Communication in a Network Game of Strategic Complements and Incomplete Information.

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Abstract

This paper experimentally studies the role of pre-play communication in determining the outcome and behaviour in a network game of incomplete information and strategic complements. I focus on the behaviour of two groups of players in the network, the core and its complement the periphery. I find that pre-play communication is informative and that it leads to an equilibrium where the players in the core are active and that the players in the periphery are inactive. I find that the length of pre-play communication can lead to the periphery to be less active although it doesn't lead to the core to be more active. The equilibrium state achieved is the second best outcome but is more preferable to the one achieved without communication.

1. Introduction

Networks can model an array of social and economic situations, where the outcomes of the decisions made within the network can have a significant positive or negative impact on people's lives (Jackson (2008), Goyal (2007)). Networks have been modelled on buyer-seller markets by Kranton and Minehart (2001) to show how individuals in these markets form strategic networks to maximise overall welfare. Hendricks et al. (1999) determine how airlines use a certain network structures to compete with each other in a duopoly. Bozionelos (2000) looks at how individuals use their different social links in an organisation to impact their career prospects. Network analysis is important in economics as a key part of economics is to build informative models of human behaviour and these models cannot ignore the social nature of human interactions and how they impact human behaviour. For instance a person may base their decision to purchase a product on products owned by their friends or they may study harder if they a surrounded by high performing peers. The structure of these networks can affect how information communicated and, ultimately, how people act.

Information in networks can be an important source of power, where the structure of the interaction amongst individuals can bestow advantages for some and as a consequence lead to unequal outcomes for others, as discussed in the extensive literature on networks; see Goyal (2007), Jackson (2008), and Wasserman and Fraust (1994). That certain individuals might gain more from communication than others is an important issue, as the knowledge of who gains most can help inform how best to organise markets or organizations. This paper will study which positions gain most from communication within a given network.

The structure of a network is a key factor in determining the behaviour of individuals, Galeotti et al. (2010) outline a series of theoretical models in which they provide a framework to analyse strategic interactions such as public good provision, when the structure affects the payoff. A significant issue in network theory is that even with simple games there are often a multitude of equilibria. This can impede the predictive power of the theory and therefore limit the possible insights on, for example, optimum organizational structure. Galeotti et al. (2010) show that the number of equilibria can be vastly reduced by only considering an incomplete information environment, as this limits the players knowledge of the network and so they are unable to condition their behaviour based on the exact details of the network. Furthermore, a setting that includes incomplete information can be representative of many economic situations in life, for instance often a company will have a rough idea of the market they operate in without knowing exactly who they're interacting with. They also consider settings with strategically complementary decisions, where a player's incentives to choose an action are increasing in the number of her neighbours who take the same action, for example criminal activity or technology adoption. Experimental studies have incorporated these features such as Charness et al. (2014). In particular the networks of experiment 3, experiment 2 and some of the treatments of experiment 1 contained incomplete information and complementarity, in which they find that the network structure is a significant factor in equilibrium selection. However these particular experiments didn't allow for communication between the individuals arranged in the network. To extend this analysis, this paper will introduce pre-play communication into a network game.

Cheap talk is non-binding pre-play communication that doesn't directly affect payoffs (Crawford and Sobel (1982)). In terms of network analysis, it is considered local communication if it only occurs between two individuals in the network who are connected to each other. It is considered global communication when it is between all individuals in the network. Discussions around this subject have led some to strongly argue that due to the non-binding nature of cheap talk, the agreements made are of no consequence to the outcome of the game (Aumann (1990)). In contrast Farrell and Rabin (1996) point out that Aumann's underlying logic is faultless that cheap talk doesn't *directly* affect payoffs, but they argue that people in the real world do respond to information communicated to them. Although cheap talk doesn't guarantee coordination on the optimal outcome it can improve people's outcomes and so does affect payoffs, therefore in certain situations cheap talk can be credible.

There have been a number of studies on cheap talk with a clear indication that in certain circumstances this form of communication is credible enough to impact players decision making. For instance Charness (2000) experimentally finds that the type of pre-play communication is significant in its effectiveness, with greater coordination on a payoff dominant outcome if the message follows the action. Choi and Lee (2014) also demonstrate that the longer players engage in pre-play communication the greater the rate of coordination in the game. These studies show that the pre-play communication can be of consequence to the players within network games, which leads this paper to believe that introducing pre-play communication into network 1 of the third experiment in Charness et al. (2014) will significantly alter the behaviour of individuals in this network.

In the third experiment from Charness et al. (2014) players choose to be active or inactive and the decision is strategically complementary. This means a player's marginal benefit of activity increases with the number of neighbours who also choose active whereas inactivity guarantees them a payoff independent of their neighbours choice. I have chosen to model my network game on network 1 from the third experiment as it was characterized by the players coordinating on inactivity, which is an inefficient equilibrium and so not the optimal outcome. I will introduce two lengths of cheap talk to experimentally explore the effect on the behaviour of individuals in that network and determine whether it allows for the efficient equilibrium to be played. It is possible that cheap talk will be non-informative, so that the individuals act as they had in the network with no communication, or informative which would lead to a new equilibrium.

The players within the network will be able to communicate locally, that is they may only send messages to those other players in their neighbourhood whom they share a link with. A link is an undirected edge that two nodes in the network share between them. Network 1 is a large 20-person asymmetric network with each position has range of connections with other positions in the network, from 1 to 4 connections: these connections are known as degrees. As the network is characterized by incomplete information, players are not informed of their exact position in the network and so are uncertain about who their neighbours are. There is a subset of players known as the core such that between any pair of players there exists at least two distinct paths between them. Conversely the rest of the players in the network who are not in the core will be known as the periphery. This set up allows me to extend the analysis of cheap talk due the variation in each players degrees I can explore the central question of how different positions within the network are affected by cheap talk in terms of coordinating on their preferred outcome. It is my belief that the core, in this particular network will gain most, in terms of coordinating on their payoff dominant choice with their neighbours, due to cheap talk and so will be more active and the periphery players will tend to be less active. Also the longer pre-play communication occurs, then the core will have a higher rate of activity and the periphery will have a lower rate of activity. This equilibrium state isn't an equilibrium outcome of the original game and is not as desirable as the efficient equilibrium, yet it is more preferable to the inefficient equilibrium and so an improvement for the network as a whole. The idea that cheap talk can improve players outcomes is put forward by Farrell and Rabin (1996) who argue that although cheap talk will not guarantee efficiency in games it can help avoid misunderstandings and coordination failures, ultimately improving a players outcome.

2. Literature Review

This paper contributes to the experimental literature on pre-play communication with the means of cheap talk; see Camerer (2003), Crawford (1998) and Ochs (2008) for surveys of the literature.

There are a number of papers which have looked at the effectiveness of cheap talk in non-network settings. Charness (2000) conducted a series of experiments to test Farrell and Rabin's (1996) argument. The author considered a control game with no communication and two games with one-way communication. The communication had two types, in the first type the messaging player send her message to the recipient player and then both players made their decisions, in the second type the messaging player made her choice and then sent a signal to the recipient player who subsequently made their choice. The author found that cheap talk leads to higher coordination on the payoff dominant outcome rather than the risk dominant one. His findings also suggest that with one way communication the degree of coordination on the payoff dominant equilibrium is higher when the choice is made following the message being sent. Yet when the order is reversed then coordination occurs less frequently. Other papers explore the effectiveness of cheap talk; Duffy and Feltovich (2002) ran a series of symmetric 2x2 games to compare the effectiveness of cheap talk in coordination compared to players observing the other players previous rounds action. They found that both methods make coordination more likely than the control game with no communication and that signals are informative, as players do condition their behaviour on the signals they receive. In one study by Blume and Ortmann (2007) players try to coordinate on Pareto-ranked equilibria in which they can send a message of action they intended to take but the participants are only informed of the distribution of the messages sent prior to making their choices. They found that cheap talk does facilitate coordination on the efficient equilibrium.
The setups of all these papers limit the length of that communication to a single round. Whereas this paper involves simultaneous two-way communication repeated over two and five rounds, so this paper will shed light on the dynamics of communication as players can repeatedly interact with their neighbourhood and potentially try and persuade their neighbours to coordinate on their preferred choice.

Cooper et al. (1989) performed a series of experiments looking at the effect of cheap talk with two types of communication in a two-way Battle of the Sexes game; one-way and two-way communication and either one round or three rounds of communication. They found coordination rates were higher in the one-way treatment than in the two-way treatment but that with more rounds of communication the coordination rates improve in the two-way treatment. Likewise Cooper et al. (1992) and Burton et al. (2005) compared two different communication structures types in different two-player coordination focusing on Pareto-ranked equilibria, looking to see whether cheap talk leads to more coordination on the efficient outcome, with two-way more effective in coordinating on the efficient outcome.
These papers have limits on the scope of their networks by only considering games with two players whereas I consider a large asymmetric network. Which allows me to explore the role cheap talk plays to different positions in the network. For instance the core consists of players with multiple degrees who are connected to each other. So if all individuals with multiple degrees send a message in the first round that relates to their actual intended action, e.g. to maximise their payoff, then those individuals in the core shall receive messages with at least two active messages. If they believe the messages, then in the following round only the positions with multiple degrees in the core shall continue to send an active message and allowing these players to coordinate on their payoff dominant choice of active.

An important part of network analysis is finding out which equilibrium is selected in a network and understanding what drives the equilibrium selection. Charness et al (2014) conducted a series of experiments looking to disseminate more thoroughly equilibrium selection based on a variety of network structures. In their third experiment they have three networks all with varying levels of connectivity with higher connectivity for networks with a large number of positions with many degrees, and clustering which is a measure of how connected each players is to each other. All the three networks involve local games with strategic complements and incomplete information. Network 1 has lower connectivity than the other two networks and no clustering, all the networks have two theoretical equilibrium, an efficient equilibrium and a secure (inefficient) equilibrium. They found that networks with higher connectivity and clustering are more likely to select the efficient equilibrium and that players with higher degrees display a higher frequency of activity. For network 1 there is clear convergence to the inefficient but secure equilibrium. Whereas Charness et al (2014) focus on the role of clustering and connectivity on the selection of the equilibrium, this paper focuses on the role of cheap talk in equilibrium selection and if the length of communication is an important factor in the equilibrium selection.

Building on the previous studies of communication in coordination games and the structure of the interactions between players influencing the outcome Choi and Lee (2014) conducted a series of experiments involving network games and cheap talk. They look at the coordination outcomes and behaviour of four players with conflicting preferences where they are allowed to use pre-play communication known in different network structures. In each game all of the four players are randomly assigned a letter from N, S, E or W, which corresponds to their location in that particular network. In order to earn a payoff they have to all coordinate on a single letter, otherwise they receive no payment for that round. If they reach a unanimous decision then the player whose letter corresponded to the final group choice earns a higher payoff than the rest of the group. They explored at two lengths of pre-play communication. At the beginning of each period only players who share an undirected edge could send messages to each other and then view the history of messages between them for that period. They found that communication improves coordination and that the higher the number rounds in the communication stage the more likely the chance of agreement and thus coordination. Also that in asymmetric network structures hub players, defined as a player linked to at least one player who themselves only has one link, have a strategic advantage and so they are in a strong position to steer the network to their preferred choice. Choi and Lee (2014) demonstrate that cheap talk can help improve the rate of coordination when players have conflicting preferences, also that the structure of the network has an impact on outcomes and finally that the longer players communicate, the higher the rate of coordination.

Other experimental papers look at role of communication in network games on coordination. Kearns et al. (2006) had a range of networks where individuals choose a colour that doesn't match their neighbours, they have treatments where the individual can see either only their direct neighbours' colours (local communication) or the entire network (global communication). They found that global communication increases the time needed to resolve the collective goal for networks formed under preferential attachment. In Kearns et al. (2009) the authors had a thirty six-person network with various levels of connectivity where players are randomly assigned to network positions and can only view the current choices of their neighbours'. Individuals in the network are given different financial incentives to choose between two colours but the network as a whole has one minute to reach a consensus in order to receive a payoff. They found that generating random networks makes it harder to reach a global consensus than networks formed by a preferential attachment process. In another study Judd et al. (2010) allowed groups of 36 subjects three minutes to reach a global consensus on one colour out of a set of nine. They have six networks with varying levels of cliquishness, which is the extent subgroups are connected to each other. They found that a global consensus is more easily achieved the less cliquishness there is.

The crucial difference between these experimental designs and this paper, is that they focus on the affect that the network structure has on outcomes. Whereas this paper is not concerned with the effect of network structure but instead how different positions within the network are affected by the use of cheap talk.

3. Experimental Design

The network in this paper based on Network One (see figure 1) from the third experiment in Charness et al. (2014). The individual's payoff in economics currency units (ECU) depends on her choice along with the choice of her neighbours, the ECU were then exchanged at the end of the experiment at a rate of £1 for every 35 ECUs. The players have a binary choice of active or inactive. In this case the players decision is strategically complementary, if she chooses active she earns 33.33 times the number of her neighbours' who also chose active. If a player chooses inactive then they a guaranteed a payoff of 50 ECU irrespective of their neighbours actions.

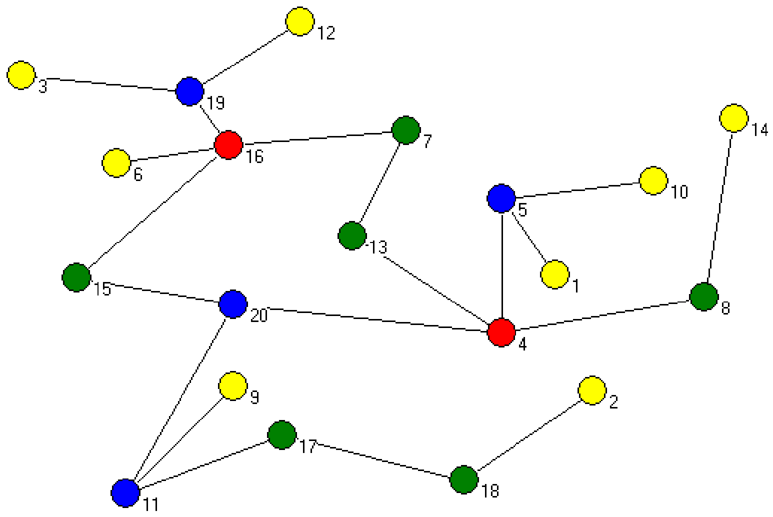


Figure 1, Yellow=Degree 1, Green=Degree 2, Blue=Degree 3, Red=Degree 4

At the beginning of each period the computer programme randomly assigned each participant to a particular position in the network, the participants were only informed on the computer screen of the number of links they had but not their exact position within the network. After players were allocated their node, they entered the message stage where they were permitted to send and receive non-binding messages to and from their neighbours (the players whom they shared an undirected edge with). They then chose to send an active or inactive message. For each individual player the messages sent to them from their neighbours were added up by the computer and then displayed in a table on their screen. For instance if a player had degree 3 and in the first round two of her neighbours had sent active messages then on her screen her table would contain 2 in the column labelled active in the row which corresponded to the first round. This would imply that her third neighbour had sent an inactive message. There were two treatments; the first where the message stage was repeated for two rounds and second where the message stage was repeated for five rounds. The network remained the same during the whole session.

Throughout the experiment there were instructions on the screen making sure that the participants knew what stage they were in, either the message stage or the active stage. In the message stage there was instructional text re-emphasising that their choice of active or inactive was a non-binding message that would be sent to their neighbours indicating their potential action in the subsequent action and would not determine their payoff for that period. In the active stage there were further on-screen instructions highlighting that now the choice they made between active and inactive would determine their payoff for that period along with the choices of their neighbours. During the message stage a table would be updated with the total number of active messages sent by that participants neighbours from the previous message round within the current message stage. The same table would appear in the action stage, with the number of active messages sent to them each round of the previous message stage for that period. This ensured that the information gleaned from the pre-play communication was always available to the participants when making their choices.

Once the last period of the experiment had been chosen, participants were automatically taken to the second section with two risk tests with twelve total decisions, designed to measure the risk attitudes of the participants. In the first test they had single decision, where they were told that they could invest as much of the show up fee as they wanted in a risky investment with a 50 percent chance of success. If they were successful they would get back 2.5 times the amount they invested less their initial investment. If they were unsuccessful they would have their initial investment taken off their show up fee. The second risk test allowed the participants to choose between 11 options where they were guaranteed an amount which increased from £0 to £10 or an equally likely chance of winning ten pounds or zero pounds. With only one of their twelve choices randomly selected to be paid out. Due to financial constraints only one individual was randomly chosen from the 20 participants to receive their payoff from the risk tests. The participants were informed about this before they began the experiment so that their decisions are still valid.

TABLE I
NETWORK CHARACTERISTICS

		Treatment A	Treatment B	Treatment C
Degree distribution (# nodes)	Degree = 1	8	8	8
	Degree = 2	6	6	6
	Degree = 3	4	4	4
	Degree = 4	2	2	2
Number of links		20	20	20
Number of pre-play communication rounds		2	5	0

Table I gives a summary of the network characteristics. Treatment A refers to the network with 2 rounds of pre-play communication and treatment B refers to the network with 5 rounds of pre-play communication. The results for treatment C are from network 1 in the third experiment of Charness et al. (2014) they will act as the control version of this experiment, with no rounds of communication.
For both treatment A and treatment B I conducted one session each with 20 new participants. Due to the introduction of pre-play communication the time needed to complete a single period was greater than for the same network with no communication as in Charness et al. (2014). Therefore the programme was designed to allow the experimenter to end it any point to make sure that the sessions did not run over an hour and a half. For treatment A I completed 32 periods and for treatment B I completed 21 periods, with participants earning on average £12.50.

The experimental sessions were conducted in the EconLab at Royal Holloway, University of London on computers linked up to each other running the experimental software zTree. Each participant was randomly allocated to a desk with a computer and an experiment pack containing instructions, a short questionnaire and labelled image of the network (an experimental pack can be found in the Appendix). All the computer locations were partitioned off from each other so that communication between participants except for that permitted within the game was not possible. At the beginning of the session all the participants were told to switch off their mobiles, had the payment scheme explained to them and were then asked to read the instructions. They were informed that of the periods completed in today's session they would have their payoffs from four periods randomly selected by the computer at the end of the session to count towards their final payment. All participants were given a show up fee that would be added to their final payment. They were asked to complete a questionnaire once they had finished reading the instructions to ensure they fully understood how the game worked and how their actions would determine their payoff. Once all participants had answered the questionnaire correctly the computer program containing the experiment began.

4. Economic Theory

A comparison of treatment C with both treatment A and treatment B allows us to study the effect of cheap talk on equilibrium selection and comparing treatment A with treatment B allows us to study the effect of the length of pre-play communication.
Charness et al. (2014) provide a proof in their Appendix that for this network there are two pure strategy equilibrium predictions, shown in Table II. When the network has no cheap talk the first equilibrium is a secure inefficient equilibrium, where all the players are inactive. The second is a risky efficient equilibrium, in which all players with a degree 1 are inactive and all players with degree 2 or higher are active.

TABLE II
EQUILIBRIUM IN EXPERIMENT

Treatment C (Network 1)	Active Degrees	Inactive Degrees
No Cheap Talk	/	1,2,3,4
	2,3,4	1

Cheap talk can take on two forms, one where it is informative and another where it is non-informative. Informative cheap talk means that there is a relation between the message and the action, so the message is related to the real intention of the sender.

In the case where cheap talk is non-informative for treatment A and treatment B we will have the same two equilibria as shown table II as players wont condition their behaviour on the results of the cheap talk. If cheap talk is informative, then the inefficient and efficient equilibria of table II cannot survive. They are replaced by a state where only the core players, which are nodes 4, 7, 13, 15, 16 & 20, are active and all other nodes are inactive (see figure 1). The intuition behind this is that cheap talk conveys some information to the individual on their position in the network. The state where the core is active and the periphery is inactive is stable. If we consider cheap talk to be informative, then players with degrees greater than 1 will send an active message and all players with degree 1 will send an inactive message. Players will update their message based on the number of active messages they receive, if they have received zero or one active message they will send an inactive message in the next round of the message stage or if they are now in the action stage, chose inactive. If they receive two or more active messages they will send an active message or chose active, depending on which stage they are in. Given the first round of messages, nodes 5, 8, 18, 19 only receive one active message. As a result, all degree 1 players and nodes 5, 8, 18, 19 depending on the stage they are in send an inactive message or choose inactive. Only the nodes in the core and node 11 would've received at least two active messages, so depending the stage they could either chose active or send an active message. However node 11 can determine her position within the network, as given the message strategy described above node 11 is the only degree 3 node that would receive two active messages. Therefore she can infer that she is in node 11 and foresee that the player located in node 17 will chose inactive and so play inactive herself. There is no strict incentive to deviate from the message strategy.

My behavioural hypotheses are that pre-play communication will be informative and as a consequence lead the core to be active more frequently and that conversely the periphery players to be active less frequently. Then with informative cheap talk the efficient equilibrium without communication is replaced by a state where only the core is active. Also the length of communication will matter and so the core will be active with a higher frequency when there are more rounds of pre-play communication and that the periphery are less active when there a more rounds of pre-play communication. Finally in the treatments with pre-play communication the frequency of activity will not necessarily increase with a players degree, as players with degree 2 and degree 3 are present in both the core and periphery.

5. Results

TABLE III

Frequency of activity by treatment and core

	Treatment A		Treatment B		Treatment C	
	Active (%)	Total	Active (%)	Total	Active (%)	Total
Periphery	109 (24.33)	448	46 (15.65)	294	345 (20.54)	1,680
Core	170 (88.54)	192	120 (95.24)	126	344 (47.78)	720

In table III displays the frequencies of the rate of activity by either being in the core or the periphery. Treatment C, which had no pre-play communication, had the smallest increase in activity comparing the periphery players to the core players, 21 to 48 percent. There is a large increase in activity for the core in both treatments with pre-play communication, with the greatest increase in treatment B of 16 to 95 percent (5 rounds of pre-play communication). For treatment A (2 rounds of communication) the increase in activity is only slightly less from 24 to 89 percent. The players in the periphery have a much lower activity rate in treatment B, 16 percent, compared to treatment C, 21 percent. Yet the periphery players in treatment A have the highest activity rate across all the treatments of 24 percent. These results suggest that cheap talk is informative and there is a strong pre-play communication effect on the core players. Whereas the periphery players are less active with 5 rounds of communication compared to no communication but are actually more active with only 2 rounds of communication.

TABLE IV

Frequency of activity by treatment and degree

	Treatment A		Treatment B		Treatment C	
	Active (%)	Total	Active (%)	Total	Active (%)	Total
Degree = 1	11 (4.30)	256	6 (3.57)	168	26 (2.71)	960
Degree =2	125 (65.10)	192	75 (59.52)	126	177 (24.58)	720
Degree =3	85 (66.41)	128	46 (54.76)	84	291 (60.62)	480
Degree = 4	58 (90.63)	64	39 (92.86)	42	195 (81.25)	240

Table IV displays the frequencies of the rate of activity by degree. Across all treatments players with degree 1 are rarely active with rates ranging from 3 to 4 percent. In treatment C there is a degree effect on activity, as these rates increase by degree, the increase is steady from 3 to 25 to 61 to 82 percent. For treatment A there is also an increase in activity by degree but the increase is staggered, as from degree 1 to degree 2 there is a sharp increase of 4 to 65 percent, then from degree 2 to degree 3 a small rise of 65 to 66 percent and finally from degree 3 to degree 4 a sharp increase of 66 to 91 percent. In treatment B there isn't a steady increasing trend of activity by degree, as although from degree 1 to degree 2 shows an increase of 4 to 60 percent, which is followed by a decrease from degree 2 to degree 3 in activity of 60 to 55 percent and ending in an increase from degree 3 to degree 4 of 55 to 93 percent. Although activity rates are all above 50 percent for players with multiple degrees in the two treatments with pre-play communication, activity doesn't necessarily increase with a players degree when pre-play communication is present.

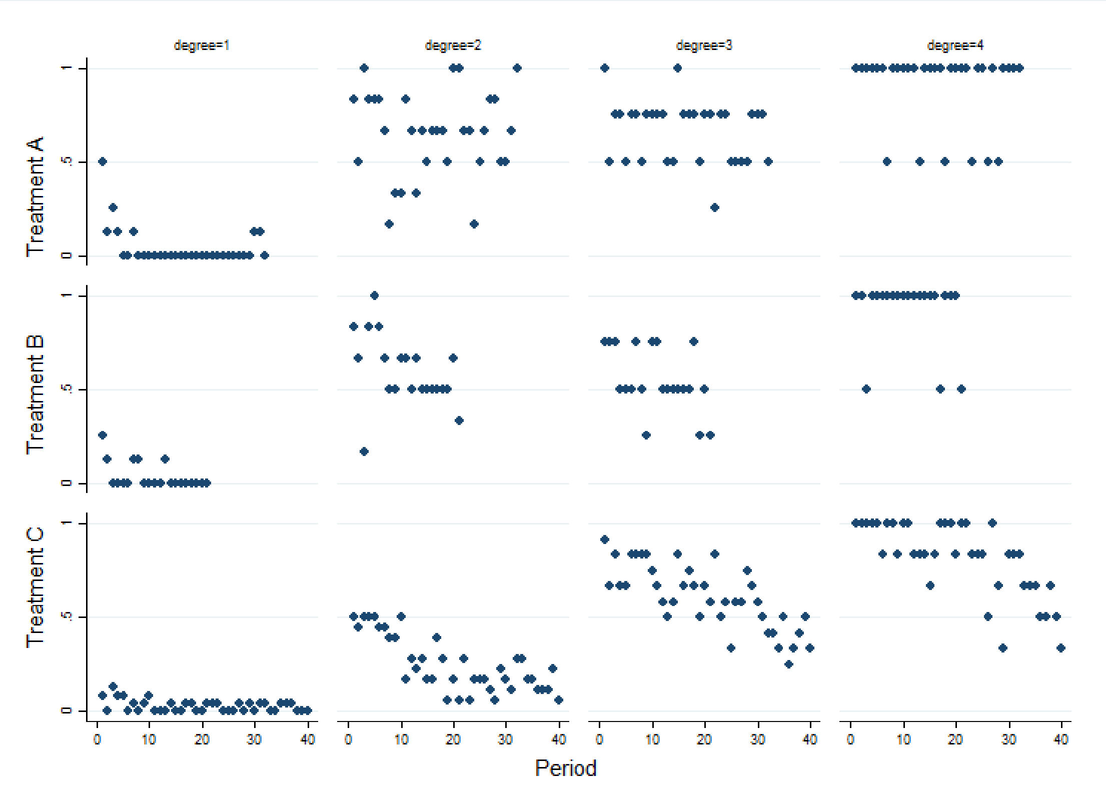


Figure 2 progression of activity by degree and period

Figure 2 displays the progression of activity in each treatment by degree. The results indicate that there is no convergence in treatment A or treatment B to either the efficient or inefficient equilibrium. However the results from treatment C however indicate a convergence to the inefficient equilibrium as found by Charness et al. (2014). We can see that for treatment A and B players with degree 1 initially have some level of activity but then quickly converge towards inactivity and that the choice of inactive is quite stable. In the same two treatments players with degree 4 have high rates of activity which are quite stable over time and only have a little bit of noise. Players with degree 2 and 3 in both the treatments with communication have a lot of noise with activity rates which are continue to be unstable as the periods progress. These results suggest that pre-play communication prevents the network converging to the inefficient equilibrium, which it had converged to without communication. Furthermore, pre-play communication doesn't lead the network to converge to the efficient equilibrium either.

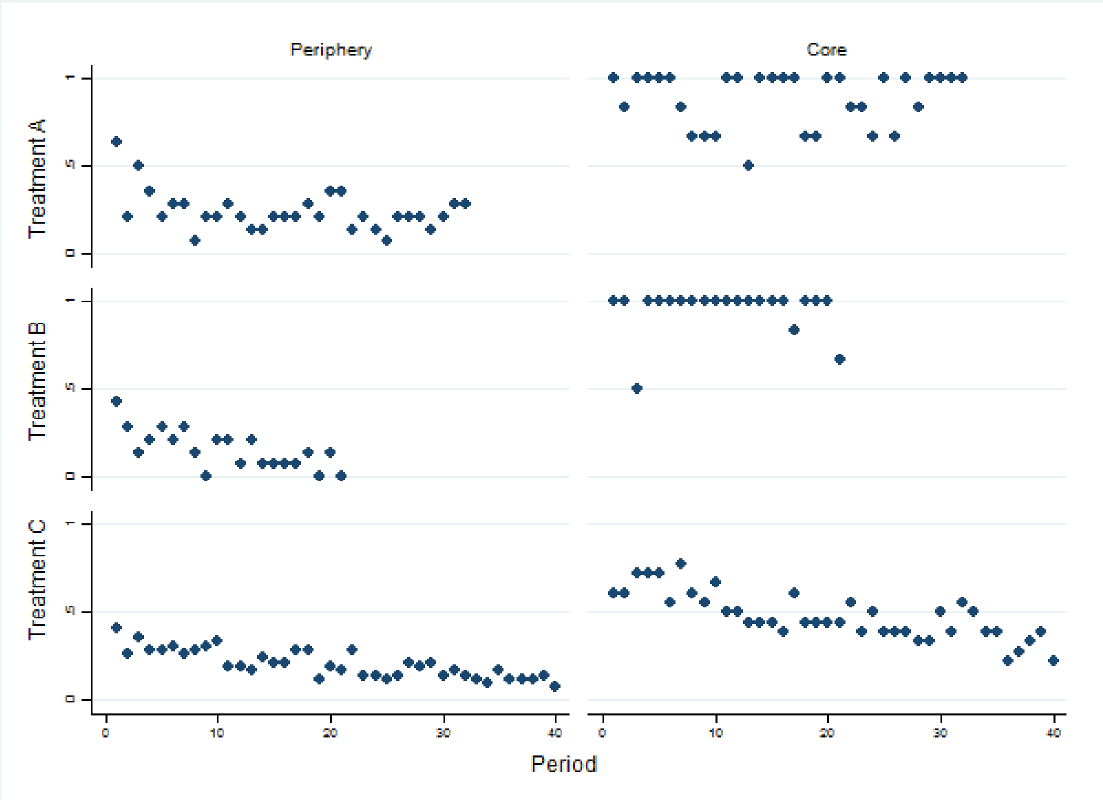


Figure 3 progression of activity by core and period

Figure 3 displays the progression of activity in each treatment both by being a member of the core or the periphery. In treatment C activity rates are initially higher in the core than the periphery by overtime both groups activity rates decrease. This demonstrates the convergence towards inefficient equilibrium, also seen in figure 2. Yet for both treatment A and treatment B there is a distinct split between being a member of the core or the periphery. The periphery players in treatment A initially had around a 50 percent chance of being active but this rate quickly decreased and remained low throughout the session. Likewise the periphery players in treatment B followed a similar trend to those of treatment A, starting with a high level of activity and then quickly decreasing and remaining low. Whereas the opposite is true for the core, in both treatments the core's activity was much higher. For treatment A the activity was often very high, with some noise while for treatment B the level activity high and more stable with much less noise. These results demonstrate that the core in both treatments with pre-play communication had persistently higher activity rates and periphery players tended to have lower activity rates.

If we consider only the player with degree 2 and degree 3, as they are the only players who are distributed between the two groups, and inspect the progression of activity in each treatment by either being a member of the core or the periphery we can see a clear trend toward activity when in the core and communication is present. Figure 4 displays the progression activity for players with degree 2 and figure 5 displays the results for players with degree 3 both when in the core and periphery. There is a distinct split where the activity rates for the players with degree 2 or degree 3 in the core for both treatment A and treatment B are much higher and more stable than those players with degree 2 and degree 3 in the periphery. This suggests cheap talk is informative and there is a strong pre-play communication effect on the core to be active.

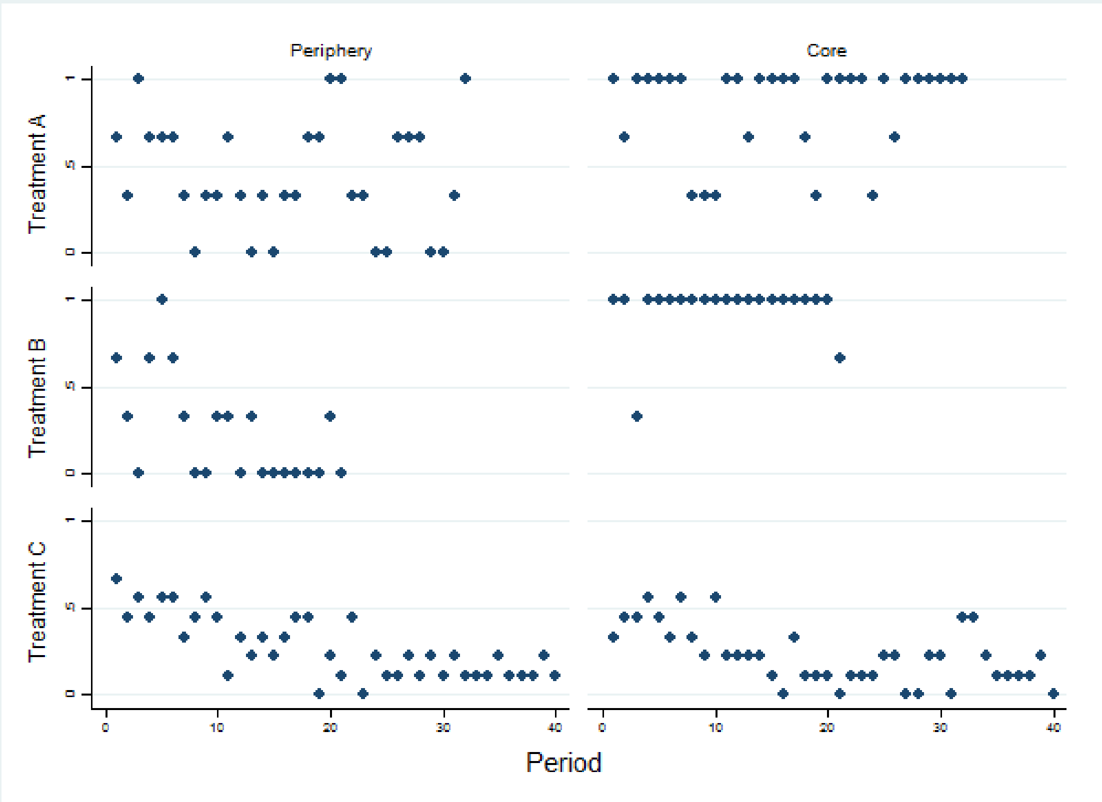


Figure 4 progression of activity for degree 2 by core and period

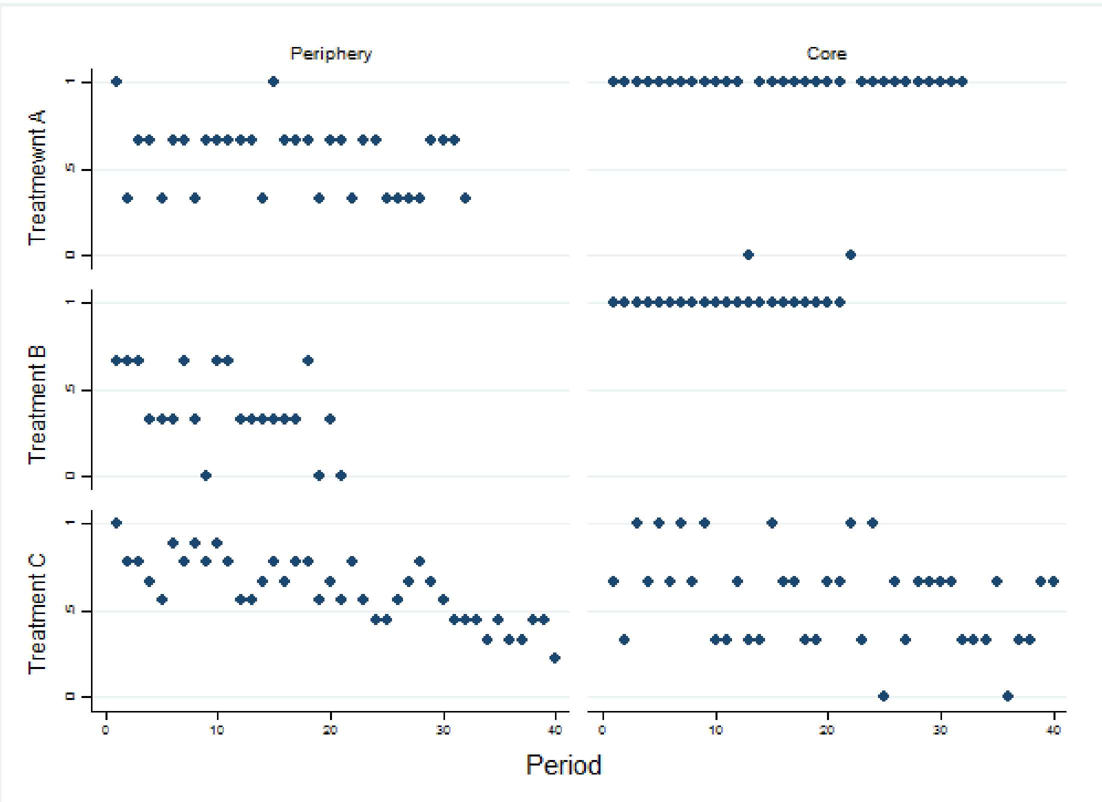


Figure 5 progression of activity for degree 3 by core and period

If we Compare treatment A and treatment B to study the impact that the length of pre-play communication has on activity, there is no clear effect if we look at the player's activity by degrees. Table IV shows that the activity rate in treatment A for degree 4 is already high at 90.6

percent and the activity rate for degree 4 in treatment B is only marginally higher at 92.9 percent. This small 2.3 percentage point increase is just under a quarter of the maximum 9.4 percentage point increase possible, which suggests the effect of longer pre-play communication for degree 4 isn't strong. Likewise for degree 1, where the probability of being active is already low for treatment A at 4.3 percentage points, the probability of being active for players with degree 1 in treatment B is 3.6. The decrease in activity of 0.7 percentage points is 16 percent of the maximum 4.3 percentage point decrease, indicating that the effect of longer pre-play communication doesn't lead to these players coordinating on inactive more frequently. However it could be argued that for players with degree 4 there is a ceiling effect as activity is already high in and conversely for players with degree 1 there is a basement effect as activity is already so low. For players with degree 2 and degree 3, the increase in the length of pre-play communication decreases the rate of activity comparing treatment A to B. The probability of being active for players with degree 2 in treatment B was 60 percent compared to 65 percent for treatment A, similarly the probability of being active for players with degree 3 in treatment B was 55 percent compared with 65 percent for treatment A. It would appear that that when looking at a players degree the length of pre-play communication doesn't lead to more activity. These results are a consequence of the players with degree 2 and degree 3 being distributed among the core and periphery. For instance in table V we can see that in treatment B when players with degree 3 were in the core, activity was 100 percent compared to when they were in the periphery at 40. Whereas for treatment C the frequencies for both groups players are very similar, for instance for players with degree 2, in the core activity was 22 percent compared to 27 percent for the periphery.

TABLE V

Frequency of activity by treatment, degree and core

		Treatment A		Treatment B		Treatment C	
		Active (%)	Total	Active (%)	Total	Active (%)	Total
Degree 1	Core	/	/	/	/	/	/
	Periphery	11 (4.30)	256	6 (3.57)	168	26 (2.71)	960
Degree 2	Core	82 (85.42)	96	60 (95.24)	63	80 (22.22)	360
	Periphery	43 (44.79)	96	15 (23.81)	63	97 (26.94)	360
Degree 3	Core	30 (93.75)	32	21 (100.00)	21	222 (61.67)	360
	Periphery	55 (57.29)	96	25 (39.68)	63	69 (57.50)	120
Degree 4	Core	58 (90.63)	64	39 (92.86)	42	195 (81.25)	240
	Periphery	/	/	/	/	/	/

Comparing the two treatments by being a member of the core however does suggest that the longer the pre-play communication the higher the probability of activity for the core and also the lower the probability of being active for those players in the periphery. The results in table III show that the activity rate of the core in treatment A is already high at 88.5 percent compared to the core in treatment B which is slightly higher at 95.2 percent. Thus there is very little room increase activity, another possible instance of the ceiling effect. Nonetheless the 6.7 percentage point increase is almost 60 percent of the maximum 11.5 percentage point increase that is possible. The activity rate for the periphery players of treatment A is 24.3 percent and for the periphery players in treatment B it is lower at 15.7 percent. This difference of 8.6 percentage points represents 35 percent of the maximum percentage point decrease possible. These results suggest that the longer the core engage in pre-play communication the higher rate of activity is and also the lower rates of activity for the periphery. Table V gives us further evidence for the length of communication effect as the probability of being active for players in treatment A who are in the core with degree 2 and degree 3 is 85 percent and 94 percent respectively. Although both are high, they are lower compared to the probability of 95 percent and 100 percent for the equivalent players in treatment B.

To test the robustness of the results I have employed an econometric model, with two variants. In the basic version I have estimated the probability of being active by using a logistic function of the independent variables using random effects and report the marginal effects across treatments in relation to the probability of being active, measured at period 20 and the average risk level. The independent variables in this econometric model are period, dummies for the number of degrees a player has, dummies for whichever treatment they are in, all interactions between period and these dummies and the measured level of risk aversion. The second version of the model contains the same basic structure as the previous model but also includes an extra independent variable, a dummy for being a member of the core, and the relevant interactions of this core variable with the previous variables. The data is arranged as panel data where the unit of observation is an individual who is observed for the total number of periods that were completed for that particular session.

TABLE VI

Marginal effect of network by degree
(at period 20 and average risk level

	treatment C vs treatment A	treatment C vs treatment B	treatment B vs treatment A
Degree 1	0.006	-0.002	-0.008
	(0.008)	(0.004)	(0.009)
Degree 2	0.548***	0.356**	-0.192
	(0.089)	(0.128)	(0.149)
Degree 3	0.014	-0.176	-0.190
	(0.100)	(0.151)	(0.165)
Degree 4	-0.003	-0.006	-0.004
	(0.042)	(0.071)	(0.077)

Standard errors in parentheses
a *, **, *** denote significance at 1%, 5% and 10%, respectively, two-tailed test

Table VI displays the marginal effects when broken down by degree and only shows a significant pre-play communication effect on the choice of being active for those players with degree 2 (The marginal effect for those players with degree 2 when comparing treatment A or B with treatment C). There is no significant pre-play communication effect on the choice for being active for those players with degree 3 or higher (The marginal effect for those players with degree 3 or 4 when comparing treatment A or B with treatment C). For degree 4 this is perhaps due to the fact that these players are always in the core. Also there is no significant effect for the length of the pre play communication effect across degrees (The marginal effect for those players with multiple degrees when comparing treatment A with treatment B).

Table VII only displays the marginal effects for the degrees which are distributed across the core and periphery. There is a significant pre-play communication effect on the core choosing to be active (The marginal effect for those players in the core with degree 2 and 3 when comparing treatment C to treatment A or treatment B[1]).

TABLE VII

Marginal effect of network by degree
(at period 20 and average risk level)

	Core	Periphery
Treatment A vs Treatment C: Degree 2	0.782***	0.310**
	(0.055)	(0.114)
Treatment A vs Treatment C: Degree 3	0.349***	-0.116
	(0.087)	(0.117)
Treatment B vs Treatment C: Degree 2	0.866***	-0.128**
	(0.037)	(0.047)
Treatment B vs Treatment C: Degree 3	0.399***	-0.425**
	(0.076)	(0.149)
Treatment B vs Treatment A: Degree 2	0.084	-0.826*
	(0.052)	(0.375)
Treatment B vs Treatment A: Degree 3	0.050	-0.308
	(0.042)	(0.173)

Standard errors in parentheses
a *, **, *** denote significance at 1%, 5% and 10%, respectively, two-tailed test

Also table VII shows there is also a significant pre-play communication effect on the choice of the periphery choosing to be inactive for treatment B (The marginal effect for those players in the periphery with degree 2 & degree 3 when comparing treatment C to treatment B). However the periphery players in treatment A with degree 2 are significantly more active when they have pre-play communication (The marginal effect for those players in the periphery with degree 2 when comparing treatment C to treatment A). This result contradicts my hypothesis that the periphery will be less active with the introduction of communication, but there is no significant effect on the same periphery players in treatment B when compared to treatment C. An explanation for this effect could be that out of the three degree 2 players in the periphery, two of them share a link with players of degree 1. They may have been misled into choosing active as in treatment A there is a high frequency of players with Degree 1 sending active messages and then switching to inactive in the action stage at 27 percent. Whereas in treatment B the frequency of players with Degree 1 sending Active messages and then switching to inactive in the action stage is much lower at 11 percent. Also in treatment A players with degree 1, who are always in the periphery, carried out 49.6 percent of this switching behaviour and this reduced to 31.7 percent for players with degree 1 in treatment B. Therefore it is possible that the degree 2 players in the periphery of treatment A were more active as they thought that they were more likely to be located in positions 15, 13 or 7 (see figure 1) as oppose to positions 12, 18 or 8. It is possible to conclude that the reason players with degree 1 would send one message and play another, is due to cheap talk being uninformative and so has no relation to the actual choice of the sender. However the desire to mislead appears to lessen the longer players communicate with each other. This suggests that there might be an increase in the amount of guilt felt when players have to repeatedly state their actions. This would also explain why the periphery are significantly less active only when comparing treatment B to treatment C as there

[1] The results from the second session which contained treatment B found that when players had degree 3 and where in positions that were in the core, they were always active. As a result when computing the marginal effect of degree 3 across treatments I consider the probability of being active when in treatment B and degree 3 and in the core as being equal to 1.

are less misleading active messages from degree 1 players the longer pre-play communication occurs. Therefore it would appear that overtime the desire for players to mislead their neighbour reduces as they have more time to consider their actions.

The results of Table VII indicates that there doesn't appear to be a significant effect on the core being active in terms of longer pre-play communication (The marginal effect for those players in the core with degree 2 and 3 when comparing treatment B to treatment A). However there is a significant effect on the periphery being less active for players with degree 2 with longer communication (The marginal effect for those players in the periphery with degree 2 when comparing treatment B to treatment A). This effect could also be explained due to the decrease in the frequency of players with degree 1 sending erroneous active messages, leading those players in the periphery to selecting inactive more often when there are numerous rounds of pre-play communication.

The behaviour of the individuals drastically alters with the introduction of cheapo talk. Whereas Charness et al. (2014) found convergence to the inefficient equilibrium with no communication, the same network with short and long pre-play communication failed to converge to this equilibrium. Instead the core players tended to have higher rates of activity and the periphery players were much less active. This behaviour would indicate that the players in the core believed that they would be better off by choosing active rather than inactive. This could arise if they believed that when they chose active at least two of their neighbours would also chose active. This suggests that they received final messages from their neighbours containing at least two active messages and thought those messages were credible.
In treatment A for players in the core their last message consisted of at least two or more active messages with a high frequency 94.3 percent compared to the periphery players with multiple degrees which was 50.5 percent. For the core players in treatment B the figure was 96.0 percent compared to 31.0 percent for the periphery players with multiple degrees. Moreover when a core player received a message in the final message stage of at least 2 or more active messages they frequently chose to be active, 93.4 percent of the time in treatment A and 98.4 percent in treatment B. Interestingly even the periphery players tended to be more active when they received a final message of at least 2 or more active messages, 88.7 percent in treatment A and 94.9 percent in treatment B. This is in line with Farrell and Rabin's argument (1996) that players do condition their behaviour on the results of cheap talk.
The evidence suggests that when a player received a message in the final message stage of at least two or more active messages they believed message to be informative and subsequently chose to be active. Therefore the reason the core had a much higher level of activity was that this situation occurred more frequently for the core players, whereas the periphery players received less often at least two active messages and subsequently were much less active.

By considering the behaviour of only players with degree 2 and degree 3 we get a clear picture of the informative nature of cheap talk in this particular network game. The frequency of the last message containing at least two active messages in treatment A for core players with degree 2 and degree 3 was 89.6 percent and 100 percent respectively. Whereas in treatment A periphery players with degree 2 and degree 3 only received a final message containing two or more active messages 41.7 percent and 59.4 percent respectively, much lower than for the equivalent core players. There is a similar pattern in treatment B with the frequency of the last message containing at least two active messages for core players with degree 2 and degree 3 as high as 95.2 percent and 100 percent respectively. Whereas in treatment B periphery players with degree 2 and degree 3 received a final message containing two or more active messages much less frequently at 23.8 percent and 38.1 percent respectively. Consistent with the findings that the core would choose active over 90 percent of the time when they had received at least two or more active messages in the final message round, when core players of degree 2 and degree 3 in both treatment A and B received at least two active messages they would choose to be active over 90 percent of the time as well. These findings further confirm the argument that being in the core increased the likelihood of receiving a final message with at least two active messages resulting in those core players choosing to be active more often. The evidence suggests that pre-play communication is informative and gives a level of assurance to the core that their neighbours will chose active and confirms to the periphery players with multiple degrees that their best option is to choose inactive. This results in the core being more active and the periphery less active.

If we look at the total returns to the three possible outcomes in term of efficiency; the efficient equilibrium, the inefficient equilibrium and the state where the core is active and the periphery inactive, we find that the state induced by pre-play communication is more preferable than the inefficient equilibrium but less so than the efficient equilibrium. So cheap talk leads to a second best outcome for this network but prevents the lest best outcome achieved with no communication.

There is experimental evidence from Choi and Lee (2014) that the longer the pre-play communication, the higher the rate of co-ordination. These results do not suggest that the length of pre-play communication has a significant effect on the core being more active. However it does appear that the periphery players with degree 2 in treatment B are significantly less active than the same players in treatment A. This could be explained by the lower frequency of players with degree 1 in treatment B, indicating that they will be active compared to treatment A. The lack of significance for the length of communication effect on the core could be a result of the already high activity of core in both treatments, indicating that there is a possible ceiling effect as well.

6. Conclusion

Networks are pervasive feature of social and economic interactions in the world and can be applied to areas such as business research decisions, political power structures and international trade. I have explored the impact of pre-play communication introduced into an asymmetric 20-player network with incomplete information, strategic complements and local payoffs. The main finding, in contrast to experimental results in Charness et al. (2014) where the network converged to the inefficient equilibrium, is that as a result of pre-play communication a group of players in the network, known as the core, are highly active. Furthermore the players known as the periphery, who are not in the core, have a much lower level of activity. This result is an equilibrium with informative cheap talk and it is more preferable to the inefficient outcome of the network without communication. When all players of multiple degrees received a final message of at least two active messages they felt the message was credible enough to assure them that they should select active along with their neighbours. Therefore main driving factor of the higher activity in the core is that of the final messages they received from their neighbours, a vast majority contained at least two or more active messages.

As the length of communication increased the activity of the core didn’t significantly increase. This could be a consequence of the already high activity seen in the core with the shorter length of communication but it could also be due to the small number of observations collected as a result of budget constraints. However the results do suggest the longer the communication the lower the activity for the periphery. This appears to be driven mainly by players of degree 1 reducing the number of misleading active messages they send the more they communicate with their neighbours leading to the periphery to coordinate on inactive, suggesting they feel less inclined to lie the more they interact with their neighbours.

These experimental findings suggest that in an environment of incomplete information and strategic complements that certain players will benefit most from pre-play communication and that there is strong evidence that people converge to a state that is more efficient than the same network without communication. This has implications for predicting outcomes of already existing network structure, for instance as it may explain why certain companies in a sector who have strong communication channels are more likely to adopt new technology than others.

However I was only able to complete two sessions and within the sessions I was only able to complete a fraction of the periods that original Charness et al. (20014) experiment had. Although we feel this has not diluted the analysis as even with a smaller number of period there was clearly a behavioural impact from cheap talk, I would suggest in order to make the results more robust that more sessions of the experiment need to be conducted. Also it would be interesting to apply the findings of Charness (2000) to study whether the players selecting their action first and then sending messages to their neighbours would impact the effectiveness of cheap talk in a network setting.

Appendix

Instructions for treatment B

The aim of this experiment is to study how individuals make decisions in a given network structure. The experiment consists of two parts, Part 1 which has up to 40 periods played one after the other and Part 2 which will only follow the completion of Part 1. First you get the instructions for Part 1 of the experiment, after which there will be instructions for Part 2, which is independent of Part 1. If you follow the instructions carefully you will earn a non-negligible amount of money in cash (Pounds) at the end of the experiment, you will also receive a £4 show up fee on top of what you earn in the experiment. During the experiment, your earnings will be accounted in ECU (Experimental Currency Units). Individual payments will remain private, as nobody will know the other participants' payments. Any verbal communication among you is strictly forbidden and will result in an immediate exclusion from the experiment.

PART 1

1.- The experiment consists of up to **40 periods**, it is possible that Part 1 will end before the allotted 40 periods are played this is due to time constraints (don't worry this won't affect your payment). There are **20 participants**, including yourself, who will remain the same throughout the experiment. Please note that there will be **no unpaid** trial periods before the 40 periods start. At the beginning of each period, you and each of the remaining nineteen participants will be randomly assigned one position of the following **Network** (figure 1 on a paper titled "Network 1"). The **positions in the network** are numbered from 1 to 20.

2.- In the network, a link is represented by a line (connection) between two positions. For example, **position 16** has four links: it is linked to **positions 6**, **7, 15** and **19** (but it is not linked to the remaining positions). Therefore this person has **four** neighbours in total.

Note that there are **four classes of positions** in the network, identified by **number of neighbours**.

- There are eight **yellow positions**: Those positions **with one neighbour** (1, 2, 3, 6, 9, 10, 12 and 14).
- There are six **green positions**: Those positions **with two neighbours** (7, 8, 13, 15, 17 and 18).
- There are four **blue positions**: Those positions **with three neighbours** (5, 11, 19 and 20).
- There are two **red positions**: Those positions **with four neighbours** (4 and 16).

3.- In each period, you (and the other participants) are randomly assigned by the computer to a **position from 1 to 20 in the network**, all of them being equally likely. The assignment process is random: At each period, you are equally likely to be located in each of the 20 positions of the network.

4.- In each period, **you will only be informed of the total neighbours you have**, that is, you will know how many links your assigned position has: **1 link (1 neighbour)**, **2 links (2 neighbours)**, **3 links (3 neighbours)** or **4 links (4 neighbours)**. However, **you will not be informed of which is your exact position**.

For example, if in a particular period you are informed that your position has 3 neighbours, then you know that you can be in position 5, 11, 19 or 20, and that you can be in any of them with the same probability. Note that, in such a case, you also know that you cannot be in the positions with 1,2 or 4 neighbours.

5.- In each period there will be two stages; a **MESSAGE STAGE** followed by an **ACTION STAGE.** In the message stage which you will be able to send **non-binding** messages to your neighbours (those you are connected to) and they will be able to send you **non-binding** messages as well. These messages can indicate your or your neighbour/s possible action in the following action stage. These messages will not affect your payment as your earnings for the period can only be affected in the action stage by your decision and the decisions of your neighbours. Knowing the network structure and your number of neighbours there will **FIVE** message rounds in which for each round you will be asked to send a message: to be **ACTIVE** or **INACTIVE** (the other participants are asked to make the same choice). The results of **your neighbour's** messages will be displayed in a table on the right hand side of the message stage active screen. However only the number of **ACTIVE** messages your neighbours have sent you will be displayed, therefore if for example you have 2 neighbours and you only receive **1 ACTIVE** message, it is the case that your other neighbour chose **INACTIVE.**

6.- In each **ACTION STAGE**, your position will remain the same as the previous message stage**.** The results of the messages your neighbours sent to you in the preceding message stage are displayed in a table on the right hand side of the action stage screen. You make the same decision as before to be **ACTIVE** or **INACTIVE** (the other participants are asked to make the same choice), **BUT** this decision along with your neighbours **WILL** determine your period payoff. If you choose to be INACTIVE, your period payoff is 50 ECU. If you choose to be ACTIVE, your period payoff is calculated as follows: First, add 100 ECU per participant linked to you that also chooses to be ACTIVE; then, divide the result by 3. Hence,

- If you choose to be **ACTIVE** your period payoff can be:
  - $\mathbf{133.33}$ **ECU** if 4 of your neighbours choose to be ACTIVE $\left[\frac{100+100+100+100}{3}\right]$, or
  - $\mathbf{100.00}$ **ECU** if 3 of your neighbours choose to be ACTIVE $\left[\frac{100+100+100}{3}\right]$, or
  - $\mathbf{66.66}$ **ECU** if 2 of your neighbours choose to be ACTIVE $\left[\frac{100+100}{3}\right]$, or
  - $\mathbf{33.33}$ **ECU** if 1 of your neighbours choose to be ACTIVE $\left[\frac{100}{3}\right]$, or
  - $\mathbf{0.00}$ **ECU** if none of your neighbours chooses to be ACTIVE.

• If you choose to be **INACTIVE** your period payoff is **50.00 ECU** for sure.

7.- At the end of every period, you will get information about the results from the current period. The information consists of:
- Your position in the network.
- Your choice (ACTIVE or INACTIVE).
- The number of participants linked to you that chose to be ACTIVE or INACTIVE.
- Your (period) payoff.

8.- Once the final period has been decide by the experimenter you will play out that peiod as before but then you will be automatically taken to Part 2 of the experiment. The final payoffs will be calculated and displayed to you once Part 2 is completed.

PART 2

Part 2 consists of two tests where you need to make 12 decisions, there is one decision in Test A and eleven in Test B so **twelve decisions** in total. In each decision, your choice can only have monetary consequences for you, but not for any other participant.

1) Test A has one decision, as follows:
You have your show up fee to invest (£4), of which you can invest a certain percentage of, ranging from 0% to 100%, into a risky option. Your investment will be successful with 50% chance. If successful, you get 2.5 times the invested amount back. If not successful, you lose your invested amount of the show up fee. All portion of your show up fee that you do not invest are for you to keep.
How much of your show up fee (£4) would you like to invest into the risky option?

2) Test B has the other 11 decisions, which are all fairly similar.
There are 11 rows each containing a pair of choices where you have to choose which of the two you prefer. Choosing the left option implies a safe payoff whereas your payoff from choosing the right option on depends on chance. Each line on the screen will correspond to a set of options. The option on the **left** will be *X* amount of pounds for sure, where *X* will be positive a value ranging from £0 to £10. The corresponding option on the **right** will always be 50% chance of getting £10 and a 50% chance of getting £0.

In each of the 11 decisions you will need to choose one of the two options on each row by selecting one of them with your mouse icon. The decision problem will be presented on the screen as follows:

5 Pounds for sure ○ ○ 50% Chance of 10 Pounds and 50% Chance of 0 Pounds
6 Pounds for sure ○ ○ 50% Chance of 10 Pounds and 50% Chance of 0 Pounds

3) Payoff from this part: At the end of the experiment only **one** of you will be randomly chosen to receive the payment. That person will have one of their 12 decisions randomly selected for payment. There will be equal probability of Test A or Test B being chosen, then within Test B there will be an equally likely chance that one of the 11 options will be chosen.

If, for instance you are selected out of the 20 participants, then if your decision from Test A is selected, then you get with 50% chance 2.5 times the invested amount, in addition to the amount of show up fee (£4) that you kept.
If one of your decision from Test B is selected you will receive the option that you chose from one of your 11 options and have your choice from that pair of choices as your payoff. If you have chosen the risky option, then you get with 50% chance £10 and with 50% chance £0. If you have chosen the safe amount, then you get the amount that was stated in that decision.

Total Payment

Once you have completed Part 2 it is the end of the experiment, you will be paid the earnings that you achieved in 4 periods from Part 1, that will be randomly selected across the final number of periods that is actually played (all periods that are played will be selected with the same probability). These earnings are transformed to cash at the exchange rate of 35 ECU = £1. In addition, you will also be paid the a show up fee of £4, however if you are the person who is selected to receive the outcome from one of their decisions from Part 2, then the corresponding amount will be added (subtracted as is the case with an unsuccessful investment in test A) to you final payment

Now you have read the instructions please complete the sheet titled "Example Payoffs for Part 1". Once you have finished filling in that sheet please raise your hand so that the invigilator can check your results. Once everyone has completed the sheet the experiment will begin.

Example Payoffs for Part 1

Based on the instructions you have just read please fill out in the space provided what you think the payoffs would be in the four scenarios which are relevant for the Main Experiment. Raise your hand when Finished and the invigilator will check your answers.

Example 1

1. You are in the MESSAGE STAGE of the experiment
2. You have 3 neighbours
3. You Select the message ACTIVE
4. Your neighbours send you their messages.
5. 2 have messaged you ACTIVE

Q. Would you receive a payoff for this period?
A. (tick the right box) YES ☐ NO☐

Example 2

1. You are in the ACTION STAGE of the experiment
2. You have 4 neighbours
3. You Select the action ACTIVE
4. Your neighbours select their actions.

Q. If two of your neighbours have chosen the action ACTIVE what would your payoff for the period be in ECU?
A. ☐ ECU

Example 3

1. You are in the ACTION STAGE of the experiment
2. You have 2 neighbours
3. You Select the action INACTIVE
4. Your neighbours select their actions.

Q. If two of your neighbours have chosen the action ACTIVE what would your payoff for the period be in ECU?
A. ☐ ECU

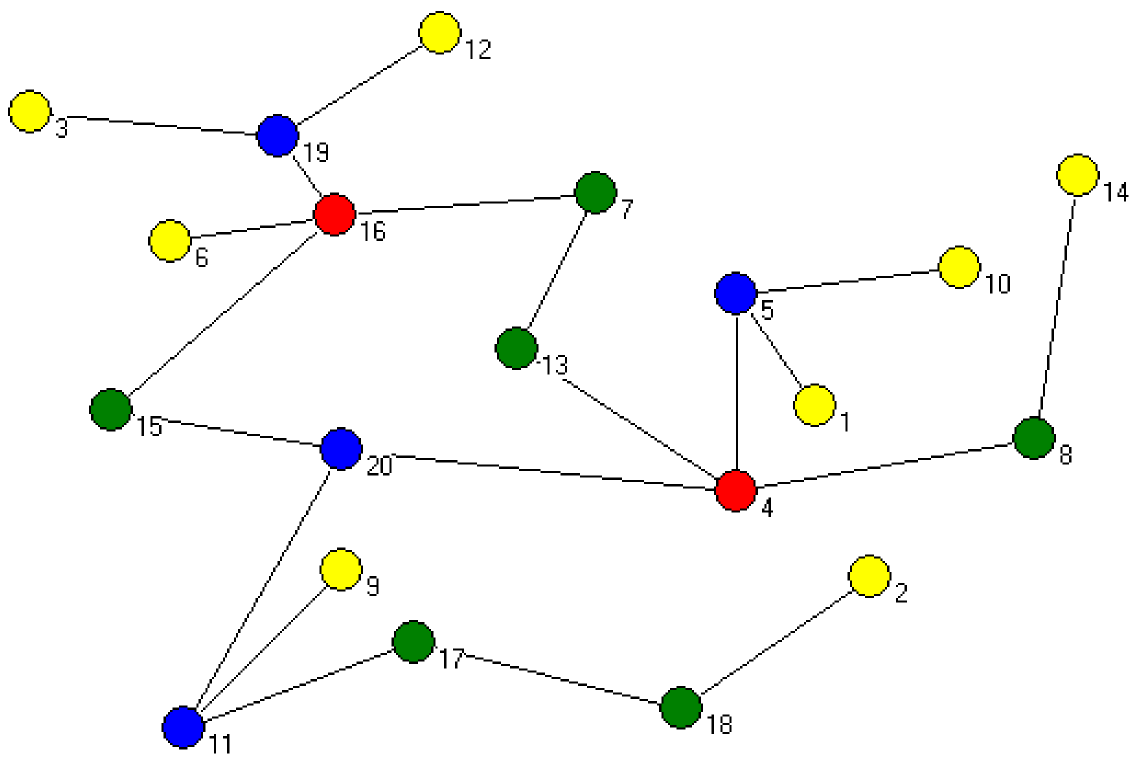
Example 4

1. You are in the ACTION STAGE of the experiment
2. You have 2 neighbours
3. You Select the action ACTIVE
4. Your neighbours select their actions.

Q. If none of your neighbours have chosen the action ACTIVE what would your payoff for the period be in ECU?
A. ☐ ECU

Network 1

The network structure will remain the same for the duration of the experiment, however the position you are assigned to at the beginning of each period will be randomly chosen. You will only know the number of neighbours (links) you have and not the exact position you are in.



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