact patterns of technological adoption, investment in research and development, segregation across neighborhoods, and differences in the quality of local public goods, such as schools and healthcare.

To understand the problem, consider the fields of three farmers – A, B, and C. They are arranged in a line where A and B share a boundary, and B and C share a boundary, but A and C do not. The farmers who share a boundary are neighbors. Every year, the farmers simultaneously decide whether to make a costly investment by learning about and adopting a new production technique or not make the investment and learn from observing their neighboring farmers' investment. Adopting the new technique improves yields, and the benefits outweigh the costs incurred. In this scenario, the farmer's decisions have local positive externalities, and the benefit from an investment is substitutable between neighbors. Suppose B invests and learns about the new technique. Then, A and C do not need to invest and can learn from B's experience. This outcome is socially efficient since everyone benefits from adoption with only one investment. Since investing is costly, B can maximize their earnings by not investing and learning from the investments made by either A or C. If B does not invest, it is in the interest of A and C to invest since the gains from adopting the technology outweigh the cost. However, they do not benefit from each other's investment since they do not share a boundary. This outcome is socially inefficient because the everyone in group adopting the technology requires two investments. Given the structure, B is aware of everyone's decision, but A and C can only observe what B does. It also gives B two potential sources to learn about the technology, thus making them less likely to invest in learning about the technology themselves, making the socially efficient outcome less likely.

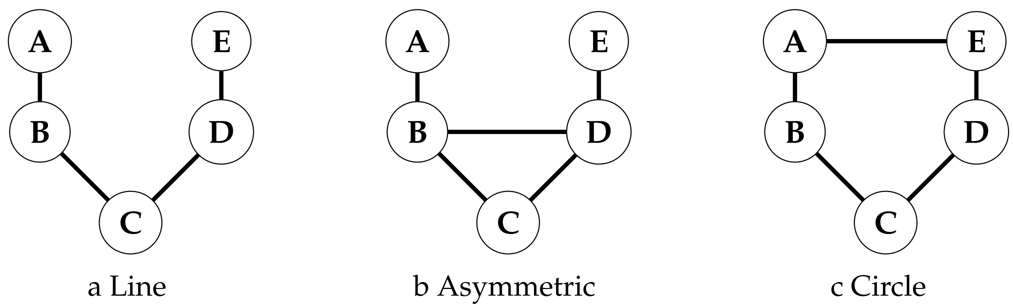
The communication structure is critical in these scenarios. Information is an essential power source and has been widely documented in network analysis. The communication structure influences coordination, thereby influencing the distribution of the surplus. Thus, it is vital to study how different communication structures that can directly affect the information available to individuals interact with the underlying structure of externalities. Suppose everyone in the group can communicate, this can offset the information advantage B has. A and C can communicate and coordinate their actions. One potential outcome is that the group always coordinates on the socially efficient outcome. Since this is a repeated interaction, another solution could be to take turns investing and share the cost of adoption across periods. This improves efficiency and leads to an equitable division of the surplus.

Compare this to letting only neighbors communicate. That is, B can talk to both A and C, but A and C can only talk to B. This reinforces the asymmetries in the underlying network. B can take advantage of their position and always free-ride on the investments of A and C. However, it can still improve efficiency by minimizing coordination failures. Note that since there are no disjoint components in this network, if B is willing to relay messages between A and C, a communication where everyone is able to communicate with each other is possible.

In this paper, I study the link between the structure of pre-play communication and the outcome of actions in a repeated best-shot public goods game across three network structures (see Figure 1) in a laboratory experiment. The aim is to explore the efficacy of the two communication structures in influencing how the surplus is generated and distributed among individuals in the group across the three networks. In the experiment, groups of five individuals participate in a repeated best-shot public goods game in one of the three networks. Each individual is assigned a position on the network. Across rounds, an individual's position and group are held fixed. The links on the network determine which individuals in the group share a local public good. Individuals simultaneously decide whether to make a costly investment. The public good is provided if an individual or at least one of their neighbors chooses to invest.[1] If the good is not provided, an individual receives no payoff. There is friction between neighbors on whether to invest or free-ride on others' investments. However, if no one else is investing, an individual is better off by incurring the costly investment decision. The network structure separates the group into different components who do not directly observe each others' actions but

[1] The benefit from the public good is not increasing if more neighbors are investing; it requires only one investment. The benefit from the public good is strictly higher than the cost of the investment.

Figure 1: Network Structures in the Experiment



are affected by them. Coordinating on an equilibrium profile requires coordination between unlinked individuals who do not observe each others' decisions.[2] This raises the possibility of coordination failures both with direct neighbors due to the friction in the incentive to invest and with indirect neighbors since they have to coordinate with them without directly observing each others' choices.

Across three networks, I vary the number of links between individuals. Adding a link has two countervailing effects. It increases access to the public good and at the same time increases the incentive to free-ride. In the Line network, there are two individuals on the periphery with one neighbor, and the remaining three have two neighbors each. Adding a link between the periphery on the Line, we get to the Circle, where everyone has two neighbors. Adding the link reduces the asymmetries in the number of connections. Adding a link between nodes B and D in the Line network leads to the Asymmetric network. This has individuals with varying numbers of neighbors - one, two, and three. Adding this increases the asymmetry in the distribution of neighbors in the group. There are two primary reasons for selecting these networks. First, across the three network structures, the efficient equilibrium profile requires two unlinked individuals to invest. In the Line and Asymmetric networks share the same inefficient stable equilibrium (Boncinelli and Pin, 2012) where three unlinked individuals are investing. This allows me to compare the outcomes across the networks based on the structure and not due to differences in characteristics of the equilibrium profiles. Second, given the constraint of space in the laboratory, the network of five individuals allows testing the effect of network structure on coordination since equilibrium requires coordination with individuals who are farther away in the network.

[2]"The equilibria in this game correspond exactly to having the set of players who choose to invest form a maximal independent set of nodes in the network; that is, a maximal set of nodes that have no links to each other in the network" (Jackson and Zenou, 2014).

In the communication treatments, before making their investment decision, the five individuals simultaneously engage in unstructured text communication. There was no restriction placed on the content of the messages. However, in the instructions, I encouraged participants to limit their discussion to their investment decisions.[3] The communication environment emulates a Twitter post environment where group members can communicate by posting messages on their "wall." Participants have one minute to communicate by writing and reading messages. In this setup, I study the following two communication structures. The first structure is global, where individual can view posts shared by all members in their group. The second structure is local, where an individual can only see their neighbors' posts.

The stable equilibrium in the Line and Asymmetric networks predicts that the largest number of unlinked individuals invest in equilibrium. This highlights the "power" that those with more neighbors have in the form of more access to the local public good. The global communication structure, which allows linked and unlinked group members to communicate, can potentially offset this asymmetry imposed by the structure of externalities. The largest number of unlinked individuals can decide not to coordinate on the inefficient equilibrium. This notion is captured by the α-permissible network (Cheng and Xing, 2022). For example, in the Line network, the equilibrium where the individuals at nodes A, C, and E invest is a stochastically stable equilibrium according to (Boncinelli and Pin, 2012), and this inefficient equilibrium is empirically more likely to be observed (Charness et al., 2014). In the global structure, individuals at A, C, and E can communicate and decide not to invest and force individuals in positions B and D to invest, which is an efficient equilibrium. Thus, the global communication structure can help resolve this tension between stability and efficiency.

The local structure superimposes the communication structure on the underlying network of externalities. This overlapping of communication and network structure can potentially exacerbate the underlying asymmetries induced by the network. However, better coordination between direct neighbors facilitated by local communication can improve overall efficiency by lowering the likelihood of under-provision of the public good when two linked individuals are not investing or over-provision when both neighbors are investing. Overall, the local communication structure allows for coordinating investment decisions among neighbors, which can help mitigate inefficiencies due miscoordination. Since there are no disjoint components in the network, if individuals relay information between different components of the network, the communication structure would be

[3]Brandts et al. (2019) find that compared to restricted chat, unrestricted communication is more effective as a coordination device.

the same as global.

In the baseline treatment, where groups do not have the option to communicate, I find that the overall efficiency of provision is low in the Line and Asymmetric networks compared to the treatments where groups can communicate. The under-provision of the local public good drives the low level of efficiency. This is particularly unfavorable for individuals with fewer neighbors. This is reflected in the differences in payoff across individuals with different numbers of neighbors. I find that in the baseline, in the Line network, the payoff of those with two neighbors ($4.81) is 41.5% higher than those with one neighbor ($3.39). In the Asymmetric network, the difference is even more striking. On average, the payoff of participants with three neighbors ($6.68) is more than double that of those with one neighbor ($2.93). This corresponds to a pattern of investment that has been widely noted in the literature studying the provision of public goods in networks, finding a negative relationship between the number of neighbors an individual has and their likelihood of investing (Charness et al., 2014, Rosenkranz and Weitzel, 2012). I observe this negative relationship in the likelihood of investing the baseline treatment as well.

The global communication structure where all group members can communicate successfully increases the efficiency of the provision in the Line and Asymmetric network but not the Circle network. In the Line and Asymmetric network, groups are successful in taking turns to invest to divide the cost of providing the local public good across rounds. This is reflected in coordinating across equilibrium profiles. As a result, there are no statistically significant differences in the likelihood of investing between individuals with one, two, or three neighbors. In the Line network, most of the group consistently alternates between the inefficient equilibrium and one of the efficient equilibrium, leading to a narrower gap in payoff between individuals with one and two neighbors. Groups in the Asymmetric network coordinate on an action profile where two linked individuals with three neighbors are investing. This is not an equilibrium profile, but it aids in taking turns across the rounds. As a result, there is only a 50-cent difference in payoff between individuals with one and three neighbors in the Asymmetric network. In contrast, in the Circle network, everyone has the same access to the public good and thus the same incentive to free-ride on their neighbors' investment. This leads to frequent miscoordination and no improvement in efficiency compared to the baseline.

Local communication overlays the structure of externalities on the underlying structure of externalities. In the Line network the individual in position C acts as an information bridge between two components of network. If the individual can exploit their advantage in the communication coordinating on the inefficient equilibrium less likely. Although there is no statistically significant difference in the likelihood of investing, individuals with two neighbors on average earn $1.88 more than individuals with one neighbors. Local communication also improves equilibrium coordination as well. In the Asymmetric network individuals with more neighbors are central both in the communication and public goods structures. Although, there is no difference in the likelihood of investing between one and three neighbors.However, ton average, the payoff of participants with three neighbors ($6.39) earns $1.56 more than participants with one neighbor ($4.83), these differences are due to lower access to the public goods form individuals with one neighbor. The Circle network benefited from local communication, with improved coordination on Nash equilibria, which is reflected in an increase in efficiency in the provision of the local public good.

This paper contributes to the literature on pre-play communication.[4] Previous research on communication networks has primarily focused on games of strategic complements. Charness et al. (2019) and Choi and Lee (2014) find that introducing communication increases the efficiency of provision in coordination games. Charness et al. (2019) also finds that restricted communication to a pre-determined set of messages is not effective in increasing efficiency in an augmented eight-player stag-hunt game. Choi and Lee (2014) emphasize the significance of communication structure in influencing efficiency and equity in a four-player battle of the sexes game. Judd et al. (2010) and Kearns et al. (2009) finds the structure of communication plays a vital role in reaching a consensus in a voting game with conflicting preferences. It is important to note that in Choi and Lee (2014), Judd et al. (2010) and Kearns et al. (2009), the underlying game is played on a complete network. In Charness et al. (2019), the network is symmetric, with each player having four neighbors. To the best of my knowledge, this paper is the first to examine two communication structures in the presence of asymmetries in the underlying network game of strategic substitutes.

This paper also contributes to the growing literature studying the effect of network structure on public goods provision (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).[5] In particular, Rosenkranz and Weitzel (2012) and Charness et al. (2014) find that individuals with more neighbors are less likely contribute 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. One central contribution of this paper is that it highlights the potential that communication has as a

[4]See Crawford (1998), Brandts et al. (2019) for related literature surveys.

[5]See Choi et al. (2016) for an excellent overview of laboratory experiments in networks.

mechanism to reverse this pattern of investment as this has equity concerns for individuals in the periphery of social and geographical networks. Caria and Fafchamps (2018) report results from an artifactual field experiment with farmers in India. They use expectations of the periphery players as a mechanism to induce central individuals (in their case, the center of a star network) to invest. They find that individuals in the center of a star network reciprocate the subjects' expectations in the periphery. However, the investment of the center is constrained by the expectations of the periphery players, which could be sub-optimal. In this paper, I present evidence that both the unstructured communication structures 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 the individual in the central position.

In the next section, I present a theoretical analysis and derive testable hypotheses. Section 3 presents the experimental design and procedures. The empirical results are presented in Section 4, and Section 5 provides a conclusion.

2 Theoretical analysis

Let the set of agents be $N = \{1, \ldots, n\}$, where $n \geq 2$. Each agent i simultaneously chooses an action $a_i\ in\{0, 1\}$, to whether to invest (1) or not invest (0) in a local public good. 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 $\boldsymbol{a} = (a_1, \ldots, a_n)$ 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 and the agents' payoffs to whom she is connected on the graph through positive externalities.

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

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

The best reply for each agent i is: (i) to invest ($a_i = 1$) if no one in her neighborhood invests and (ii) to not invest ($a_i = 0$) if at least one of her neighbors invests. The Nash equilibrium for this game is characterized by agents belonging to a maximal independent set investing in the local public good (Bramoullé and Kranton, 2007, please see Theorem 1, page 483).[6] The multiplicity of the maximal independent sets gives rise to multiple equilibria (Jackson and Zenou, 2014, Goyal, 2023). The larger the maximal independent set higher the total cost of providing the public good. To quantify the effect of equilibria on social welfare, I use a standard utilitarian measure of social welfare, defined as: $W(\boldsymbol{a}, \boldsymbol{G}) = \sum_{i \in N} b \times \mathbb{1}\left\{\sum_j g_{ij} a_j + a_i \geq 1\right\} - c \times \sum_{i \in N} a_i$. For the three network structures in this study (see Figure 1): Line, Asymmetric, and Circle, Table 1 reports the pure strategy Nash equilibria and the associated social welfare for each network structure. Given the multiplicity of the equilibria, equilibrium selection is an open empirical question. There are two theoretical results that provide guidance which equilibrium profiles are stable and more likely to be observed. (Bramoullé and Kranton, 2007, Theorem 2) show that an equilibrium profile is stable if and only if every agent who is not investing is connected to at least two agents who are investing. Boncinelli and Pin (2012) addresses equilibrium selection through stochastic stability in a best-shot public goods game in networks. Boncinelli and Pin (2012) shows that if both agents who are investing and not investing randomize or follow a logistic best reply, the only stochastically stable states are Nash equilibria with the largest number of unlinked agents investing. Applying these results, *L1* and *A1* emerge as the two stable equilibrium profiles in the Line and Asymmetric networks. The stability results highlight the tension between stability and social efficiency of payoffs. There are equity consequences of coordinating on the inefficient equilibrium since agents with more neighbors earn the benefit, b, from the public good in all rounds, whereas agents with fewer neighbors would end up with $b - c$, leading to inequality in the payoffs at the end of the game. This leads to the following hypotheses:

Hypothesis 1a *There is an inverse relationship between the number of neighbors and their likelihood of investing in the local public good.*

Hypothesis 1b *Agents with more neighbors will have higher payoffs than those with fewer neighbors.*

[6] An independent set of a graph is a set of agents such that no two agents who belong to the set are linked.

Table 1: Pure strategy nash equilibria

Network (equilibrium)	Investment Choice					$W(\boldsymbol{a}, \boldsymbol{G})$
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 7 for proof

2.1 Communication

Before making an investment decision, each agent can engage in free-form communication with a subset of agents in the network. The costless communication stage is cheap talk (Farrell and Rabin, 1996) since the commitments made in the communication stage are non-binding and do not directly alter the payoffs in the game. I am interested in studying how overlaying two communication structures affects the decisions in the underlying public goods game. The first communication structure is *global*. The global structure is widely studied in the literature, where all group members can communicate before making investment decisions. The second communication structure is *local*, which is more natural in a network setting where agents can communicate only with their neighbors.

If no information is transferred during the communication stage, this leads to a *babbling equilibrium*, where the equilibrium set is identical to the game without communication. However, theoretical and empirical evidence suggests that if agents' interests are sufficiently aligned, cheap talk can be informative and aid in coordinating actions (Crawford, 1998, Brandts et al., 2019). However, in the presence of asymmetric payoffs, full efficiency cannot be achieved with communication (Rabin, 1994, Farrell and Rabin, 1996). In the underlying public goods game, the set of pure strategy Nash equilibria involves asymmetric payoffs for agents. But, coordinating on a pure strategy Nash equilibrium profile is a Pareto improvement vis-á-vis coordinating on the mixed strategy Nash equilibrium profile (Rabin, 1994). The credibility of the messages in the communication stage could be crucial in lowering miscoordination between neighbors, which can improve the efficiency of the provision of the local public good. Commitments to invest made during the pre-play communication stage can be self-enforcing. Suppose an agent i commits to invest. Their neighbor(s)'s best reply is not to invest. In this case, if agent i follows through with her commitment, she earns $b - c$. If she chooses to renege, she ends up with a lower payoff of 0.

Proposition 1 ***Commitments to invest in the communication stage are self-enforcing.***[7]

Note that commitments not to invest are only self-enforcing. For example, an agent in position A in the Line network commits to not invest, but it would be the best reply for an agent in position B to invest if both agents in position A and C have committed to not invest. On the other hand, if the agent in position B commits not to invest, the agent in position A's best reply is to invest and get $b - c$ instead of not investing and getting a payoff of zero. This is not true for the B's neighbor in position C. The agent in position C can still have access to the local public good from the investment of the agent in position D.

Based on Proposition 1 and discussion above, I derive the following hypothesis.

Hypothesis 2 *In the two communication treatments, agents will honor their commitments to invest at a higher rate compared to their commitments to not invest.*

2.1.1 Global communication

In the underlying public goods game, the maximal independent set determines the subset of agents investing in equilibrium. The equilibrium where the largest set of unlinked agents in the network are investing is stable but least efficient (Boncinelli and Pin, 2012). This status quo typically results in agents with fewer neighbors investing, as those with more connections can access the public good through multiple neighbors. The global communication structure offers a potential mechanism to shift away from inefficient equilibria in the Line and Asymmetric network. In the global structure, all group members can communicate with each other. The largest number of unlinked agents who were investing in the stable but inefficient equilibrium now becomes the largest voting block. This aligns with Cheng and Xing (2022) definition of an α-stable equilibrium, where $\alpha = 0.5$, i.e., at least half of the group members can vote against the inefficient equilibrium.[8]

[7] Proof in the appendix 7

[8] The Line and Asymmetric network structures are $0.5-$ permissible Cheng and Xing (2022).

In both the Asymmetric and Line networks, agents in nodes A, C, and E can vote against coordinating on the inefficient equilibrium by committing to not investing. This forces the group to coordinate on one of the efficient equilibria where two agents are investing. In the Line network, this leads to a clear alternative (*L2*, where B and D invest). However, when A, C, and E are not investing in the Asymmetric network, groups can coordinate on either *A2* or *A3*. The payoffs for C are higher in either equilibrium. But, for A or E, A would prefer *A2*, whereas E would prefer *A3*. Since the game is implemented as a finitely, they can alternate between the two.

The Circle network presents a unique challenge. With all agents having two neighbors, it is not α-permissible (Cheng and Xing, 2022, page 1474).[9] Since all agents in the network have the same incentive to free-ride, it is an open empirical question whether the global communication structure can improve efficiency. Based on the $\alpha-$stability of the networks, I derive the following hypotheses.

Hypothesis 3a *The global structure will lead to higher efficiency in the Line and Asymmetric networks compared to no communication, but have a muted effect in the Circle network.*

Hypothesis 3b *Agents with fewer neighbors will have higher payoffs than those with more neighbors.*

2.1.2 Local communication

The local communication structure reinforces the asymmetries in the underlying network of externalities. On the one hand, in the Line and Asymmetric network, this could mean a return to the inefficient equilibrium. However, there are potential gains to efficiency by improving the best replies between neighbors. However, there is a striking difference between the criticality of the agent in the local communication structure in position C in the Line network. Subjects in this position act as an information bridge between the two components of the network. One way to measure centrality in the information network is using the eigenvector centrality measure.[10] Node C has the highest eigenvector centrality since it acts as an information bridge between the components {A, B} and {D, E}. This provides incentives to move away from the inefficient equilibrium. However, in the Asymmetric network, eigenvector centrality coincides with the number of neighbors agents have. This can potentially lead to groups coordinating on the stochastically stable equilibrium, which favors the payoffs of agents who are central in the network, agents in positions B and D. In the Circle network, limiting the communication to only neighbors

[9] $\alpha = 0.5$-permissible since there is no clear voting block to veto any one equilibrium profile.

[10] Table 34 reports the eigenvector centrality of the agents across the three networks.

can potentially help with focusing agents' actions with just their immediate neighbors which can improve coordination.

On the other hand, the three network structures have no disjoint edges; therefore, agents can communicate with others indirectly and form coalitions to share information across the entire network. The grand coalition of all group members generates an equivalent information structure as if all group members could communicate directly as in the global communication structure. In that case, there shouldn't be any differences between the two communication structures. I derive the following hypotheses.

Hypothesis 4a *The local communication structure, compared to no communication, will lead to higher efficiency in the Line and Circle networks and have a muted effect in the Asymmetric network.*

Hypothesis 4b *Agents with more neighbors will have higher payoffs than those with fewer neighbors.*

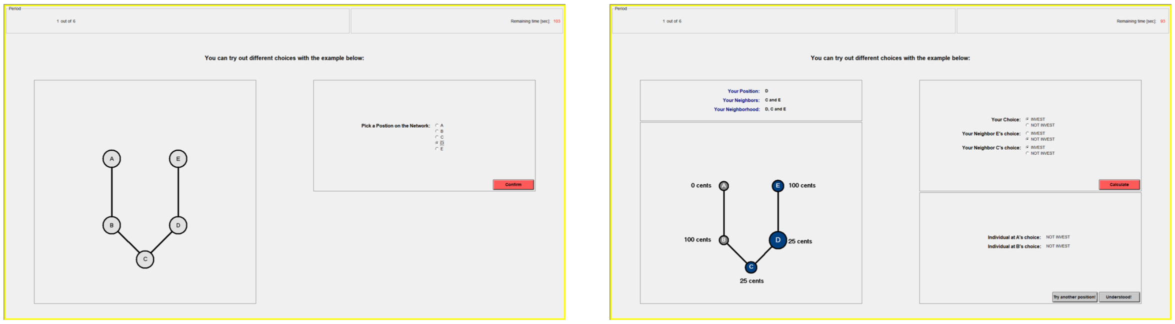
3 Experiment design and procedures

The experiment sessions were conducted at the ExCEN lab at Georgia State University between June and November 2018. One hundred eighty subjects participated in the experiment over 12 sessions. The subjects were recruited using an automated system that randomly invited participants via the ExCEN's automated email system from a pool of more than 2,600 students who signed up for participation in economic experiments. Upon arrival at the lab, the subjects reviewed and signed the consent form and were randomly assigned seats.

Each session was conducted in three stages, followed by a demographic survey. At the start of each stage, subjects were asked to read the experimental instructions at their own pace.[11] Given the complexity of the decision environment, before the start of each session, subjects explored a game simulator at their own pace to ensure they understood the game. In the game simulator, subjects could pick any position in the network and their payoff for a combination of their and their neighbors' actions (see Figure 2b). In addition, they also played five practice rounds before the baseline treatment. The experiment was computerized using z-Tree (Fischbacher, 2007). Each session lasted for roughly one hour and fifteen minutes.

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

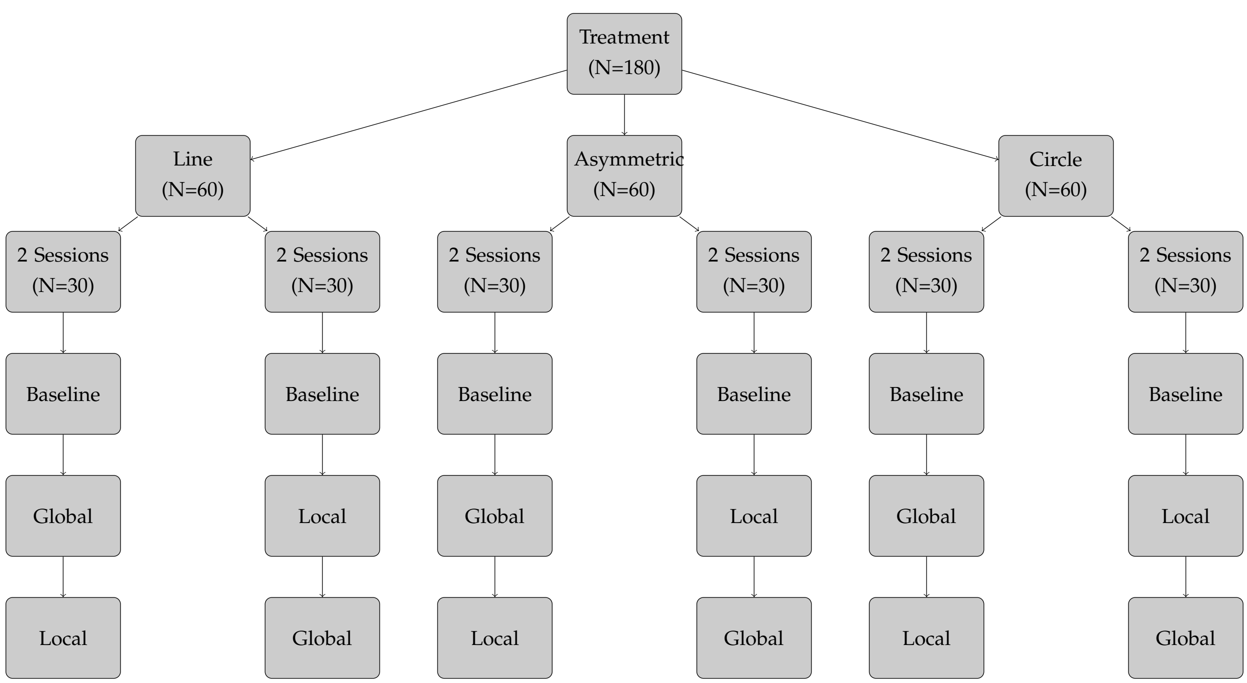
Figure 2: Game Simulator



(a) Screen 1 (b) Screen 2

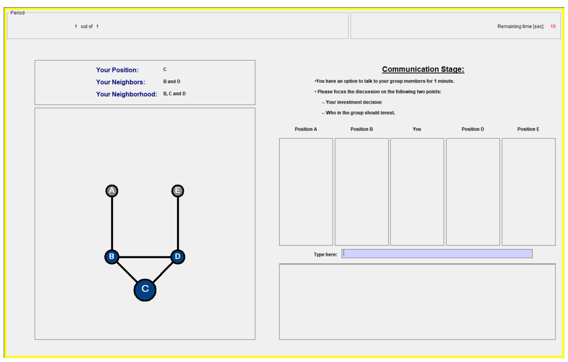
There were thirty rounds in each session, which were implemented in three stages of ten rounds each. At the start of each stage, subjects were randomly matched to form groups of five. Each subject was then randomly assigned a position in the network. The group and the position of the subjects remained fixed within each stage but varied across stages. Across stages, treatments were introduced. In the first stage, subjects played the *baseline* game without communication, followed by the two communication structures: *global* and *local*. Across sessions, the order in which the two communication structures were introduced was randomized. The experiment design is summarized in Figure 3 below.

Figure 3: Experiment Design

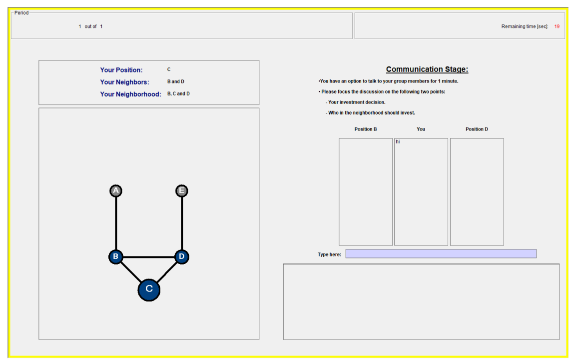


Each subject decided whether to invest in the neighborhood common fund. The benefit of investing in the neighborhood common fund was 100 cents for all individuals in the investor's neighborhood, and the cost was 75 cents. In both stages with communication, there was a one-minute communication period before making their investment decision. The communication interface mimicked a Twitter Post, where each individual could post messages on their wall (see Figure 4a). In the global communication treatment, all group members were able to see each others' posts. In the local communication structure, individuals could only see their neighbors' posts. Subjects wrote their own messages. In the instructions, they were urged to focus their communication solely on their investment decisions.

Figure 4: Communication treatment



(a) Global communication



(b) Local communication

At the end of every round, the subjects were provided with a summary of the following information: the number of neighbors who contributed to the group fund, their position on the network, their investment decision, and their payoff. This information was available for all 30 periods. At the end of each session, each subject answered a questionnaire on demographics. Subjects were paid privately for all 30 periods in cash right after the experimental session. The average payoff in the experiment was $16.10 per subject, with a minimum of $9 and a maximum earning of $26.75.

4 Results

4.1 Overview of the analysis

I use the data from the first two stages of the experiment to quantify the effect of the two communication structures on group outcomes and individual decisions. This is to avoid the results to have any potential spillover effects. In the first stage, across all networks, groups did not have the option to communicate. For the baseline, there are 120 groups and 600 individual observations for each network structure. In the second stage, groups interact either in the global or local communication structure. Each network and communication structure has 60 groups and 300 individual observations.

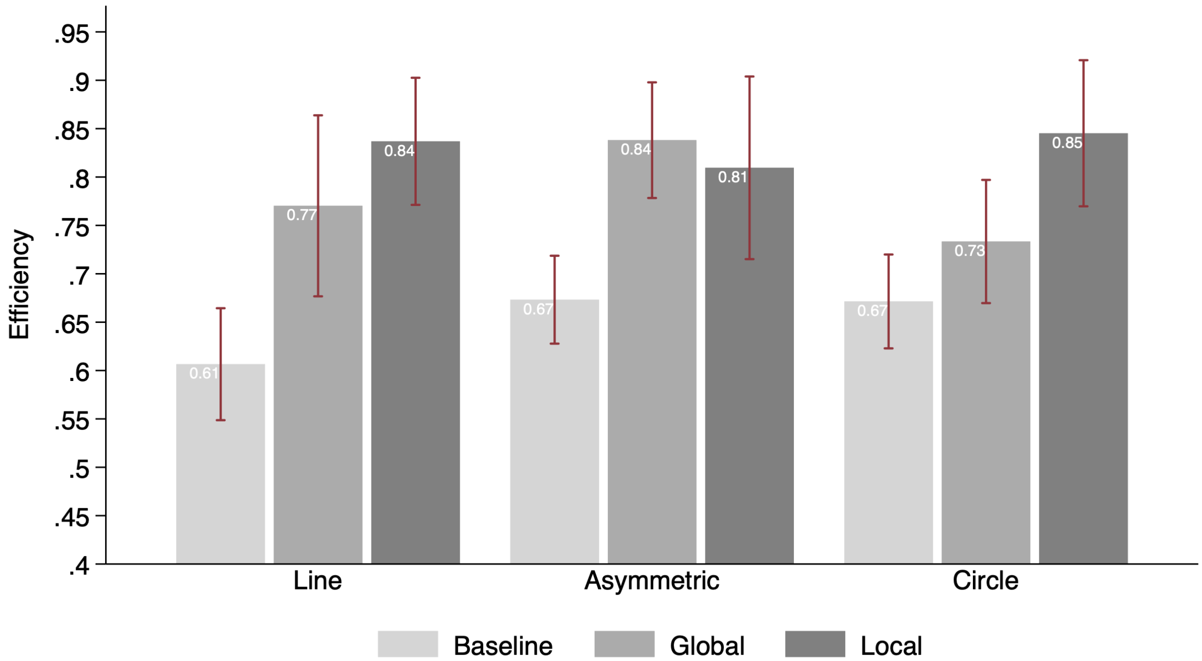
4.2 Efficiency

I use a traditional measure of efficiency to study the effect of the two communication structures on group outcomes.[12] Figure 5 presents a bar plot of efficiency across the treatments and networks. Hypothesis 3a predicts that global structure will lead to efficiency gains in the Line and Asymmetric network compared to no communication but have a muted effect in the Circle network. Hypothesis 3a predicts that global communication structure will lead to increase in efficiency in the Line and Asymmetric network but will have muted effects in the Circle network. I find evidence supporting hypothesis, compared with the baseline without communication, the global structure improves efficiency in Line (Mann-Whitney, $p < 0.001$) and Asymmetric (Mann-Whitney, $p < 0.001$) networks, but there are no gains in efficiency in the Circle network.[13] Hypothesis 4a predicts that local communication structure will lead to gains in efficiency in the Line network, muted effect in the Asymmetric network, and modest efficiency gains in the Circle network. I find that the local structure is successful in improving efficiency across the three networks (Mann-Whitney, $p < 0.001$, please see Table 11).

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

[13] Throughout the analysis, I report p-values of two-tailed tests. See Appendix 6.2 for tables containing all relevant parametric and non-parametric test results.

Figure 5: Efficiency across treatments



Note: 95% CIs clustered at the group level

Given the repeated nature of the interaction, there are two possible sources of learning in the game. First, individuals understand playing the game better as the stages progress. To mitigate the learning effects about the game itself across stages, participants completed a game simulator and five practice rounds before the actual experiment. The game simulator clearly illustrated how their and neighbors' decisions affect their payoff. Second, learning about subjects in their neighborhood and groups can help with coordination and increase efficiency. I control for these trends across rounds in the regression analysis using the reciprocal of the round number.

To estimate the effect of the two communication structures on efficiency, I estimate a generalized panel least squares model where the errors are clustered at the group level.[14] I perform separate estimations for each of the network structures. The model for each network structure is:

$$E_{it} = \sum_{k=1}^{3} \beta_k C^k + \kappa 1/Round + \varepsilon_{it} \tag{2}$$

where E_{it} is the group i's efficiency in period t, C^K indicates the communication treat-

[14]Decisions are made within a fixed group within a stage. Clustering the standard errors at the group level allows for robust estimation of the treatment effects.

ment variable, where C^1 is no communication, C^2 is the global structure, and C^3 is the local structure. I use the reciprocal of the round number as a control for learning. Table 2 reports changes in the efficiency with respect to C^1, the treatment without communication.

Table 2: Efficiency across treatments

	(1) Line	(2) Asymmetric	(3) Circle
Baseline (mean)	0.607	0.673	0.671
	(0.0296)	(0.0233)	(0.0248)
Global	0.164**	0.165***	0.0619
	(0.0563)	(0.0384)	(0.0410)
Local	0.230***	0.136*	0.174***
	(0.0448)	(0.0536)	(0.0459)
1/Round	-0.0788	-0.0583	0.0189
	(0.0572)	(0.0472)	(0.0569)
Observations	240	240	240

Robust standard errors in parentheses clustered at the group level.
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The results from the regression confirm Hypothesis 3a and 4a for the three network structures. Compared with the baseline in the Line and Asymmetric network, there is an increase in efficiency in the presence of either communication structure. The result is muted in the Asymmetric network when only neighbors can communicate in the local communication structure. As predicted by Hypothesis 3a, in the Circle network where everyone has the same number of neighbors, thus everyone has the same access to the public good and the same incentive to free-ride on their neighbors' investment. The global communication structure does not lead to any gains in efficiency. However, when communication is restricted to neighbors, the local communication structure increases efficiency in the Circle network.

There are two potential sources of inefficiency. The first source is *under-investment* in the local public good. This arises when all subjects in the group do not have access to the public good. I measure under-investment as the proportion of the group members who receive a benefit from the public good. Figure 6a shows the bar plot for the proportion group members who have access to the public good. The second source of inefficiency is *over-investment* in the local public good, where the public good is provided, but there are wasteful investments. I measure over-investment as scenarios where everyone in the group has access to the public good, but there are more than two investments. Figure 7 shows the bar plot for the proportion of observation where there was an over-provision of the public good.

Under investment in the public good is a more severe issue since some subjects in the group have no payoff, which lowers efficiency more than over-investing in the public good where subjects at least get 25 cents in that round. Both communication structures are successful in increasing access to the public good in the Line and Asymmetric network (see Figure 6a).[15] In the Circle network, only the local structure is successful in increasing access to the public good (Mann-Whitney, $p < 0.001$). On average, access to the public good increases from 74% to around 90% once groups can communicate across the three networks. On average, access to the public good increases from 74% of the group members to 90% in the presence of a communication structure across the three network structures.

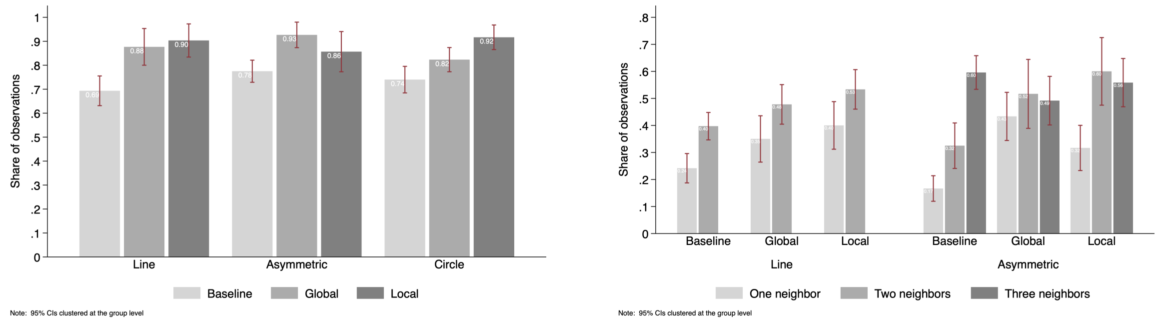
Subjects with more neighbors in the Line and Asymmetric networks have access to the public good from multiple sources. Figure 6b is bar plot of access to the public good by the number of neighbors. In the Line network subjects with two neighbors have 10 percentage points or have an access to the public good for one more round than subjects with one neighbor (Mann-Whitney, $p < 0.05$). In the Asymmetric network, the effect is more pronounced subjects with three neighbors have 20 percentage points or have access to the public good for two more than subjects with one neighbor (Mann-Whitney, $p < 0.001$).[16]

Once all group members can communication in the global communication structure in the Line network there is no statistically significant differences between access to the local public between one and two neighbors. In the Asymmetric network, although there are statistically significant difference however qualitatively these differences are on average 6 percentage points. Subjects with one neighbor has access to a public good in 91.7% of the rounds whereas those with three neighbors have access 97.5% of the rounds. The access does reverse to the trend in the baseline when only neighbors can communicate in both the Line and Asymmetric network. Subjects with more neighbors have more access to the public good. But, overall the access is higher than in the baseline which is reflected in the increase in efficiency.

[15] Mann-Whitney tests show the differences are significant at $p < 0.001$ for the Line network with both communication structures, and at $p < 0.001$ for global and $p < 0.05$ for local in the Asymmetric network (see Table 12).

[16] see Table 13 for Line network and 14 for Asymmetric network.

Figure 6: Under-provision

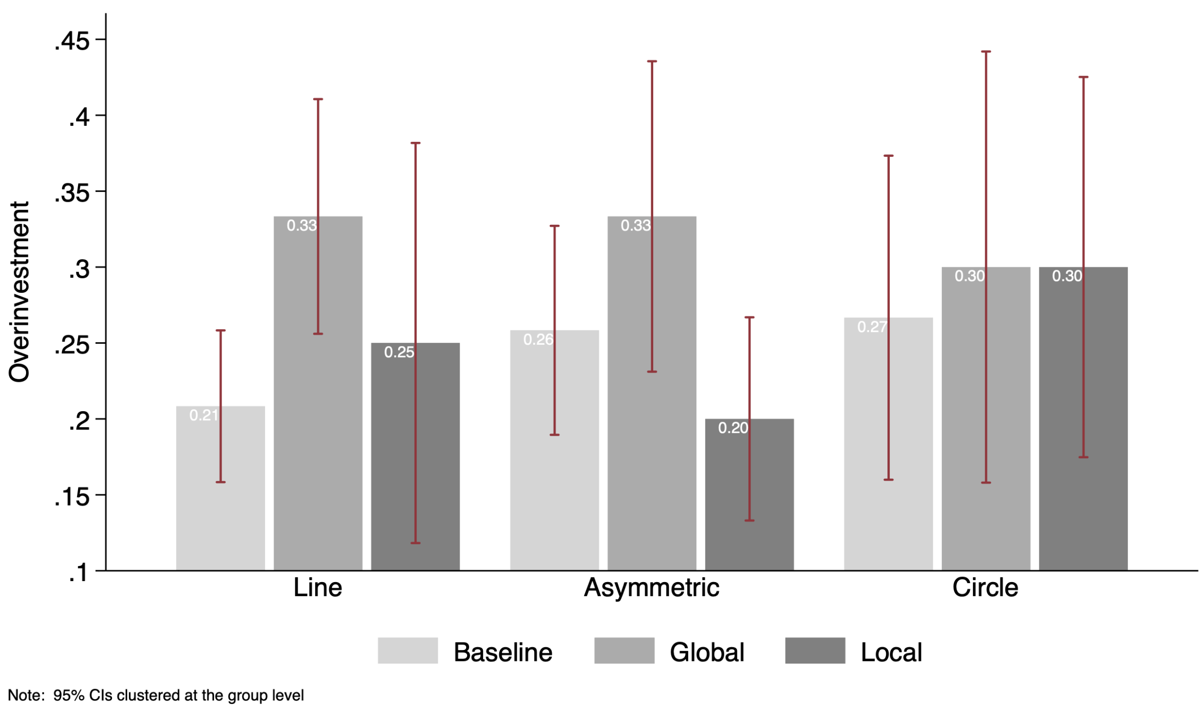


(a) Access

(b) Access - by number of neighbors

Over-investment can manifest in the data in two ways: (i) groups coordinating on the inefficient equilibrium and (ii) coordination failure between neighbors and two connected neighbors are investing. The results indicate that the increase in efficiency does not come at the cost of an increase in over-investment.[17]

Figure 7: Over-investment



[17]These differences are not statistically significantly different. Please see Table 15 for results from Mann-Whitney and t-test.

Result 1 *Communication improves efficiency, reducing under-provision of the public good without leading to over-investment in the public good. In both Line and Asymmetric networks, subjects with more neighbors have greater access to local public goods in the baseline condition. This trend is only alleviated by the global communication structure.*

The equilibrium profiles group coordinate on can be critical in understanding the gain in efficiency through the generation and division of the surplus. In the next section, I explore how the two communication structures influence equilibrium coordination.

4.3 Equilibrium Coordination

Table 3 reports the share of observations consistent with a pure strategy Nash equilibrium prediction.[18]

Table 3: Frequency of equilibrium

		Baseline	Global	Local
Line	Not an equilibria	79%	48%	32%
	L1 - A, C & E	7%	20%	20%
	L2 - B & D	4%	25%	23%
	L3 - B & E	3%	3%	15%
	L4 - A & D	7%	3%	10%
Asymmetric	Not an equilibria	85%	40%	60%
	A1 - A, C & E	5%	18%	8%
	A2 - B & E	5%	7%	8%
	A3 - A & D	5%	10%	17%
	A4* - B & D	0%	25%	7%
Circle	Not an equilibria	84%	75%	52%
	C1 - A & D	3%	7%	10%
	C2 - A & C	1%	3%	8%
	C3 - B & E	6%	7%	8%
	C4 - C & E	3%	7%	10%
	C5 - B & D	3%	2%	12%

*Behavioral Equilibrium - B & D invest

The multiplicity of equilibria is a central feature of games on networks (Goyal, 2023). This multiplicity poses a challenge for groups to successfully coordinate on an equilibrium profile. For example, in the Line network, if the individual at position A is invest-

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

ing, there are two possible equilibria the group can coordinate on: one where the subject in position D is investing (*L4*) or one where subjects in C and E are investing (*L1*). This arises because coordinating on any Nash equilibrium profile requires individuals who do not directly observe each others' actions to coordinate. This increases the strategic uncertainty of investing in the public good. This is evident in the baseline where in the absence of the option to communicate, only 17.5% of the observation is consistent with an equilibrium prediction. Communication if informative, can be critical in lowering the strategic uncertainty around the investment decision. Both communication structures increase the likelihood of coordinating on equilibrium in the Line (Mann-Whitney, $p < 0.001$) and Asymmetric (Mann-Whitney, $p < 0.05$) networks. In the Circle network, only local communication structure is successful in improving coordination on an equilibrium (Mann-Whitney, $p < 0.001$).[19]

Equilibrium coordination determines how the total surplus is generated and divided among different nodes in the network. Table 4 reports the average total earnings of group members by the number of neighbors they have for each treatment across the three network structures. There are two ways in which a subject has access to the public good, either by paying the cost and getting access the benefit or by free-riding of their neighbors' investment. Figure 8 shows a bar plot of the proportion of the access to the public good coming from free-riding.[20] Hypothesis 1b predicts that subjects with more neighbors will earn more than subjects with fewer neighbors. In the Line network subjects with two neighbors on average make $1.41 more than subjects with one neighbor (Mann-Whitney, $p < 0.001$). This difference is more striking in the Asymmetric network where subjects with three neighbors on average have a payoff more than double that of the subjects with one neighbor (Mann-Whitney, $p < 0.001$) and one-third more than subjects with two neighbors (Mann-Whitney, $p < 0.001$).[21] The differences in payoffs are driven by subjects with more neighbors gain access to the public good by free-riding on their neighbors' investment (see Figure 8). This result is consistent with the finding in Charness et al. (2014) that groups are more likely to coordinate on the stable equilibrium in games of strategic substitutes in networks, which leads to this pattern of earning.

In the Line and Asymmetric networks, once communication is introduced, there is an increase in total group payoff, which is reflected in the increase in efficiency of provision. At the same time, the differences between the payoffs of subjects across nodes are dis-

[19]see Table 16 for the results from the non-parametric and parametric test.

[20]Note that this is not a measure of best-reply, it represents the proportion of the observations where the subject did not invest but had access to the public good.

[21]See Table 17 (Line network) and Table 18 (Asymmetric network) for the results from the non-parametric and parametric tests.

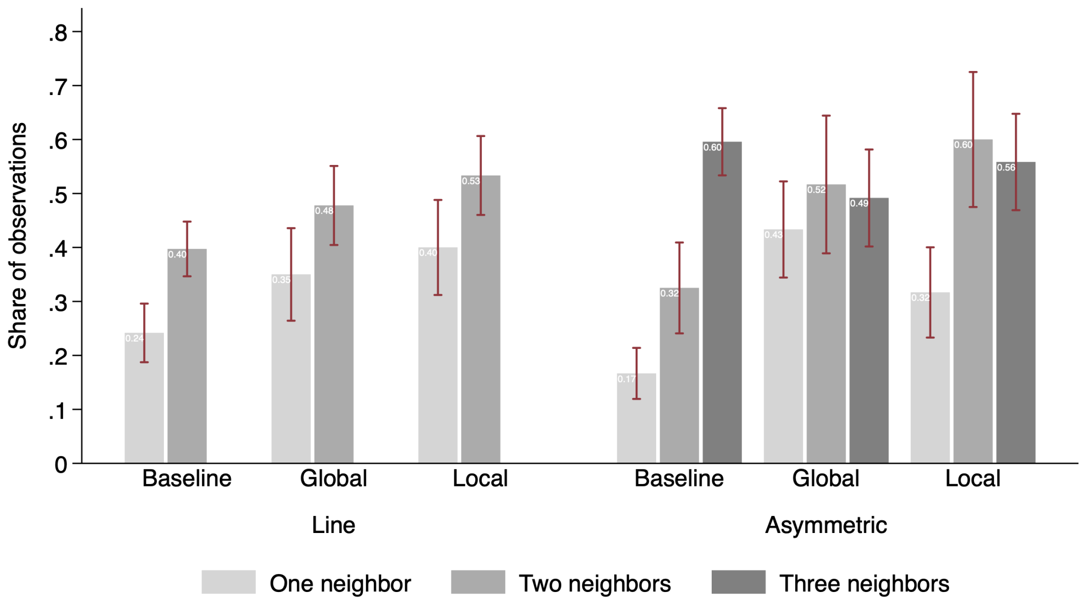
sipating. Subjects are in fixed positions and groups for ten rounds in each stage, which allows for coordinating on different equilibrium profiles across the rounds. In the baseline, I do not find consistent alternating patterns over equilibrium profiles in any of the three networks.[22] However, once the subjects can communicate before their investment decision patterns emerge. The patterns vary across the two communication structures. Next, I examine the impact of communication structures on equilibrium coordination and surplus distribution among group members.

Table 4: Total earnings of subjects (*in $*)

	Line			Asymmetric			Circle		
	Baseline	Global	Local	Baseline	Global	Local	Baseline	Global	Local
One neighbor	3.40	4.75	5.14	2.93	5.54	4.25			
Two neighbors	4.81	5.81	6.33	4.31	6.00	6.70	4.70	5.13	5.91
Three neighbors				6.68	6.12	6.56			
Total	**21.22**	**26.95**	**29.29**	**23.56**	**29.33**	**28.33**	**23.50**	**25.66**	**29.58**
Difference between two and one neighbors	1.41	1.06	1.19	1.38	0.46	2.45			
Difference between three and one neighbors				3.75	0.58	2.31			
Difference between three and two neighbors				2.37	0.12	-0.14			

[22]See figure 16a for the Line network, figure 17a for the Asymmetric network, and figure 18a for the Circle network.

Figure 8: Proportion of access to the public good by free-riding



Note: 95% CIs

4.3.1 Global communication structure

The global communication structure in the Line and Asymmetric network can potentially offset the asymmetries in outcomes for subjects on the periphery induced by the underlying network of externalities. Hypothesis 3b predicts an inverse relationship between the number of neighbors and their payoff. Global communication structure successfully counters the asymmetries induced by the underlying network of externalities. In the Asymmetric network, there is no statistically significant difference between the payoffs of subjects with one, two, or three neighbors (Mann-Whitney, $n.s.$). However, in the Line network, subjects with one neighbor on average earn \$1.06 less than the subjects with two neighbors (Mann Whitney, $p < 0.05$).[23] The difference in free-riding behavior can explain this difference in payoffs. Subjects with two neighbors are more likely to gain access to the public good free-riding than subjects on the periphery (Mann-Whitney, $p < 0.05$).

In the Line network, four of the six groups share the burden of providing the local public good by alternating between the following two equilibrium profiles: (i) subjects in positions A, C, and E (*L1*) invest and (ii) subjects in positions B and D (*L2*) invest (see Figure 16b) across rounds.

In the Asymmetric network, besides the three pure strategy Nash equilibrium profiles, 18% of group decisions are consistent with an action profile where B and D are investing

[23]See Table 19 for Line network and Table 20 for Asymmetric network.

(*A4*). This is not a Nash equilibrium; either B or D can get a higher payoff by not investing. However, coordinating across these profiles leads to sharing the burden of providing the public good since group members take turns to invest. Three of the six groups consistently alternate between A, C, and E investing (*A1*) or B and D investing (*A4*). One group alternate between the two efficient equilibria.[24]

In the Circle network, everyone has the same access to the public good and the incentives to free-ride on their neighbors' investments. Conflicting interest and a large equilibrium set lead to frequent miscoordination in both the baseline and global structure. Global communication does not improve coordination on equilibrium; only two groups successfully coordinate on equilibrium profiles. This is evident as the average payoff only increase by 43 cents in the Circle network when global communication is introduced (see Table 4).

4.3.2 Local communication structure

The local communication structure can potentially improve the coordination on equilibrium, but it is an open empirical question on which equilibrium profile groups will coordinate. In the Line network, subjects in position C have the highest eigenvector centrality and act as an information bridge between {A, B} and {D, E}. If subjects in this position successfully capitalize on their centrality, then groups are less likely to coordinate on the inefficient equilibrium. I find evidence in favor of hypothesis 4b, subjects with more neighbors earn more than those with fewer neighbors. I find that those with two neighbors earn \$1.88 more than those with one neighbor (Mann-Whitney, $p < 0.05$). This is reflected in free-riding behavior as well. Those with two neighbors get 53% of their access to the public good from free-riding. Whereas, those on the periphery, 40% of their access comes from free-riding (Mann-Whitney, $p < 0.05$). Note that there are still gains in efficiency due to better coordination on the equilibrium. In the Line network, two of the six groups consistently alternate between *L1* and *L2*, as if the entire group shares information and the grand coalition is the same as the global communication structure. One group consistently coordinates between A and C investing, and *L2*, where B and D invest. The subject in position E only invests once (see Group 12 in Figure 16c).[25] Two groups successfully alternated between the two efficient equilibrium profiles, which is in line with the prediction from eigenvector centrality where the subject in position C is not investing.

Unlike the global communication structure in the local communication structure in the

[24]Group 5 see Figure 17b.
[25]L1 without E investing.

Asymmetric network there is heterogeneity across groups on which equilibrium profiles they coordinate on based on their group's preferences. Overall, I find evidence in favor of hypothesis 4b, subjects with one neighbor on average earns \$2.35 less than subjects with two and three neighbors (Mann-Whitney, $p < 0.001$). The difference in payoffs is driven by subjects with one neighbor less than a third of their access to the public good from free-riding from their neighbor's investments, which is statistically significantly lower than 55.8% of the access for subjects with three neighbors (Mann-Whitney, $p < 0.001$). The share of observations consistent with *A4* where B and D are investing falls more than half to 8%, highlighting the importance of communication structure on action profiles groups can coordinate on. Local communication structure leads to frequent miscoordination, reflected in a low coordination rate on any equilibrium profile and lower access to the public good.[26]. Only one group consistently alternates between *A1* and *A4*. Overall, Some groups consistently coordinate on the efficient equilibrium, reflected in no statistically significant differences in subjects' earnings with two and three neighbors (Mann-Whitney, $n.s$). However, the payoff differences are not as striking as in the baseline, suggesting that communication successfully assuages some of the structure asymmetries induced by the underlying network of externalities.

The Circle network benefits from local communication and helps with focusing actions. Four of the six groups successfully coordinate on a Nash equilibrium. Groups, on average, coordinate on an equilibrium in 48.3% of the rounds, which is statistically significantly more than the baseline of 15.8% of the observations (Mann-Whitney, $p < 0.001$). However, there are no discernible patterns of investing behavior in the group across rounds. Groups are equally likely to coordinate on any of the five equilibria (see Table 3). Subjects on average are earning \$1.20 more than the baseline (see Table 4, Mann-Whitney, $p < 0.001$).

Result 2 *In the absence of communication across the three networks, there is no discernible pattern of investment. Both communication structures successfully improve coordination on equilibrium in the Line and Asymmetric networks. There is heterogeneity in the pattern of investment across the two communication structures. Only local communication is successful in aiding coordination in the Circle network.*

[26]Equilibrium coordination drops from 60% of the observation to 40% (Mann-Whitney, $p < 0.05$ see Table 16.) Access to the public good reduces from 93% to 86% (Mann-Whitney, $p < 0.05$, see Table 12)

4.4 Chat content analysis

Subjects had 60 seconds to communicate with group members by posting messages on their "message wall" before making their investment decision. The number of words in the message and the number of messages measures engagement with the communication structure. Table 5 breaks down the average number of words shared in messages and the number of messages sent at the individual and group level for each network structure. Overall, subjects on average wrote four words and share about two messages on their wall.

In the Line and Asymmetric network there is no statistically significant difference between the two communication structures in the number of words shared.[27] However, in the Circle network, I find that subjects share more messages and more words on average in each message in the global structure compared to the local communication structure. This highlight the strategic tension between subjects since everyone has the same access to public good therefore the same incentive to free-ride in the Circle network. Sharing more information during pre-play communication does not lead to better equilibrium coordination.

The local communication structure restricts messages to only allow neighbors, which leads to subjects sending more messages in the Line and Asymmetric network (Mann-Whitney, $p < 0.05$). However, more messages do not translate to better coordination on equilibrium in the Asymmetric network, but there are still gains in efficiency. In contrast, in the Circle network, subjects send fewer messages in the local communication (Mann-Whitney, $p < 0.05$), leading to better equilibrium coordination and gains in efficiency.

[27] See Table 31.

Table 5: Breakdown of messages sent

	Global	Local
Individual		
Line		
Average words	3.93	3.96
Average number of messages	2.23	2.54
Asymmetric		
Average words	3.75	3.68
Average number of messages	1.34	1.67
Circle		
Average words	4.6	3.96
Average number of messages	2.66	2.28
Group		
Line		
Total words	43.37	50.38
Total messages	11.13	12.72
Asymmetric		
Total words	25.58	31.37
Total messages	6.68	8.35
Circle		
Total words	54.35	44.77
Total messages	13.3	11.42

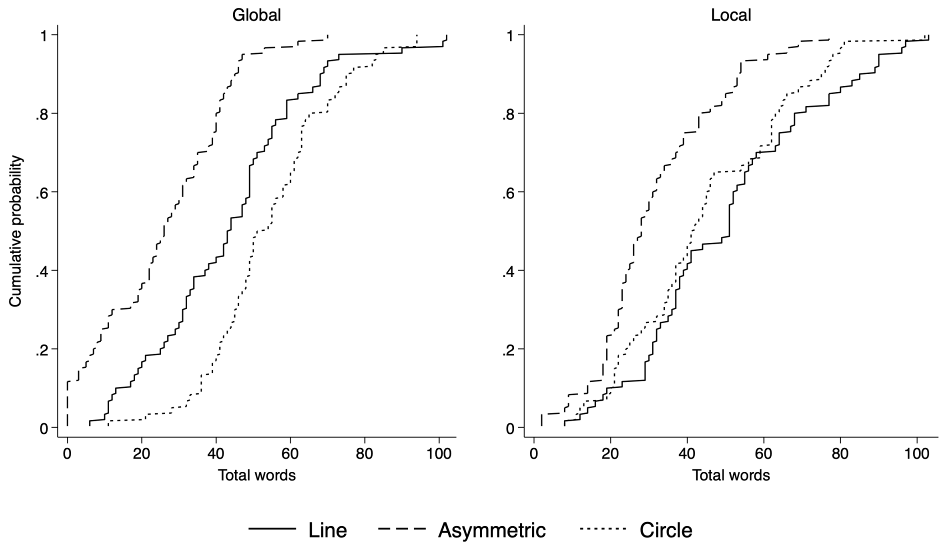
Figure 9 plots the cumulative distribution of the total number of words sent in each round at the group level across the three network structures. In the global communication structure, the more symmetric the distribution of neighbors across nodes becomes, the more intensely groups communicate, reflected in the number of words shared in each round.[28]

In the local communication structure, there are no statistically significant differences between the Line and Circle in the total number of words sent by the group in each round (Mann-Whitney, $n.s$). However, groups in the Asymmetric networks groups share fewer

[28]Groups in the Asymmetric network sent the fewest words in their messages, followed by the Line network, and then the Circle network (Mann-Whitney, $p < 0.001$). This also holds for the total number of messages shared each round; in the Asymmetric network, groups send fewer total number of messages (Mann-Whitney, $p < 0.001$), and the difference between Line and Circle networks is significant at the 5% level (Mann-Whitney, $p < 0.05$). Please see Table 32.

words compared to the Line and Circle networks (Mann-Whitney, $p < 0.001$).

Figure 9: Total number of words - group



Result 3 *There is a positive correlation between the symmetry in the network structure and message frequency and total number words sent. However, higher communication intensity doesn't always lead to better equilibrium coordination.*

Figure 10 shows the word cloud for the top 50 words from the two communication treatments for each of the three networks.[29] Given the brevity of the content and words shared in the messages in the pre-play communication stage, I created a simple structure to code the messages posted using the categories described in Table 6.

[29]Additional word clouds for each communication structure for the three network is available in the appendix. Please see Figure 19 for the Line network, 20 for the Asymmetric network, and 21 for the Circle network.

Figure 10: Word cloud of top 50 words

(a) Line (b) Asymmetric (c) Circle

Table 6: Content analysis categories

Code category	Condition
Not invest	Subject explicitly indicated they will not invest, or acknowledged their neighbor's message that they were investing.
Invest	Subjects explicitly indicated they will invest.
Not sure	Subjects are confused and are not clear whether to invest.
Strategy	If subjects proposed strategy.
Others	Irrelevant/junk.
Did not send message	If the subject did not share a message.

Table 7 reports the share of chat in each of the categories. There is substantial variation in the nature of the messages shared across the three networks in the two communication structures. When all group members can communicate, groups in Line and Asymmetric networks focus their discussion around strategy. However, once only neighbors can communicate, the focus shifts to investment decisions. In contrast, in the Circle network with local communication structure, subjects focus more on strategy vis-á-vis global communication, the focus on strategy helps improve coordination on equilibrium and efficiency.

Table 7: Content Analysis: Percentage of message in each code category

	Line		Asymmetric		Circle	
Message content	Global	Local	Global	Local	Global	Local
Not invest	12%	26%	5%	23%	20%	11%
Invest	21%	34%	15%	30%	21%	28%
Unsure	13%	3%	11%	16%	16%	24%
Strategy	27%	13%	48%	12%	16%	28%
Not related	15%	2%	12%	13%	13%	2%
Did not send message	11%	22%	9%	6%	14%	7%

Subjects following through with their commitment made in the communication stage is crucial for pre-play communication to be an effective coordination device. Hypothesis 2 predicts that commitment to invest is self-enforcing. In Table 8, for commitment to "Invest" and "Not Invest", I report the proportion of investment decisions where a subject reneges on their commitments. There is mixed evidence in support of the hypothesis and varies across the two communication structure. In the global communication structure across all network structures, subjects renege on less than 7% of commitments to not invest, and on less than 14% of commitments to invest. In contrast in the local structure, subjects renege on 4.5% commitments to not invest and less than 10% on commitments to invest.

Table 8: Reneging on pre-play chat commitments

	Commitment				
	Not invest		Invest		
	Global	Local	Global	Local	Total
Line	0%	4%	11%	11%	8%
Asymmetric	10%	2%	15%	6%	9%
Circle	7%	9%	14%	11%	11%

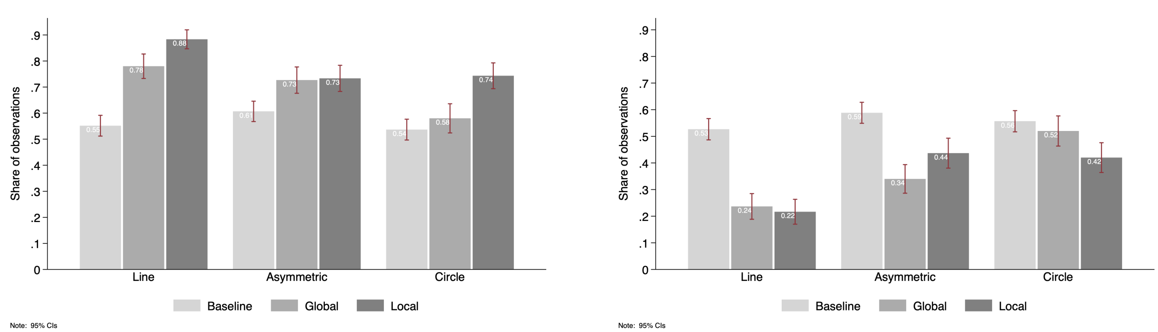
Result 4 *In both global and local communication structures, subjects generally adhere to their pre-play commitments, with slightly higher commitment follow-through in local structures.*

4.5 Individual decisions

A subject's best reply is to do the opposite of their neighbors' actions. Local coordination is critical for groups to successfully coordinate on Nash equilibria. For each period, I code all decisions where subjects give a best reply to their neighbors' current period action as the contemporaneous best reply. Figure 11a shows the bar plot for the average rate of the best reply for the group. Both communication structures improves local coordination in the Line (Mann-Whitney, $p < 0.001$) and Asymmetric (Mann-Whitney, $p < 0.05$) networks (see Figure 11a). In the Circle network only local communication structure is successful in enhancing local coordination (Mann-Whitney, $p < 0.05$).[30]

In the absence of communication, subjects can base their decision on their neighbors' actions in the previous period. For each period I code all decision where subjects give a best reply to their neighbors' decision in the previous period as a myopic best reply. Figure 11b shows the bar plot for the myopic best reply. In the baseline, subjects' based their decisions on their neighbors' decision in the previous period. Both communication structures lead to a lower rate of myopic best reply in the Line and Asymmetric network (Mann-Whitney, $p < 0.001$, see Table 29). Whereas, in the Circle network, only local structure reduces dependency on the previous period decision (Mann-Whitney, $p < 0.001$, see Table 29).

Figure 11: Group best reply



(a) Local best reply

(b) Myopic best reply

The level of strategic uncertainty varies the number of neighbors an individual has, as they have to coordinate actions with more subjects in the group. To study the effect of communication structure on subjects' actions, I estimate the following linear probability panel model with errors clustered at the individual level based on the number of

[30] Please see Table 28

neighbors:

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

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 structure, and C^3 is the local structure. $\mathbb{1}\{\sum_{j \in N_i} a_j \geq 1\}$ 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, and demographic variables – gender and race. The results from the regressions are reported in Table 9.

Table 9: Effect of communication on investment decision

	Line		Asymmetric			Circle
	One neighbor	Two neighbors	One neigbhor	Two neighbors	Three neighbors	Two neighbors
Global	0.368***	0.398***	0.227***	0.220	0.374**	0.149**
	(0.081)	(0.097)	(0.077)	(0.174)	(0.181)	(0.073)
Local	0.242**	0.459***	0.0138	0.0388	0.614***	0.382***
	(0.111)	(0.082)	(0.086)	(0.177)	(0.166)	(0.061)
At least one neighbor invest	-0.0839	-0.0690	-0.0977	-0.0267	-0.0498	-0.0148
	(0.065)	(0.058)	(0.090)	(0.048)	(0.070)	(0.050)
At least one neighbor investxGlobal	-0.375***	-0.542***	-0.496***	-0.278*	-0.232	-0.128
	(0.143)	(0.128)	(0.135)	(0.156)	(0.166)	(0.093)
At least one neighbor investxLocal	-0.497***	-0.755***	-0.341***	-0.511**	-0.516***	-0.401***
	(0.100)	(0.078)	(0.106)	(0.207)	(0.155)	(0.080)
Invest lag	-0.272***	-0.0539	-0.242***	-0.157**	-0.263***	-0.162***
	(0.047)	(0.046)	(0.049)	(0.080)	(0.076)	(0.035)
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	432	648	432	216	432	1080

Robust standard errors in parentheses clustered at the individual level.
$^{*}p < 0.10, ^{**}p < 0.05, ^{***}p < 0.01$

Compared to the baseline, the global communication structure increases the likelihood of investing in the local public good across all network structures. Subjects are more likely to give a best reply to their neighbors in the global communication structure in the Line and Asymmetric networks. Note that in the Asymmetric network, the effect is not significant for subjects with three neighbors since groups regularly coordinate on the behavioral equilibrium (*A4*) where both B and D are investing. The global structure does not improve the likelihood of giving a best reply in the Circle network. Meanwhile, the local communication structure improves coordination across all network structures and positions. These findings suggest that communication helps assuage strategic uncertainty, which improves local coordination, as reflected in an improvement in efficiency and coordination on equilibrium profiles.

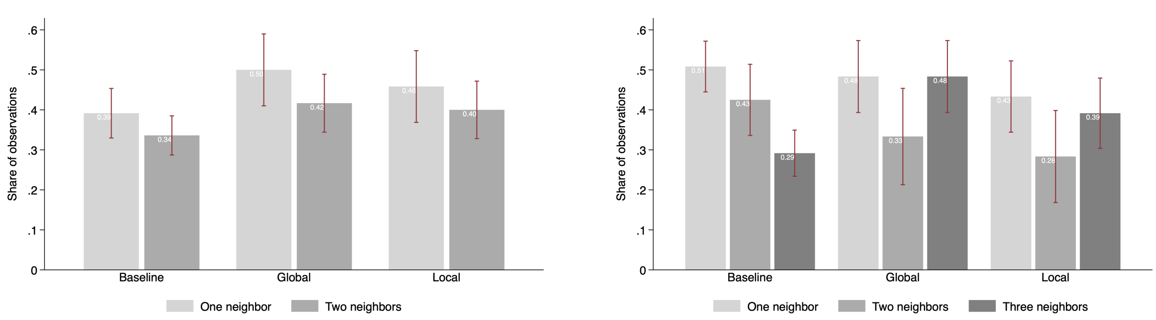
Result 5 *Communication successfully changes the best-reply dynamic from myopic to contemporaneous, improving coordination on a Nash equilibrium. Fewer instances of miscoordination lead to improved efficiency.*

Effect of number of neighbors of investment decision

Since investment decisions are substitutable as the number of neighbors increases which increases the access to the local public good thus subjects have more incentives to free-ride (see Figure 8).[31] This has been an ubiquitous finding in the experimental literature studying the effect of network structure on public goods provision is the negative relationship between the number of neighbors and their probability of investing (Charness et al., 2014, Rosenkranz and Weitzel, 2012).

Figure 12 shows bar plots of the proportion of subjects who choose to invest by the number of neighbors. The effect of the number of neighbors the average investment is more pronounced in the Asymmetric network. Individuals with three neighbors in the absence of communication are less likely to invest in the public good, which is in line with the literature's observation.

Figure 12: Proportion of subjects who choose to invest by number of neighbors



(a) Line network (b) Asymmetric network

[31] In a best-shot public goods where agents are not aware of the exact network structure and only the number neighbor they have. Galeotti et al. (2010) shows that in a symmetric Bayes-Nash equilibria that uses monotone (threshold) strategies, agents invest only if the number of neighbors they have is below a certain threshold. The threshold is lower as the number of neighbors is increasing.

There are other learning effects, improvement in the best reply dynamic, and the behavior consistent with alternating across round. I control for these other factors in a linear probability panel model and study the effect of the number of neighbors. I analyze each treatment separately. The model for each treatment is:

$$invest_{it} = \sum_{k=1}^{3} \beta_k degree_i^K + \zeta X + \varepsilon_{it} \quad (4)$$

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 whether at least of their invested in the current period, last period decision, round , session fixed effect, and demographic variables – gender and race.

Table 10: Number of neighbors and investment decision

	Baseline		Global		Local	
	Line	Asymmetric	Line	Asymmetric	Line	Asymmetric
Two neighbors	0.00361	-0.0206	-0.0406	-0.207***	0.0806*	0.0201
	(0.055)	(0.084)	(0.076)	(0.074)	(0.048)	(0.074)
Three neighbors		-0.188***		0.0874		0.155*
		(0.069)		(0.054)		(0.089)
Invest lag	-0.112**	-0.0608	-0.203**	-0.535***	-0.197***	-0.212***
	(0.048)	(0.065)	(0.080)	(0.070)	(0.061)	(0.073)
At least one neighbor invest	-0.0842*	-0.0941**	-0.500***	-0.294***	-0.689***	-0.520***
	(0.045)	(0.042)	(0.085)	(0.065)	(0.061)	(0.070)
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	270	270	270	270

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

In line with the observation in Figure 12, I find that the negative relationship is present only in the Asymmetric network. Subjects with more neighbors are less likely to invest in the public good in the absence of communication. Both the communication structure are successful in reversing this negative relationship. Subjects in central positions like B & D are more likely to invest compared with subjects with one neighbor in the Asymmetric network. In fact, with global structure subjects at position C in the Asymmetric network., they are less likely to invest crucial in coordinating on the efficient equilibrium profiles (see Table 10). In the Line network, the pattern of alternating investments between subjects on the periphery and interior is reflected in no statistically significant differences between the likelihood of investing across the number of neighbors.

This evidence suggests that the two communication structures, subjects can understand the full implication of their action, especially this tension between the number of neighbors and the decision to invest. Subjects in a central position with communication comprehend the full implications of their choice to free-ride on individuals' investment decisions on the periphery that is reflected by a negative relationship between a subject's and their neighbors' investment decisions.

Result 6 *Communication structures are successful in offsetting the negative relationship between the number of neighbors and a subject's likelihood of investing.*

5 Conclusion

This study addresses two key research questions. First, does communication effectively countervail the local nature of information in strategic interactions in networks that favor individuals with more neighbors? Second, does the structure of communication influence group coordination? This paper uses a best-shot public goods game across three networks. I introduce two communication structures to study the interplay between the underlying network of externalities and the two communication structures - global and local. In the global communication structure all group members had the opportunity to communicate, whereas, in the local communication structure only neighbors could communicate.

Relative to no communication, both global and local communication improves the efficiency in Line and Asymmetric networks. However, in the Circle network, only letting neighbors communicate improves efficiency. Communication increases efficiency by decreasing the under-provision of the public good. Communication also improves the equity of payoffs in the two non-symmetric networks. This effect is more pronounced when all neighbors can communicate in the Asymmetric network.

In the presence of the global communication structure the groups in Line and Asymmetric networks consistently alternate between action profiles where group members take turns to invest. This leads to more equitable investment patterns and narrows payoff gaps between nodes with different numbers of neighbors, indicating a preference for both equity and efficiency (Charness and Rabin, 2002). However, having the same access to the public good, the Circle network with global communication are not successful in negotiating on strategies they could coordinate across the rounds.

The local communication structure mirror's the underlying network of externalities, although enhances coordination and efficiency across all network structures. In the Line and Asymmetric networks it reinforces the payoff advantages of those individuals who have more neighbors in these structures despite equalizing the likelihood of investing in the public good. The Circle network sees improved equilibrium coordination and efficiency with local communication.

These findings have implications for policy interventions involving actions that are locally substitutable and exhibit externalities. These decisions could range from an investment decision in technology by farmers[32] to doctors adopting a new practice protocol.[33] Communication can be used as a device to resolve inefficiencies in providing local public goods. This paper lends further empirical evidence pointing at the efficacy of endogenously occurring social norms in sustaining cooperation in social dilemmas (Ostrom, 2014). A global or local communication structure can be implemented depending on the underlying network structure. For more symmetric groups, the global communication structure is ineffective in improving coordination. Although local communication is more natural to implement in a network setting where individuals are more likely to communicate with their neighbors. The efficacy of local communication is more effective in symmetric networks like the Circle rather than in non-symmetric networks such as the Line and Asymmetric networks.

While a controlled experimental setting allows for a clear identification of the network structure in 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 network's size is restricted by the seats available in the lab. Communication is an effective coordination device in these three stylized networks. However, generalizing these results for policy requires testing these mechanisms over larger networks in an online experiment or field setting.

[32] 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).

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

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6 Appendix

6.1 Instructions

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**

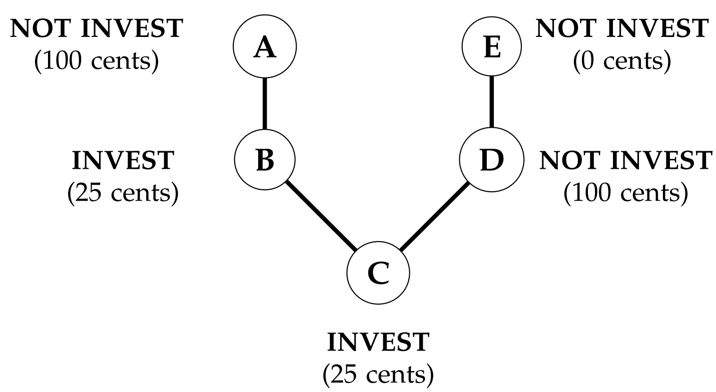
neighborhood.

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)

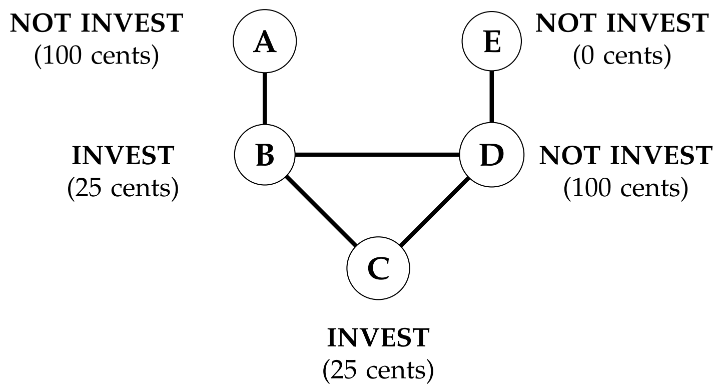
Figure 13: Stage 1 - Instruction - Line



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)

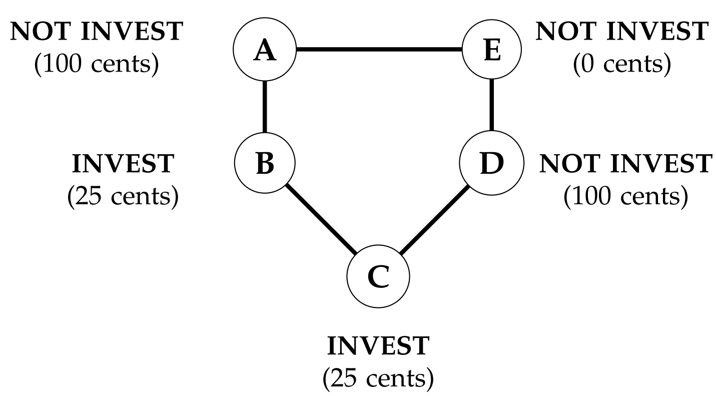
Figure 14: Stage 1 - Instruction - Asymmetric



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:

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.

6.2 Tables - Parametric and non-parametric tests

Table 11: Efficiency across treatments

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
			Line		
Baseline(1)-Global(2)	0.607	0.770	-0.164	0.000	0.000
Baseline(1)-Local(2)	0.607	0.837	-0.230	0.000	0.000
Global(1)-Local(2)	0.770	0.837	-0.067	0.089	0.036
			Asymmetric		
Baseline(1)-Global(2)	0.673	0.838	-0.165	0.000	0.000
Baseline(1)-Local(2)	0.673	0.810	-0.136	0.000	0.000
Global(1)-Local(2)	0.838	0.810	0.029	0.427	0.366
			Circle		
Baseline(1)-Global(2)	0.671	0.733	-0.062	0.117	0.114
Baseline(1)-Local(2)	0.671	0.845	-0.174	0.000	0.000
Global(1)-Local(2)	0.733	0.845	-0.112	0.004	0.002

Table 12: Access

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
			Line		
Baseline(1)-Global(2)	0.693	0.877	-0.183	0.000	0.000
Baseline(1)-Local(2)	0.693	0.903	-0.210	0.000	0.000
Global(1)-Local(2)	0.877	0.903	-0.027	0.490	0.298
			Asymmetric		
Baseline(1)-Global(2)	0.775	0.927	-0.152	0.000	0.000
Baseline(1)-Local(2)	0.775	0.857	-0.082	0.036	0.034
Global(1)-Local(2)	0.927	0.857	0.070	0.042	0.008
			Circle		
Baseline(1)-Global(2)	0.740	0.823	-0.083	0.068	0.060
Baseline(1)-Local(2)	0.740	0.917	-0.177	0.000	0.000
Global(1)-Local(2)	0.823	0.917	-0.093	0.023	0.009

Table 13: Access by neighbor - Line

	One neighbor	Two neighbor	Difference	t-test - (p-value)	Mann-Whitney (p-value)
Baseline	0.633	0.733	-0.100	0.009	0.009
Global	0.850	0.894	-0.044	0.253	0.252
Local	0.858	0.933	-0.075	0.031	0.032

Table 14: Access by neighbor - Asymmetric

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
			Baseline		
1 neighbor(1) - 2 neighbors(2)	0.675	0.750	-0.075	0.144	0.144
1 neighbor(1) - 3 neighbors(2)	0.675	0.887	-0.212	0.000	0.000
2 neighbor(1) - 3 neighbors(2)	0.750	0.887	-0.138	0.001	0.001
			Global		
1 neighbor(1) - 2 neighbors(2)	0.917	0.850	0.067	0.172	0.171
1 neighbor(1) - 3 neighbors(2)	0.917	0.975	-0.058	0.046	0.046
2 neighbor(1) - 3 neighbors(2)	0.850	0.975	-0.125	0.001	0.002
			Local		
1 neighbor(1) - 2 neighbors(2)	0.750	0.883	-0.133	0.037	0.037
1 neighbor(1) - 3 neighbors(2)	0.750	0.950	-0.200	0.000	0.000
2 neighbor(1) - 3 neighbors(2)	0.883	0.950	-0.067	0.104	0.104

Table 15: Over investment

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
			Line		
Baseline(1)-Global(2)	0.208	0.333	-0.125	0.069	0.069
Baseline(1)-Local(2)	0.208	0.250	-0.042	0.529	0.527
Global(1)-Local(2)	0.333	0.250	0.083	0.319	0.317
			Asymmetric		
Baseline(1)-Global(2)	0.258	0.333	-0.075	0.295	0.294
Baseline(1)-Local(2)	0.258	0.200	0.058	0.390	0.388
Global(1)-Local(2)	0.333	0.200	0.133	0.100	0.100
			Circle		
Baseline(1)-Global(2)	0.267	0.300	-0.033	0.640	0.639
Baseline(1)-Local(2)	0.267	0.300	-0.033	0.640	0.639
Global(1)-Local(2)	0.300	0.300	0.000	1.000	1.000

Table 16: Equilibrium

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
			Line		
Baseline(1)-Global(2)	0.208	0.517	-0.308	0.000	0.000
Baseline(1)-Local(2)	0.208	0.683	-0.475	0.000	0.000
Global(1)-Local(2)	0.517	0.683	-0.167	0.063	0.064
			Asymmetric		
Baseline(1)-Global(2)	0.150	0.350	-0.200	0.002	0.002
Baseline(1)-Local(2)	0.150	0.333	-0.183	0.004	0.005
Global(1)-Local(2)	0.350	0.333	0.017	0.849	0.848
			Circle		
Baseline(1)-Global(2)	0.158	0.250	-0.092	0.140	0.140
Baseline(1)-Local(2)	0.158	0.483	-0.325	0.000	0.000
Global(1)-Local(2)	0.250	0.483	-0.233	0.008	0.008

Table 17: Average payoff difference between neighbors - Line

	One neighbor	Two neighbor	Difference	t-test (p-value)	Mann-Whitney (p-value)
Baseline	33.958	48.125	-14.167	0.000	0.000
Global	47.500	58.194	-10.694	0.025	0.027
Local	51.458	63.333	-11.875	0.013	0.009

Table 18: Average payoff difference between neighbors - Asymmetric

	Mean(1)	Mean(2)	Difference	t-test (p-value)	Mann-Whitney (p-value)
			Baseline		
1 neighbor(1) - 3 neighbors(2)	29.375	66.875	-37.500	0.000	0.000
1 neighbor(1) - 2 neighbors(2)	29.375	43.125	-13.750	0.001	0.005
2 neighbor(1) - 3 neighbors(2)	43.125	66.875	-23.750	0.000	0.000
			Global		
1 neighbor(1) - 3 neighbors(2)	55.417	61.250	-5.833	0.249	0.192
1 neighbor(1) - 2 neighbors(2)	55.417	60.000	-4.583	0.477	0.641
2 neighbor(1) - 3 neighbors(2)	60.000	61.250	-1.250	0.843	0.631
			Local		
1 neighbor(1) - 3 neighbors(2)	42.500	65.625	-23.125	0.000	0.000
1 neighbor(1) - 2 neighbors(2)	42.500	67.083	-24.583	0.000	0.000
2 neighbor(1) - 3 neighbors(2)	67.083	65.625	1.458	0.817	0.899

Table 19: Access by free-riding by neighbors - Line

	One neighbor	Two neighbor	Difference	t-test - (p-value)	Mann-Whitney (p-value)
Baseline	0.242	0.397	-0.156	0.000	0.000
Global	0.350	0.478	-0.128	0.028	0.029
Local	0.400	0.533	-0.133	0.024	0.024

Table 20: Access by free-riding by neighbors - Asymmetric

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
			Baseline		
1 neighbor(1) - 2 neighbors(2)	0.167	0.325	-0.158	0.001	0.001
1 neighbor(1) - 3 neighbors(2)	0.167	0.596	-0.429	0.000	0.000
2 neighbors(1) - 3 neighbors(2)	0.325	0.596	-0.271	0.000	0.000
			Global		
1 neighbor(1) - 2 neighbors(2)	0.433	0.517	-0.083	0.293	0.292
1 neighbor(1) - 3 neighbors(2)	0.433	0.492	-0.058	0.367	0.366
2 neighbors(1) - 3 neighbors(2)	0.517	0.492	0.025	0.753	0.752
			Local		
1 neighbor(1) - 2 neighbors(2)	0.317	0.600	-0.283	0.000	0.000
1 neighbor(1) - 3 neighbors(2)	0.317	0.558	-0.242	0.000	0.000
2 neighbors(1) - 3 neighbors(2)	0.600	0.558	0.042	0.597	0.595

Table 21: Words in messages - Line

	One neighbor	Two neighbor	Difference	t-test - (p-value)	Mann-Whitney (p-value)
Global	3.255	4.348	-1.093	0.001	0.000
Local	3.681	4.147	-0.466	0.138	0.486

Table 22: Average number of messages - Line

	One neighbor	Two neighbor	Difference	t-test - (p-value)	Mann-Whitney (p-value)
Global	2.050	2.344	-0.294	0.157	0.299
Local	2.708	2.433	0.275	0.159	0.322

Table 23: Average number of messages - Asymmetric (Global)

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
1 neigbor(1) - 3 neighors(2)	1.467	1.300	0.167	0.239	0.160
1 neigbor(1) - 2 neighors(2)	1.467	1.150	0.317	0.070	0.032
2 neigbor(1) - 3 neighors(2)	1.150	1.300	-0.150	0.396	0.291

Table 24: Average number of messages - Asymmetric (Local)

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
1 neigbor(1) - 3 neighors(2)	1.733	1.342	0.392	0.010	0.020
1 neigbor(1) - 2 neighors(2)	1.733	2.200	-0.467	0.037	0.064
2 neigbor(1) - 3 neighors(2)	2.200	1.342	0.858	0.000	0.000

Table 25: Average number of words - Asymmetric (Global)

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
1 neigbor(1) - 3 neighors(2)	4.076	3.533	0.544	0.230	0.048
1 neigbor(1) - 2 neighors(2)	4.076	3.469	0.608	0.228	0.325
2 neigbor(1) - 3 neighors(2)	3.469	3.533	-0.064	0.909	0.497

Table 26: Average number of words - Asymmetric (Local)

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
1 neigbor(1) - 3 neighors(2)	3.941	2.780	1.160	0.001	0.000
1 neigbor(1) - 2 neighors(2)	3.941	4.831	-0.890	0.095	0.188
2 neigbor(1) - 3 neighors(2)	4.831	2.780	2.051	0.000	0.000

Table 27: Average number of words and messages - Circle

	Global	Local	Difference	t-test - (p-value)	Mann-Whitney (p-value)
Average words	4.601	3.961	0.640	0.011	0.026
Number of messages	2.660	2.283	0.377	0.004	0.020

Table 28: Contemporaneous Best Reply

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
			Line		
Baseline(1)-Global(2)	0.552	0.780	-0.228	0.000	0.000
Baseline(1)-Local(2)	0.552	0.883	-0.332	0.000	0.000
Global(1)-Local(2)	0.780	0.883	-0.103	0.027	0.027
			Asymmetric		
Baseline(1)-Global(2)	0.607	0.727	-0.120	0.005	0.005
Baseline(1)-Local(2)	0.607	0.733	-0.127	0.003	0.005
Global(1)-Local(2)	0.727	0.733	-0.007	0.884	0.870
			Circle		
Baseline(1)-Global(2)	0.537	0.580	-0.043	0.332	0.547
Baseline(1)-Local(2)	0.537	0.743	-0.207	0.000	0.547
Global(1)-Local(2)	0.580	0.743	-0.163	0.002	0.002

Table 29: Myopic Best Reply

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
			Line		
Baseline(1)-Global(2)	0.527	0.237	0.290	0.000	0.000
Baseline(1)-Local(2)	0.527	0.217	0.310	0.000	0.000
Global(1)-Local(2)	0.237	0.217	0.020	0.628	0.770
			Asymmetric		
Baseline(1)-Global(2)	0.588	0.340	0.248	0.000	0.000
Baseline(1)-Local(2)	0.588	0.437	0.152	0.000	0.000
Global(1)-Local(2)	0.340	0.437	-0.097	0.039	0.091
			Circle		
Baseline(1)-Global(2)	0.557	0.520	0.037	0.316	0.400
Baseline(1)-Local(2)	0.557	0.420	0.137	0.000	0.400
Global(1)-Local(2)	0.520	0.420	0.100	0.033	0.034

Table 30: Comparing Contemporaneous and Myopic Best Reply - Line

	Contemporaneous	Myopic	Difference	t-test - (p-value)
		Line		
Baseline	0.552	0.527	0.025	0.381
Global	0.780	0.237	0.543	0.000
Local	0.883	0.217	0.667	0.000
		Asymmetric		
Baseline	0.607	0.588	0.018	0.458
Global	0.727	0.340	0.387	0.000
Local	0.733	0.437	0.297	0.000
		Circle		
Baseline	0.537	0.557	-0.020	0.472
Global	0.580	0.520	0.060	0.142
Local	0.743	0.420	0.323	0.000

Table 31: Average number of words and messages sent by individuals

	Global	Local	Difference	t-test (p-value)	Mann-Whitney (p-value)
			Line		
Average words	3.927	3.958	-0.031	0.888	0.922
Number of messages	2.227	2.543	-0.317	0.024	0.003
			Asymmetric		
Average words	3.752	3.684	0.068	0.798	0.686
Number of messages	1.337	1.670	-0.333	0.001	0.001
			Circle		
Average words	4.601	3.961	0.640	0.011	0.026
Number of messages	2.660	2.283	0.377	0.004	0.020

Table 32: Total number of words at the group level

	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
			Global communication structure		
Line (1) - Asymmetric (2)	43.367	25.583	17.783	0.000	0.000
Line (1) - Circle (2)	43.367	54.350	-10.983	0.002	0.001
Asymmetric (1) - Circle (2)	25.583	54.350	-28.767	0.000	0.000
			Local communication structure		
Line (1) - Asymmetric (2)	50.383	31.367	19.017	0.000	0.000
Line (1) - Circle (2)	50.383	44.767	5.617	0.167	0.238
Asymmetric (1) - Circle (2)	31.367	44.767	-13.400	0.000	0.000

Table 33: Total number of messages at the group level

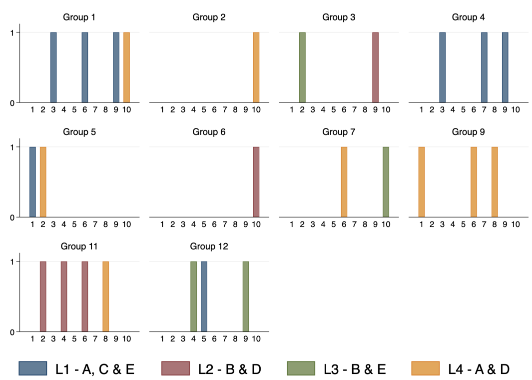
	Mean(1)	Mean(2)	Difference	t-test - (p-value)	Mann-Whitney (p-value)
			Global communication structure		
Line (1) - Asymmetric (2)	11.133	6.683	4.450	0.000	0.000
Line (1) - Circle (2)	11.133	13.300	-2.167	0.008	0.010
Asymmetric (1) - Circle (2)	6.683	13.300	-6.617	0.000	0.000
			Local communication structure		
Line (1) - Asymmetric (2)	12.717	8.350	4.367	0.000	0.000
Line (1) - Circle (2)	12.717	11.417	1.300	0.111	0.171
Asymmetric (1) - Circle (2)	8.350	11.417	-3.067	0.000	0.000

Table 34: Eigenvector centrality by position

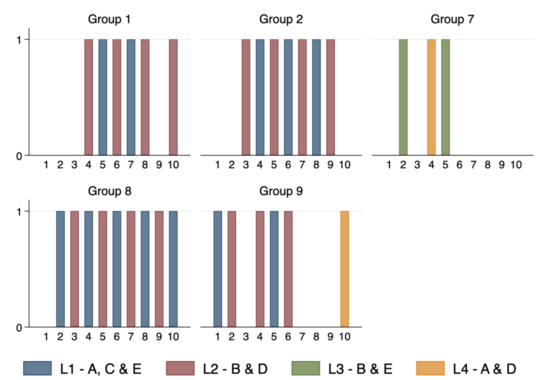
	A	B	C	D	E
Line	0.50	0.87	1	0.87	0.50
Asymmetric	0.43	1	0.87	1	0.43
Circle	1	1	1	1	1

6.3 Additional Figures and Tables

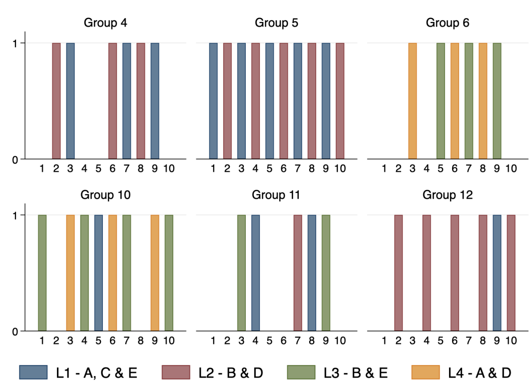
Figure 16: Equilibrium across rounds - Line network



(a) Baseline



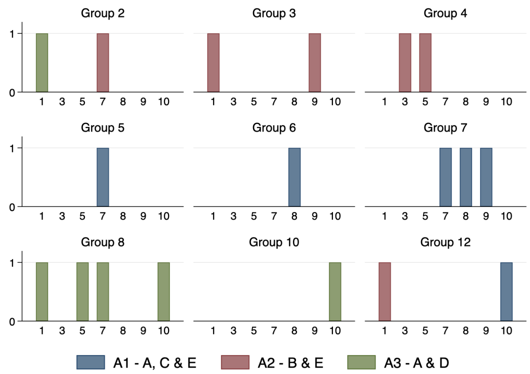
(b) Global



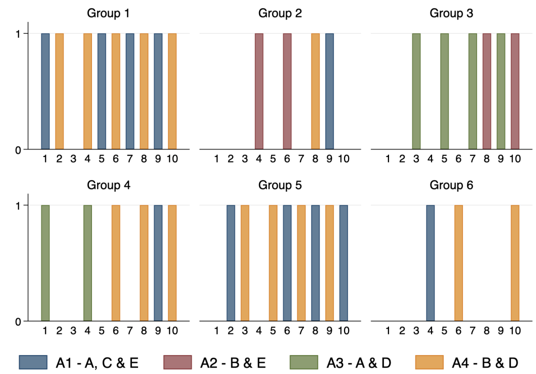
(c) Local

Note: In the baseline and global communication structure there are groups missing who failed to coordinate on an equilibria in any of their 10 rounds.

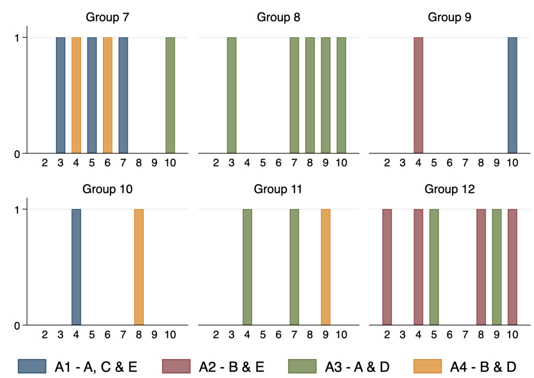
Figure 17: Equilibrium across rounds - Asymmetric network



(a) Baseline



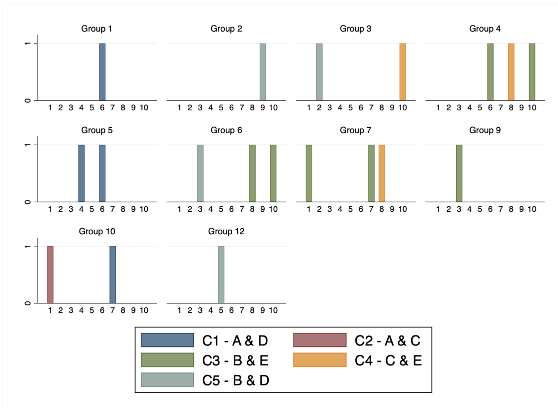
(b) Global



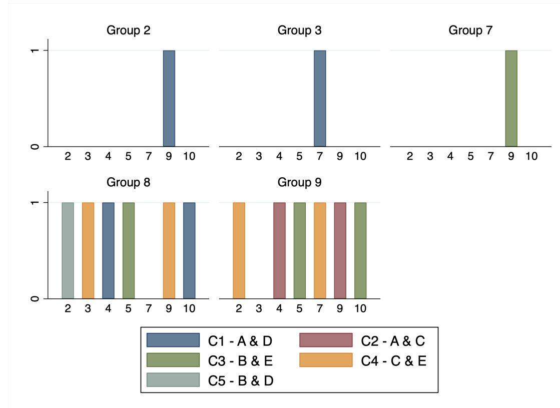
(c) Local

Note: In the baseline there are groups missing who failed to coordinate on an equilibria in any of their 10 rounds.

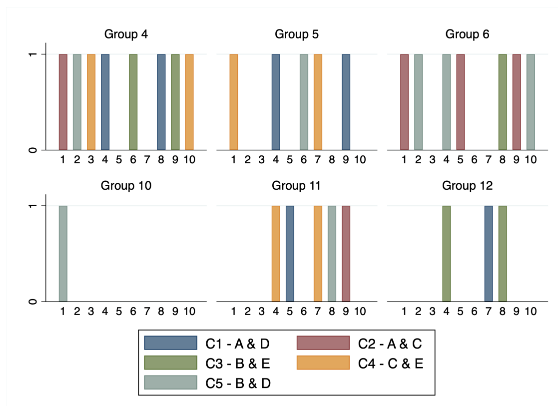
Figure 18: Equilibrium across rounds - Circle network



(a) Baseline



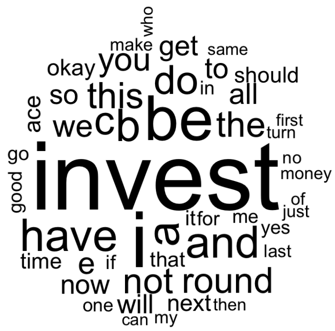
(b) Global



(c) Local

Note: In the baseline and global communication structure there are groups missing who failed to coordinate on an equilibria in any of their 10 rounds.

Figure 19: Line - word cloud (Top 50 words)

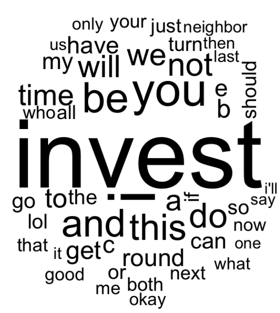


(a) Global

(b) Local

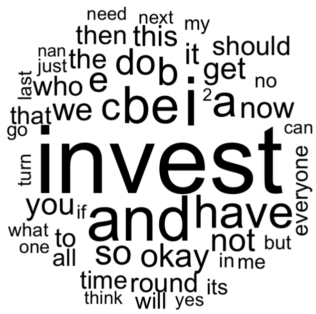
Figure 20: Asymmetric - word cloud (Top 50 words)

(a) Global

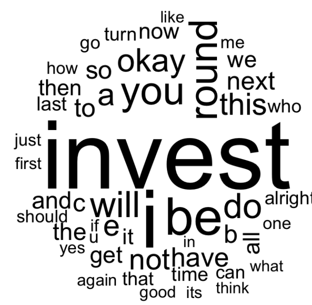


(b) Local

Figure 21: Circle - word cloud (Top 50 words)



(a) Global



(b) Local

7 Proof

Lemma 1 *In the baseline game 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 1 ***Commitments made in the communication stage are self-enforcing.***

Proof

Suppose agent i commits to invest. Based on Lemma 1 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 yields a lower payoff $u_i(0, \boldsymbol{a_j}, G) = 0$. Similarly, suppose agent i commits to not invest, based on Lemma 1 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 yields a lower payoff $u_i(1, \boldsymbol{a_j}, G) = b - c$.

■