An experimental study on information sharing networks

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Abstract

We design an experiment to study how agents make use of different pieces of information in the lab, depending on how many others have access to them and the strategic nature of interaction. Agents receive signals about a payoff relevant parameter, and the information structure is represented by a non directed network, whose nodes are agents and whose links represent sharing agreements. We compare the use of information in different information sharing networks, considering games in which strategies are substitute, complement and orthogonal. We then study the incentives to share information across games by analyzing the scenario where subjects have the chance to modify the network prior to playing the game.

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1 Introduction

There has been an extensive theoretical effort to understand the use of information in environments with fundamental uncertainty and its relation to the strategic nature of the game, i.e. to wether players actions are strategic complements, substitutes or orthogonal (see Morris and Shin, 2002 and Angeletos and Pavan, 2007). In these influential papers, agents observe private signals (only revealed to them) and public ones (observed by all) and then play a game.[1] Recent studies complement this setting by analyzing information transmission in networks. Galeotti et al (2013) study the "many sender - many receivers" game of cheap talk, interpreting the flows of truthful information as directed links in a network. The focus is there on the incentives to truthfully report the observed information, and while in their model all agents would benefit from the disclosure of all available information, this may not be feasible in equilibrium. Hagenbach and Koessler (2010) enrich this cheap talk model by adding a coordination motive (a là Morris and Shin, 2002). They assume that the state of the world takes the form of the sum of agents' independent signals and show that agents always benefit from disclosing or receiving additional information.

In this vein, Currarini and Feri (2014) propose a general model that encompasses the whole class of linear quadratic games. They consider a first stage where, prior to observing their own private signal, agents decide on bilateral information sharing agreements (network formation) and then,[2] in a second stage, they play a linear quadratic game of incomplete information, in which information sets are determined by the resulting network.[3] Regarding the second stage, Currarini and Feri (2014) find that the sensitivity of each player's strategy to each observed signal in the network depends on the strategic nature of the underlying game. In line with previous works in the literature, strategic complementarities induce agents to use more intensively those signals that are observed and used more intensively by other agents in the network. Opposite conclusions apply to games with strategic substitutes. On the other hand, all the signals are treated symmetrically when players' strategies are orthogonal. Regarding the first (network formation) stage, they find that the incen-

[1] See also Cornand and Heinemann (2008), who introduce a concept of partial publicity by allowing for information that is provided to just a fraction of agents.

[2] They approach information sharing from a bilateral perspective, assuming that each pair of agents can commit (ex-ante) to mutually (and truthfully) disclose their own private information to each other. The ex-ante assumption allows them to dismiss all strategic considerations that relate to the inference of other agents' information from their sharing behaviour. In this context, an information structure is well represented by a non directed network, in which an agent's private information consists of the signals observed by herself and by her "neighbors" in the network.

[3] In the framework of imperfect market competition, the issue of understanding the incentives of firms to share information before engaging in market competition dates back to the seminal contributions of Novshek and Sonnenschein (1982) and Vives (1985). One main insight from this body of literature is that incentives to share are associated with either strategic complementarity or weak substitutability, be it induced by products differentiation, by cost convexity or by price competition (see Vives, 1985, Kirby, 1988 and Raith, 1996).

tives to share information (specifically, they study the architecture of pairwise-stable networks) crucially depend on how sensitive payoffs are to the volatility of one's own action, on aggregate volatility, and to the covariance of opponents' actions and the state of the world.

Despite the relevance of these recent theoretical efforts to understand the incentives to share information on a bilateral basis (resulting in information networks) and the use of such information in relation to the strategic nature of the game, to the best of our knowledge this (network) framework has not been explored in the lab. In this paper we design an experiment to test whether observed behavior is consistent with the theoretical predictions in this setting, and to identify (network) variables that introduce significant behavioral effects. To this aim, we implement three treatments, that correspond to three classical examples of (linear quadratic) games of incomplete information studied in the literature that differ in the strategic nature of interaction: the Keyness beauty contest game (Morris and Shin, 2002, Hagenbach and Koessler, 2010), in which agents' actions are strategic complements; the Cournot oligopoly game (Vives, 1985, Kirby, 1988, Raith, 1996), in which agents actions' are strategic substitutes; and the public goods game with linear benefits and quadratic costs (Ray and Vohra, 1999), in which agents' actions are orthogonal.[4]

In the first part of the experiment, information networks are exogenous, and we study the (intensity of) use of each signal depending on how many others observes it in the network. In the second part of the experiment, prior to playing the game players have the chance to modify the network.[5] This new stage allows us to identify the architectures of stable networks in the lab for each different game.

Regarding the use of information, we find that the behavior in the beauty contest game (strategic complements) is quite consistent with the theoretical predictions. Subjects put more weight on the signals that are more observed in the network, and these weights are very close to the theoretical coefficients in symmetric networks. In asymmetric networks we observe a bias that depends on the amount of information of the subject (i.e., the subjects' degree). Subjects with a degree above (below) the average overweight (underweight) all their observed signals. In the Cournot game (strategic substitutes) there are significant qualitative and quantitative deviations from the theoretical predictions. Whereas less observed signals should be assigned more weight by agents, precisely the opposite occurs in symmetric networks. Moreover the weights are extremely lower than the theoretical coefficients. This discrepancy is somehow reduced in the asymmetric networks: subjects with degree above the average present a non-monotonic pattern in the weights assigned to signals, the coefficient being closer to the theoretical predictions, and subjects with degree below the average present a flat pattern (all signals are assigned the same weight, much lower than the

[4]The equilibrium properties of these three classic examples are deeply studied by Currarini and Feri (2014).

[5]Our focus is on the incentives to share information at the ex-ante stage, as they result from the gains from acquiring and the possible losses from disclosing.

theoretical predictions). In the public goods game (orthogonal strategies) we also observe deviations from the theoretical predictions. In this case, agents should assign the same weight to all signals and we find one exception: Signals observed by the whole population are more used than the remaining ones. Weights assigned to signals that are not fully observed are under the theoretical prediction.

Regarding network formation, as the theory predicts we find that subject mostly optimally decide to form any possible additional link prior to playing the beauty contest game (consistently with the complete network being the unique pairwise-stable network). In the Cournot game significant deviations from optimal behavior are observed. Subjects barely choose to sever links or not to create a new link when it is optimal to do so. However, these choices can be rationalized if subjects anticipate the subsequent behavior in the Cournot game.[6] Finally, in the public goods game subjects mostly best respond by creating any possible additional link.

The closest experimental paper to ours is Cornand and Heinemann (2014), who design an experiment based on Morris and Shin's (2002) setup. Hence, they restrict the analysis to the beauty contest game (strategic complements) and to the case where each agent observes a private signal (only revealed to her) and a public signal (observed by all). They measure the actual weights that subjects attach to public and private signals and find, in line with the theory, that subjects put larger weights on the public signal than on the private ones. However, the weights put on the public signal are smaller than theoretically predicted. They show that observed weights are distributed around the predictions from a cognitive hierarchy model, where players take into account that other players receive the same public signals, but neglect that other players also account for others receiving the same public signals. Differently to Cornand and Heinemann (2014), in our case each signal is public to a specific subset of agents (the neighborhood) and, in our framework, the use of private information is potentially related to the possibility that agents share their private information before engaging in non-cooperative behavior. We extend their findings for the BC game by showing that to the extent that a signal is "more public" (more observed in the network) subjects put more weight on them. Other experiments that explore the use of private versus public information are, for instance, Heinemman et al (2004), Cornand (2006) and Cabrales et al (2007).[7]

Former experiments that consider games of complements or substitutes in net-

[6] The fact that players underweight all the signals as compared to the theoretical predictions might turn optimal to form any additional link and not to sever any one.

[7] Heinemman et al (2004) design an experiment on the speculative-attack model by Morris and Shin (1998), and compare sessions with public and private information. The main differences in behavior between the two treatments are that with public information, subjects rapidly coordinate on a common threshold, attack more successfully, and achieve higher payoffs than with private information. Cornand (2006) extends the analysis of Heinemman et al (2004) to allow for signals of different nature. Cabrales et al (2007) study equilibrium selection in an experiment on a pure coordination game with uncertainty, where subjects receives noisy signals about the true payoffs.

works are Kearns et al (2006, 2009), Charness et al (2014), and Choi and Lee (2014).[8] Kearns et al (2006, 2009) develop a series of experiments where players located in a network aim to get a collective goal (subjects' payoffs depend on the global performance of the network) and study the capacity to achieve the common goal, depending on the network structure. Kearns et al (2006) consider a game of substitutes (framed as a graph-coloring problem) and Kearns et al (2009) examine a game of complements (framed as a voting game).[9] Charness et al (2014) conduct a series of experiments in which actions are either strategic substitutes or strategic complements, and participants have either complete or incomplete information about the structure of a random network. They study equilibrium selection and relate it to network characteristics like connectivity and clustering. Finally, Choi and Lee (2014) investigate how the interaction between the network structure of pre-play communication and the length of such communication affects outcome and behavior in a coordination context.

The paper is organized as follows: Section 2 presents our three basic games and derives the theoretical predictions. Section 3 contains the experimental design. Section 4 presents the results. Section 5 concludes the paper.

2 The games

In this Section, we introduce our three basic games in two frameworks, exogenous and endogenous networks, and report the equilibria.

2.1 Exogenous networks

We consider 4 players, $N = \{1, 2, 3, 4\}$ and a network of 4 nodes: A, B, C and D. Prior to playing the game, each player is randomly assigned to a node. For each $i \in N$, we denote by $N_i \subset N$ the set of player i's neighbors in the network. The degree of a player is $|N_i|$, and we denote $n_i = |N_i| + 1$. At the beginning of the game each individual $i \in N$ receives a signal $y_i \in \{-1, 1\}$, uniformly and i.i.d. distributed. The state of the world is

$$\theta = 5 + \sum_{i=1}^{4} y_i.$$

[8] See also Fatas et al (2010) that propose a public goods experiments in which a network determines the information subjects receive about others' prior choices.

[9] Kearns et al (2006) find that networks generated by preferential attachment make solving the coloring problem more difficult than do networks based on cyclical structures, and "small worlds" networks are easier still. Kearns et al (2009) find that in some networks the minority preference consistently wins globally, and that certain behavioral characteristics of individual subjects (such as stubbornness) are strongly correlated with earnings.

Then, each player is informed on the value of his signal, y_i, and of the signals of his neighbors, i.e., y_j for each $j \in N_i$.[10] With this information at hand, individual i takes action $a_i \in [0, 10]$. The payoff function depends on the game.[11]

- **Keynes Beauty Contest game (BC)**

$$u_i = 100 - \frac{1}{2}\left((a_i - \theta)^2 + \left(a_i - \frac{\sum_{j \neq i} a_j}{3}\right)^2\right)$$

In this game, players actions are strategic complements. The equilibrium strategies are:

$$a_i^* = 5 + \sum_{j \in N_i \cup \{i\}} \frac{3}{7 - n_j} y_j$$

Note that, for each $j \in N_i \cup \{i\}$, $\frac{3}{7-n_j} \in \{0.5, 0.6, 0.75, 1\}$ and that $\frac{\partial a_i^*}{\partial n_j} > 0$, i.e., the more observed a signal is, the more it is weighted in the equilibrium actions (complements).

- **Cournot Oligopoly game (CO)**

$$u_i = 70 + \left(\theta - \frac{1}{5}\sum_{j \in N} a_j\right) a_i$$

In this game, players actions are strategic substitutes. The equilibrium strategies are:

$$a_i^* = 5 + \sum_{j \in N_i \cup \{i\}} \frac{5}{1 + n_j} y_j$$

Note that, for each $j \in N_i \cup \{i\}$, the coefficient applied to signal y_j is $\frac{5}{1+n_j} \in \{2.5, 1.\widehat{6}, 1.25, 1\}$ and that $\frac{\partial a_i^*}{\partial n_j} < 0$, i.e., the more observed a signal is, the less it is weighted in the equilibrium actions (substitutes).

- **Public Goods game (PG) with linear benefits and quadratic costs**

$$u_i = 40 + \theta \sum_{j \in N_i \cup \{i\}} a_j - \frac{1}{2} a_i^2$$

In this game, players strategies are orthogonal. The equilibrium strategies are:

$$a_i^* = 5 + \sum_{j \in N_i \cup \{i\}} y_j$$

[10] Hence, n_i is the number of signals observed by player i (including his own signal) and, also, the number of players (including i) that observe the signal received by player i.

[11] Constants are added to avoid for the posibility of negative payoffs. They are irrelevant for the predictions and prevent loss aversion considerations.

Note that, for each $j \in N_i \cup \{i\}$, the coefficient applied to signal y_j is 1, i.e., all the observed signals are equally weighted in equilibrium (orthogonal actions). Therefore, $\frac{\partial a_i^*}{\partial n_j} = 0$.

2.2 Endogenous networks

We consider 4 players, $N = \{1, 2, 3, 4\}$ and a network of 4 nodes: A, B, C and D. Prior to playing the game, each player is randomly assigned to a node. Then in a first stage players are asked, for each possible link (existing or not) involving them, to simultaneously choose whether they want to maintain the status of the link or change it (sever an existing link or create a missing link). Then one of the six possible links (AB, AC, AD, BC, BD, CD) is picked at random (with uniform probabiliy) and a new status of the link is determined. The new status depends on the choices of the two players involved in the link: If the link was missing, it is created if and only if both players involved decided to create it. If it was present, it is severed if and only if at least one of the two players involved decided to sever it. Then once the new status of the selected link is determined, in a second stage the players play one of the three games defined in the former section (BG, CO or PG) in the new network.

When in equilibrium all players decide not to sever any single link and there are not any pair of players that want to create a new link, the original network is pairwise stable (See Jackson and Wolinsky, 1996), and otherwise it is not.[12]

For each network, the equilibrium strategies of the second stage are reported in the previous section. We now report the theoretical predictions for the first stage and the corresponding pairwise stable networks.

- **Keynes Beauty Contest game (BC)**

The theoretical prediction is that players choose to create all possible new links and not to sever any link. The unique pairwise stable network is the complete network.

- **Cournot Oligopoly game (CO)**

The theoretical prediction is that: (i) players with no links choose not to form any link; (ii) players with one link choose to sever the existing link and to form links with those players that either have no link or one link;[13] (iii) players with two links choose to create the missing link and to sever the links with those players that have either two or three links; (iv) players with three links choose not to sever any link.

Thus, there are three pairwise stable network structures: the empty network, the complete network, and a network composed by a complete component of three

[12] In the experiment we design a non-cooperative implementation of pairwise stability by making agents decide on the status of all their links, knowing that only one (randomly selected) link will be modified according to the decisions of the involved agents.

[13] Recall that at most one of the link decisions of the player is implemented.

players and a singleton (there are four such structures, depending on the identity of the singleton).

- **Public Goods game (PG) with linear benefits and quadratic costs**

The theoretical prediction is that players choose to create all possible new links and not to sever any link. The unique pairwise stable network is the complete network.

3 Experimental design

3.1 Experimental procedures

We conducted our computerized experimental sessions at the ExpReSS lab at Royal Holloway, University of London in May of 2014, using the software zTree (Fischbacher 2007). A total of 120 undergraduate students were recruited from a pool of students registered for experiments. No subject was allowed to participate in more than one session. There were six treatments: BC, CO and PG games, both with exogenous and endogenous networks. The same game (BC, CO or PG) under different network conditions was played in the same session (first the networks were exogenous -22 rounds- and later endogenous -11 rounds):

- Two sessions of the BC game (24+16 participants): 22 rounds with exogenous networks and 11 rounds with endogenous networks.
- Two sessions of the CO game (24+16 participants): 22 rounds with exogenous networks and 11 rounds with endogenous networks.
- Two sessions of the PG game (24+16 participants): 22 rounds with exogenous networks and 11 rounds with endogenous networks.

In each session, the participants were split randomly into matching groups of 8 subjects, and this was common information to the participants. In each one of the 33 rounds, the members of a matching group were randomly assigned to groups of four subjects who played the stage game of a given treatment.[14] The average payoff was 20£ per subject (including a 4£ show-up fee) for a session lasting around 90 minutes. The experimental instructions are provided in the Appendix.[15]

At the beginning of the experiment, Part 1 of the general instructions –common to all treatments– were read aloud in the room and printed copies were also distributed to each participant. Participants were informed that they would receive instructions

[14] In this way we get a total of 5 independent observations per game.

[15] We only provide the instructions for the BC game. The remaining cases only differ in the payoff function, and are available from the authors upon request.

for a second part, independent of Part 1, once this part finishes. Any kind of communication was prohibited. Subjects in the same treatment were split into sections of 8 subjects each and they were re-matched (in groups of four) from one round to the next within the same section.

Part 1 of the experiment consisted of 22 rounds. At each period, the computer selected a network from the set of networks depicted in Figure 1. Subjects were informed that each of the these 11 networks would be selected twice during Part 1 of the experiment, and that the order would be randomly determined at the beginning of the experiment. Once a network is selected, the members of each group of 4 participants were randomly assigned to a player position: A, B, C or D. At each round, subjects knew the selected network and their player position.

[Insert Figure 1]

Then, the signals of all players were realized,[16] and each player was informed of his signal and of his neighbors' ones. With this information at hand, subjects had to choose a number between 0 and 10 (with two decimal positions). The precise payoff function of the game was provided in the instructions, but subjects could also use a payoff calculator to facilitate calculations. To use the payoff calculator, subjects selected a state of the world (1, 3, 5, 7 or 9 - the possible values of θ), by clicking a button in the screen. A "color map" appeared, where different colors correspond to different earnings (computed for the chosen value of the state of the world) in the payoff function. Subjects could select coordinates by clicking inside this map.[17] Once they clicked inside the map, in the lower part of the screen they could see the resulting payoff that corresponds to: (i) the selected state of the world, (ii) the selected value for sum of the other three players' decision (horizontal coordinate) and (iii) the selected value for their decision (vertical coordinate). Subjects could explore as many possibilities as they wanted and they were explained that the colors in the map provide the direction in which earnings vary (a legend below the map provided an approximate idea of the earnings that corresponds to each point in the color map).[18] Once they were ready, subjects took their round choice by using a scroll bar.

At the end of each period, subjects got the following information about the current period: the selected network, their player position, the sum of the other players' decisions, the signals of all the players, the state of the world and their (period) earnings.

Once Part 1 of the experiment was finished, the participants received the instructions for Part 2. The novelty was that, once a "original" network was selected for

[16] Recall that each signal can be either $+1$ or -1.

[17] The selected horizontal coordinate represented a value for the sum of the other three players' decision (from 0 to 30) and the selected vertical coordinate represented the value for their choice (from 0 to 10).

[18] While subjects were using the payoff calculator, they could see the signals that they were informed of in the upper-right part of the screen and, at any moment, they could also recall the selected network of the period by clicking on a button.

the round, there was a *Network Modification* stage prior to playing the game. In this stage each subject took three choices: for each of the other three positions in the network, a subject decided whether to alter the status of the link (that could be either present or absent) or leave it as it is. Then, one link (AB, AC, AD, BC, BD, CD) was randomly selected and its new status was determined by the subjects choices: If the link was originally present, it was severed if and only if at least one of the two involved players chose to sever it. If the link was originally absent, it was created if and only if both players involved chose to create it. Then, subjects were informed of the resulting (current) network (one of the networks depicted in Figure 2 below), and proceeded to play as in Part 1 of the experiment. Subjects played 11 rounds in Part 2, and each of the networks depicted in Figure 1 was selected once as "original network".

[Insert Figure 2]

Finally, at the end of the experiment, we implemented Charness and Gneezy (2010) risk test, by allowing participants to choose which share (if any) of their show up fee they want to invest in a risky asset (it provides 2.5 times the amount invested with probability 0.5 and the lose of the amount invested with probability 0.5).

3.2 Hypotheses

According to the theoretical predictions, we postulate the following hypotheses regarding the use of signals in each strategic environment (H1-H3) and the network modification stage (H4-H6).

- H1. In the BC game the weight assigned to each signal by subjects in their decisions is increasing in the number of players that observe the signal.
- H2. In the CO game the weight assigned to each signal by subjects in their decisions is decreasing in the number of players that observe the signal.
- H3. In the PG game all signals are equally weighted by subjects, regardless how many players observe them.
- H4. In the BC game, subjects choose to create all possible new links and not to sever any link.
- H5. In the CO game, subjects with no links choose not to form any link; subjects with one link choose to sever the existing link and to form links with those players that either have no link or one link; subjects with two links choose to create the missing link and to sever the links with those players that have either two or three links; and subjects with three links choose not to sever any link.
- H6. In the PG game, subjects choose to create all possible new links and not to sever any link.

4 Results

We first analyze how subjects make use of the information (observed signals) in the three games of different strategic nature (BC, CO, PG) and then analyze the stability of networks in each case.

4.1 Use of the information across games

We first analyze behavior in the three games (BC -complements, CO -substitutes, PG -orthogonal), once the network is given, i.e., using the data from period 11 onwards.[19] In Table 1 we report the results of a panel data analysis, in which we regress the choices of agents using the following independent variables: For each $i \in \{1, 2, 3, 4\}$, variable S_i is is the sum of signals that are observed by i agents in the network (i.e., i is the "degree" of the signal); variable *More* is a dummy that takes value 1 if the degree of the agent is strictly larger than the average degree in the network, and 0 otherwise; the variable *Less* is a dummy that takes value 1 if the degree of the agent is strictly smaller than the average degree in the network, and 0 otherwise; and, for each $i \in \{1, 2, 3, 4\}$, the variables $S_i \times More$ and $S_i \times Less$ are interactions.[20] The variables *More* and *Less* allow us to study if there is a behavioral degree (network) effect.[21]

[Insert Table 1]

The first observation is that the constant is very close to 5 and very significant in all the three games. We observe that behavior in the BC game (by subjects with degree equal to the average) follows quite accurately the theoretical predictions. The coefficients of S_1, S_2, S_3 and S_4, (0.566, 0.705, 0.891 and 0.939) are significant at the 1% level and quite close to the equilibrium weights assigned to signals observed by 1, 2, 3 and 4 agents, respectively (0.5, 0.6, 0.75 and 1). This result supports hypothesis H1.

The behavior in the PG game qualitatively follows the flat path associated to the theoretical predictions. In equilibrium all subjects weight equally all the signals and, indeed, we observe that the coefficients associated to signals observed by 1, 2 and 3 subjects are all very similar to each other (around 0.75). However, the signals observed by 4 subjects are more used (coefficient 0.89) than the former ones.

[19] Given the complexity of the game, we use the data once there is some scope for learning. Note that we analize behavior in the corresponding game (BC, CO or PG) aggregating the data of periods when the network is endogneous (rounds 12-22) and the 11 additional rounds where agents could modify the network.

[20] Hence note that the coefficients of S_1, S_2, S_3 and S_4 are, respectively, those applied to signals with "degree" 1, 2, 3, and 4 in symmetric networks (or in cases in which the subject's degree coincides with the average degree of the network).

[21] It allows us to study whether to be more or less informed than the average affects behavior (for instance, if more informed subjects are overconfident).

This suggests a behavioral effect in which subjects differ signals observed by the whole population from signals that are imperfectly observed, while all of them are theoretically equivalent. In all cases the coefficients are significant at the 1% level, but the signals observed by less than 4 players are underweighted with respect to the theoretical prediction (a weight of 1 to all signals). Hence, although there is some qualitative support for hypothesis H3, deviations are observed.

On the other hand, the theory performs quite poorly to predict the outcome of the CO game. In this case, the more observed a signal is, the less used it should be in equilibrium. However, the data shows exactly the opposite pattern: the coefficients of S_1, S_2, S_3 and S_4 are 0.27, 0.71, 0.73 and 0.92, respectively, all significant at the 1% level. Another remarkable fact is the very small value of all the estimated coefficients. While the theoretical predictions suggest a more intense use of all the signals in this game (with weights ranging from 1 -for signals observed by 4 agents- to 2.5 -for signals observed by 1 agent), all the estimated coefficients are below 1. Hence, our data clearly rejects hypothesis H2.

In Table 2 we show the estimates of the variations of the coefficients of S_2, S_3 and S_4 for those players with a degree above the average (with respect to the estimates for players with the average degree). We observe that the general tendency for those (more informed) players is to overweight the signals with respect to those with average degree (overconfidence), as shown by the positive sign of all these estimates but one.[22] In any case, we find that most of these variations are small and not significant. Indeed, the highest coefficients (and the significant ones) are mainly those associated to S_2 and S_3 in the CO game, which make behavior of these more informed players in less contrast to the theoretical predictions (for these players, the increasing pattern in the use of signals with respec to how many players observe them is replaced by a non-monotone one).

[Insert Table 2]

In Table 3 we show the estimates of the variations of the coefficients of S_1, S_2, S_3 and S_4 for those players with a degree below the average (with respect to the estimates for players with the average degree). We observe that the general tendency for those (less informed) players is to underweight the signals with respect to those with average degree (under-confidence), as shown by the negative sign of all these estimates but one.[23] In any case, we find that most of these variations are not significant. Indeed, the significant coefficients are mainly those associated to the variations of S_2, S_3 and S_4 in the BC game (-0.249, -0.273 and -0.181 respectively).

[22] It only hapens in the PG game, in which players with degree above the average weight the signals observed by the whole population less than players with the average degree (but the difference, -0.047, is not significant).

[23] It only hapens in the CO game, in which players with degree below the average weight the signals observed only by 1 player (i.e. by them) more than players with the average degree (but the difference, 0.169, is not significant).

[Insert Table 3]

We now turn our attention to the behavior in the network modification stage.

4.2 Pairwise stability

We start analyzing stability in the BC game. In Table 4, we show the number of best responses selected by subjects in the network modification stage of this game. Each player could select from 0 to 3 best responses (recall that in this stage each player takes 3 decision, regarding each of the potential links she has). In this case, the theoretical prediction points towards the formation/maintenance of any possible link.

[Insert Table 4]

In panel A of the table we study the number of best responses by player's degree (i.e. his number of links). We observe that, in aggregate, with a frequency of 88.18% subjects best responded in all their three decisions regarding network formation. This pattern holds separately for any player's degree. In panels B and C of the table we study separately the best responses associated to forming a new link and those associated to not severing an existing links. In both cases, and for any feasible degree we observe that the majority of the times the mode corresponds to playing the maximum number of best responses. This provides support for hypothesis H4.

In Table 5, we show the results for the network modification stage of the CO game. As shown in Section 2.2 the best responses are more complex in this case than in the other ones and, in particular, they depend on the subject's degree and on the degree of the other player. Depending on the specific case, it can be a best response to create, sever, maintain or not to initiate a link.

[Insert Table 5]

As Panel A of Table 5 shows, the theoretical predictions perform quite poorly to explain the data. It is still the case that, in the aggregate, the most frequent case is that of players choosing three best responses in their linking decisions. However, as compared to the previous game, now this frequency goes down to 37.50% and there is a lot of dispersion.

Given the different kind of best responses available for different degrees, in panels B to E we study separately, for each kind of best response (to create, not to initiate, to sever or to maintain a link, respectively) the number of observed best responses of each kind over the maximum number of available ones.[24] Some patterns seem clear:

[24] For example, the last row of panel B corresponds to individuals with a theoretical best reponse including asking for exactly two new links. Of these cases, 15 times no links were asked, 8 times only 1 link was asked, and 87 times both links were asked.

Subjects do very well performing best responses when this means to ask for new links or to maintain links (panels B and E), but they perform very poorly when the best response requires to sever a link or not to ask for a new one (panels C and D). Hence the data clearly rejects hypothesis H5 and suggest that the behavior in the network formation stage in this game follow a similar pattern than in the former one despite the very different strategic nature.[25]

In Table 6, we show the results for the network modification stage of the PG game. In this case, as it happened in the BC game, the theoretical prediction points towards the formation of any possible link: It is always a best response to create/maintain every link.

[Insert Table 6]

As we can observe, the results are very similar to those observed in Table 4 for the BC game, and they provide support for hypothesis H6.

5 Conclusion

Our experiment reveals that subjects perform quite well in the use of information in games of strategic complements like the BC. As theory predicts the use of a piece of information is increasing in the number of people that observes it and the weights are close to the theoretical predictions. In this game, where the incentives are to create/maintain every possible link, we observe a overwhelming majority of best responses in the network formation stage.

In contrast, the theoretical predictions perform quite poorly in games of strategic complements like the CO, at least with respect to the use of information. In this case, subjects significantly underweight available information in their decisions and, in contrast to the theory, it is not the case that the less a piece of information is observed the more it is used by those agents that see it. In the network formation stage, there is a general tendency to create/maintain links, even when it goes against the theoretical prediction. An explanation of this pattern could be that players react to the suboptimal (posterior) pattern of play in the CO game (cf. Footnote 25).

Finally, in games where agents' strategies are orthogonal, like the PG, we observe that to some extent the behavior in the lab resembles the flat behavior (all pieces of information equally weighted) predicted by the theory, but with a difference: The results suggest a behavioral effect consisting in that those pieces of information observed by the whole population are more weighted than the remaining ones. In the

[25] An explanation can be found in the fact that we find clear deviations from equilibrium play in the subsequent use of the information in the second stage (CO game), in which players significantly underweight all observed signals in their decisions. Thus, a possibility is that in the network modification stage players could be best responding to the (suboptimal) play observed in the CO game. A preliminary analysis suggests that this is the case.

network modification stage (of the same nature than the BC game), in this case we observe a very high frequency of best responses.

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APPENDIX

Experimental Instructions (BG game)

The aim of this experiment is to study how individuals make decisions in certain contexts. The instructions are simple. You first receive the instructions for Part 1 of the experiment, after which you will receive instructions for a second part that is independent of Part 1. If you follow the instructions carefully you will earn a non-negligible amount of money in cash (£) at the end of 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 communication among you is strictly forbidden and will result in an immediate exclusion from the experiment.

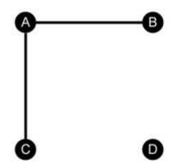
1.- Part 1 of the experiment consists of 22 periods. In each period you will be randomly assigned to a group of 4 participants. In this room, there are 8 participants (including yourself) that are potential members of your group. At the beginning of each period your group of 4 participants is selected at random among these 8 participants, each of them being equally likely to be in your group. You will not know the identities of any of these participants and they will not know yours.

2.- At each period, the computer selects a **network for your group**. The network is **selected from the set of 11 networks depicted in the additional sheet** provided to you, entitled <u>NETWORKS</u>. Note that, in this sheet, each network is identified by a number, from 1 to 11. Each of the 11 networks will be selected twice (that is, in two periods) during Part 1 of the experiment, and the order at which the networks are selected is randomly determined at the beginning of the experiment.

Once the network is selected, you (and the other members of your group) are randomly assigned to a **player position**: **A**, **B**, **C** or **D**, all of them being equally likely. At each period, you will be informed of the selected network (from 1 to 11) and of your player position (you will be player A, B, C or D).

In a network, a <u>link</u> is represented by a line (connection) between two players.

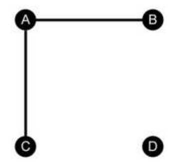
For example, consider **network 3** (depicted in the right)
- **Player A** has <u>two links</u>: he/she is linked to **players B** and **C** (but not linked to **player D**).
- **Player B** has <u>one link</u>: he/she is linked to **player A** (but not linked to **players C** and **D**).
- **Player C** has <u>one link</u>: he/she is linked to **player A** (but not linked to **players B** and **D**).
- **Player D** has <u>no links</u>.



3.- At each period, **the computer randomly selects a signal for each of the four players (A, B, C and D)**. The signal of a player can be **either +1 or –1**, and each of these two possibilities (+1 and –1) is <u>equally likely</u> (that is, each player gets the signal +1 with a probability of 50% and gets the signal –1 with a probability of 50%). The computer selects the signal of each player separately, and independently, meaning that the signals that you and the other players of your group receive are unrelated.
At each period, each player will be informed of his/her own assigned signal for the period, and also of the signals assigned to those players to whom he/she is linked in the network:

If, for example, **network 3** (depicted in the right) is selected in a period, then:

- **Player A** will observe his/her signal and the signals of players B and C.
- **Player B** will observe his/her signal and the signal of player A.
- **Player C** will observe his/her signal and the signal of player A.
- **Player D** will only observe his/her signal.



4.- As explained in the next points, your earnings in a period will depend on the realized value of "**the state of the world**" (a number ***X***). The state of the world X is obtained by adding 5 to the sum of the signals of all players.

Therefore, **the state of the world *X* can take the following values**:

- ***X* = 1**, when all the four signals are –1 ($X = -4 + 5$),
- ***X* = 3**, when three signals are –1 and one signal is +1 ($X = -2 + 5$),
- ***X* = 5,** when two signals are –1 and two signals are +1 ($X = 0 + 5$),
- ***X* = 7,** when one signal is –1 and three signals are +1 ($X = 2 + 5$) and
- ***X* = 9,** when all the four signals are +1 ($X = 4 + 5$).

How accurately a player is informed about X depends on the network (that is, on how many signals he/she observes).

For example, consider again network 3 and suppose that player A is informed of the fact that his/her signal is –1 and that the signals of players B and C are both +1 (recall that in network 3 player A is uninformed of the signal of player D). In such a case, what player A knows about X is that it can be either 5 or 7 (depending on whether the signal of player D is –1 or +1), both with a probability of 50%.

5.- At each round, being informed of the selected network, your player position, your signal and the signals of the players to whom you are linked in the network, you will be asked **to choose a number between 0.00 and 10.00 (with two decimal positions)**.

Your earnings of the round will depend on your decision, on the sum of the decisions of the other three players of your group, and on the state of the world X, as follows:

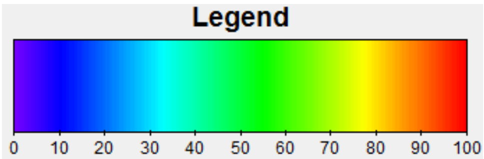
$$100 - \frac{1}{2}\left[(Your\ decision - X)^2 + \left(Your\ decision - \frac{Sum\ of\ the\ others'decisions}{3}\right)^2\right]$$

Given this expression, your earnings result from subtracting *a loss* from 100 ECU. *This loss* is the average of the squared difference between your decision and X and the squared difference between your decision and the average of the other three players' decisions. This means that your earnings are higher the closer that your decision is to X and to the average of the other three players' decisions. We recommend that you take some time to become familiar with the way in which your earnings depend on the various elements of the above expression.

6.- In order to allow you to precisely calculate the earnings that your choices can provide you, at each period, you will be provided with a **payoff calculator** in your screen. To use the payoff calculator, you first need to select a state of the world, by clicking in one of the buttons of the upper part of the screen: I (X=1), II (X=3), III (X=5), IV (X=7) or V (X=9). Immediately, a "**color map**" appears where different colors correspond to different earnings, computed for the chosen value of the state of the world in the expression shown at point 5. You can select coordinates by clicking inside this map. The selected horizontal coordinate represents a value for the sum of the other three players' decision (from 0 to 30) and the selected vertical coordinate represents the value for your decision that you are exploring (from 0 to 10).

Once you click inside the map, in the lower part of the screen you can see the **earnings (resulting payoff)** that you *would* obtain for:
- The selected state of the world (*X*)
- The selected value for sum of the other three players' decision (horizontal coordinate)
- The selected value for your decision (vertical coordinate)

You can explore as many possibilities as you wish in order to familiarize with the payoff scheme, just by clicking in different points of the map (note that you can *fine tune* the selected points by clicking on the appropriate buttons below the map). The colors in the map provide the direction in which earnings vary. The legend below the map provides an approximate idea of the earnings that corresponds to each point in the color map.



At any moment, you can change the state of the world that you want to explore in the payoff calculator by clicking on a new button of the upper part of the screen: I (*X*=1), II (*X*=3), III (*X*=5), IV (*X*=7) or V (*X*=9). When you select another button, a new "color map" appears (the one corresponding to the selected value of *X*). Then you can learn the earnings that correspond to different coordinates (combinations of your choice and the sum of other choices) under such a state of the world.

While you are using the payoff calculator, you will see the signals that you were informed of in the upper-right part of the screen. At any moment, you can also recall the selected network of the period by clicking on the button "Show Network Info" in the lower-right part of the screen.

7.- Once you are ready to take **your decision for the period**, you can introduce it using the scroll bar in your screen (note that you can *fine tune* by clicking on the appropriate buttons below the scroll bar). Then, click on "Confirm decision".

8.- When all players have taken their decision, you will get information about the current period. The information consists of:
- The selected network
- Your player position in the network,
- The sum of the other players' decisions,
- The signals of all the players,
- The state of the world (*X*) and
- Your (period) earnings.

9.- Payoffs. At the end of the experiment, you will be paid the earnings that you achieved in 4 periods, that will be randomly selected across the 22 periods of play (all periods selected will have the same probability). These earnings are transformed to cash at the exchange rate of **40ECU = 1£**. In addition, just by showing up, you will also be paid a fee of **4£**.

Part 2 of the experiment

1.- Part 2 of the experiment consists of 11 periods. In each period you will be randomly assigned to a group of 4 participants. This group is determined randomly at the beginning of the period (among the same 8 participants than in part 1).

2.- As previously, at each period, the computer selects a network for your group from the set of 11 networks depicted in the sheet provided to you in part 1 of the experiment, entitled NETWORKS. Each one of these 11 networks will be selected once (that is, in one period) during part 2 of the experiment, and the order at which the networks are selected is random. The selected network is the **original network** of the period, which may be modified by you and the other members of your group as explained below.

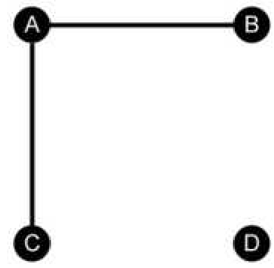
Again, once the network is selected, you (and the other members of your group) are randomly assigned to a **player position**: **A**, **B**, **C** or **D**, all of them being equally likely. At each period, you will be informed of the selected network (from 1 to 11) and of your player position (you will be player A, B, C or D).

3.- Network modification (I). The novelty of part 2 of the experiment is that, prior to being informed of the signals, you and the other players of your group have **the possibility to modify the original network**. Only one link of the network can be modified (that is to say, added to the original network if it was absent, or removed from the network if it was present). The link that can be modified (AB, AC, AD, BC, BD or CD) will be randomly selected by the computer.

The process is as follows. Knowing the original network and their positions, but before knowing which link can be modified, all the four players simultaneously decide whether they consent to modify each one of their links (in case it is the link selected by the computer).

If, for example, **network 3** (depicted in the right) is selected in a period, then

- **Player A** will have to answer YES or NO to the following questions:
  (i) *Do you want the link AB to be removed from the network?*
  (ii) *Do you want the link AC to be removed from the network?*
  (iii) *Do you want the link AD to be added to the network?*
- **Player B** will have to answer YES or NO to the following questions:
  (i) *Do you want the link AB to be removed from the network?*
  (ii) *Do you want the link BC to be added to the network?*
  (iii) *Do you want the link BD to be added to the network?*
- **Player C** will have to answer YES or NO to the following questions:
  (i) *Do you want the link AC to be removed from the network?*
  (ii) *Do you want the link BC to be added to the network?*
  (iii) *Do you want the link CD to be added to the network?*
- **Player D** will have to answer YES or NO to the following questions:
  (i) *Do you want the link AD to be added to the network?*
  (ii) *Do you want the link BD to be added to the network?*
  (iii) *Do you want the link CD to be added to the network?*



4.- Network modification (II). Once all these decisions are made, **the computer randomly selects one link (AB, AC, AD, BC, BD or CD)**, all of them being equally likely**.** The selected link is the only link from the original network that can be modified**.** Whether the link is modified or not depends on the decisions formerly taken by the two players involved. For example, if the selected link is BD, the decisions taken by players B and D determine whether the link is modified or not.

The rules for the network modification are the following: The creation of a new link requires the consent of both players involved, whereas for the removal of a link it suffices the consent of one of the two players involved. This means that the **current network** (resulting from the network modification stage) is determined as follows:

- **If the selected link was absent in the original network**, then:
    - The link is created if both players involved answered YES to the question of *whether they want this particular link to be added to the network*. In such a case, the current network is the original one plus the selected link.
    - If at least one of the players involved answered NO, then the link is not created. In such a case, the current network is equal to the original one.
- **If the selected link was present in the original network**, then:
    - The link is severed if at least one of the two players involved answered YES to the question of *whether they want this particular link to be removed from the network*. In such a case, the current network is the original one minus the selected link.
    - If both players involved answered NO, then the link is not severed. In such a case, the current network is equal to the original one.

The current network will be one of the 64 networks depicted in the new sheet entitled NETWORKS (PART 2) that we have provided to you. These are the initial 11 networks (that are the first 11 networks of this sheet) plus all the possible networks that arise by creating or severing one link from any of the initial networks.

5.- Then, all the four players are informed of:
- The original network.
- The link randomly selected by the computer to be potentially modified.
- Whether there was or was not consent (by the players involved) to modify the selected link.
- The current network.

6.- From that point on, **the current network is the relevant one for the period**. Then, as in part 1 of the experiment, the computer randomly selects a signal (+1 or –1) for each of the four players (A, B, C and D), and the current network determines which signals each player observes. Then, the game proceeds exactly as in part 1 of the experiment.

7.- Payoffs from this part. At the end of the experiment, you will be paid the earnings that you achieved in 2 periods, that will be randomly selected across the 11 periods of play of part 2 (all periods selected will have the same probability). As in Part 1 the exchange rate is: **40 ECU = 1£**.

[These are the instructions for the elicitation of risk attitudes. They were used at the end of all experimental sessions]

Finally, you have the chance to invest your show-up fee. The monetary consequence of your choice will not affect any other participant.

In particular, you can invest any share (from 0% to 100%) of your show-up fee (£4) in a risky option. The chance of success of your investment is 50% (independently of what share you deeded to invest). In case of success, you will receive 2.5 times the amount invested. If case of failure, you will lose the amount you invested. The non invested share of your show-up fee is for you to keep.

Which share of your show up fee (from 0% to 100%) would you like to invest in the risky option?

TABLES AND FIGURES

Table 1. Intensities of use of signals in each game (subjects with degree equal to the average)

	(1) BC game	(2) CO game	(3) PG game
Constant	5.030***	5.020***	5.130***
	(0.035)	(0.109)	(0.090)
S_1	0.566***	0.276	0.700***
	(0.098)	(0.290)	(0.260)
S_2	0.705***	0.712***	0.773***
	(0.050)	(0.150)	(0.134)
S_3	0.891***	0.736***	0.757***
	(.0368)	(0.108)	(0.094)
S_4	0.939***	0.926***	0.895***
	(0.042)	(0.116)	(0.092)
More	0.054	0.357**	0.185
	(0.057)	(0.171)	(0.144)
Less	-0.130**	-0.243	-0.022
	(0.0576)	(0.172)	(0.144)
S_1*Less	-0.024	0.412	-0.176
	(0.126)	(0.367)	(0.315)
S_2*More	0.117*	0.123	-0.155
	(0.066)	(0.199)	(0.172)
S_2*Less	-0.118	-0.117	-0.123
	(0.081)	(0.248)	(0.208)
S_3*More	0.021	0.321**	0.005
	(0.050)	(0.143)	(0.134)
S_3*Less	-0.143*	-0.029	-0.180
	(0.082)	(0.241)	(0.211)
S_4*More	0.006	-0.294	-0.232
	(0.070)	(0.197)	(0.194)
S_4*Less	-0.051	-0.232	-0.301*
	(0.066)	(0.188)	(0.177)

Standard errors in brackets. *, **, *** significant at 10%, 5%, 1% resp.

Table 2. Increases in the weights assigned to signals by subjects with degree above the average (More=1)

	BC game	CO game	PG game
S_2	0.172*	0.480*	0.030
	(0.088)	(0.265)	(0.212)
S_3	0.076	0.678***	0.191
	(0.077)	(0.224)	(0.186)
S_4	0.061	0.063	-0.047
	(0.089)	(0.266)	(0.255)

Standard errors in brackets. *, **, *** significant at 10%, 5%, 1% resp.

Table 3. Increases in the weights assigned to signals by subjects with degree below the average (Less=1)

	BC game	CO game	PG game
S_1	-0.155	0.169	-0.197
	(0.135)	(0.399)	(0.348)
S_2	-0.249**	-0.360	-0.145
	(0.101)	(0.301)	(0.243)
S_3	-0.273***	-0.272	-0.201
	(0.101)	(0.301)	(0.249)
S_4	-0.181**	-0.475*	-0.323
	(0.084)	(0.262)	(0.243)

Standard errors in brackets. *, **, *** significant at 10%, 5%, 1% resp.

Table 4. Number of observed best responses in the network modification stage of the BC game, by degree

A) All best responses (% in brackets)

Degree\#BR	0	1	2	3	Total
0	10	1	1	68	80
	(12.50)	(1.25)	(1.25)	(85.00)	(100.00)
1	6	4	7	123	140
	(4.29)	(2.86)	(5.00)	(87.86)	(100.00)
2	7	3	8	122	140
	(5.00)	(2.14)	(5.71)	(87.14)	(100.00)
3	2	0	3	75	80
	(2.50)	(0.00)	(3.75)	(93.75)	(100.00)
Total	25	8	19	388	440
	(5.68)	(1.82)	(4.32)	(88.18)	(100.00)

B) Cases in which the best response is "ask for a new link" (% in brackets)

Degree\#BR	0	1	2	3	Total
0	10	1	1	68	80
	(12.50)	(1.25)	(1.25)	(85.00)	(100.00)
1	10	6	124		140
	(7.14)	(4.29)	(88.57)		(100.00)
2	14	126			140
	(10.00)	(90.00)			(100.00)

C) Cases in which the best response is "not to sever a link" (% in brackets)

Degree\#BR	0	1	2	3	Total
1	7	133			140
	(5.00)	(95.00)			(100.00)
2	9	3	128		140
	(6.43)	(2.14)	(91.43)		(100.00)
3	2	0	3	75	80
	(2.50)	(0.00)	(3.75)	(93.75)	(100.00)

Table 5. Number of observed best responses in the network modification stage of the CO game

A) All best responses, by degree (% in brackets)

Degree\#BR	0	1	2	3	Total
0	56	6	1	3	80
	(70.00)	(7.50)	(1.25)	(3.75)	(100.00)
1	16	28	89	7	140
	(11.43)	(20.00)	(63.57)	(5.00)	(100.00)
2	4	26	33	77	140
	(2.86)	(18.57)	(23.57)	(55.00)	(100.00)
3	7	2	5	66	80
	(8.75)	(2.50)	(6.25)	(82.50)	(100.00)
Total	83	62	130	165	440
	(18.86)	(14.09)	(29.55)	(37.50)	(100.00)

B) Number of realized best responses when the BR is "ask for a new link", by maximal number of such best responses (% in brackets; note that here degree 3 is omitted)

# of BR of this kind \ # realized BR	0	1	2	Total
1	29	131		160
	(18.13)	(81.88)		(100.00)
2	15	8	87	110
	(13.64)	(7.27)	(79.09)	(100.00)

C) Number of realized best responses when the BR is "not to ask for a new link", by maximal number of such best responses (% in brackets; note that here degree 3 is omitted)

# of BR of this kind \ # realized BR	0	1	2	3	Total
1	16	4			20
	(80.00)	(20.00)			(100.00)
2	8	0	2		10
	(80.00)	(0.00)	(20.00)		(100.00)
3	56	6	3	15	80
	(70.00)	(7.50)	(3.75)	(18.75)	(100.00)

D) Number of realized best responses when the BR is "sever a link", by maximal number of such best responses (% in brackets; note that here degree 0 is omitted)

# of BR of this kind \ # realized BR	0	1	2	Total
1	134	26		160
	(83.75)	(16.25)		(100.00)
2	15	3	2	20
	(75.00)	(15.00)	(10.00)	(100.00)

E) Number of realized best responses when the BR is "not to sever a link", by maximal number of such best responses (% in brackets; note that here degree 0 is omitted)

# of BR of this kind \ # realized BR	0	1	2	3	Total
1	5	15			20
	(25.00)	(75.00)			(100.00)
2	6	7	87		100
	(6.00)	(7.00)	(87.00)		(100.00)
3	7	2	5	66	80
	(8.75)	(2.50)	(6.25)	(82.50)	(100.00)

Table 6. Number of observed best responses in the network modification stage of the PG game, by degree

A) All best responses

Degree\#BR	0	1	2	3	Total
0	2	2	6	70	80
	(2.50)	(2.50)	(7.50)	(87.50)	(100.00)
1	0	7	10	123	140
	(0.00)	(5.00)	(7.14)	(87.86)	(100.00)
2	0	4	12	124	140
	(0.00)	(2.86)	(8.57)	(88.57)	(100.00)
3	1	0	3	76	80
	(1.25)	(0.00)	(3.75)	(95.00)	(100.00)
Total	3	13	31	393	440
	(0.68)	(2.95)	(7.05)	(89.32)	(100.00)

B) Cases in which the best response is "ask for a new link"

Degree\#BR	0	1	2	3	Total
0	2	2	1	68	80
	(2.50)	(2.50)	(1.25)	(85.00)	(100.00)
1	3	13	124		140
	(2.14)	(9.29)	(88.57)		(100.00)
2	5	135			140
	(3.57)	(96.43)			(100.00)

C) Cases in which the best response is "not to sever a link"

Degree\#BR	0	1	2	3	Total
1	5	135			140
	(3.57)	(96.43)			(100.00)
2	3	9	128		140
	(2.14)	(6.43)	(91.43)		(100.00)
3	1	0	3	76	80
	(1.25)	(0.00)	(3.75)	(95.00)	(100.00)

Figure 1: Networks

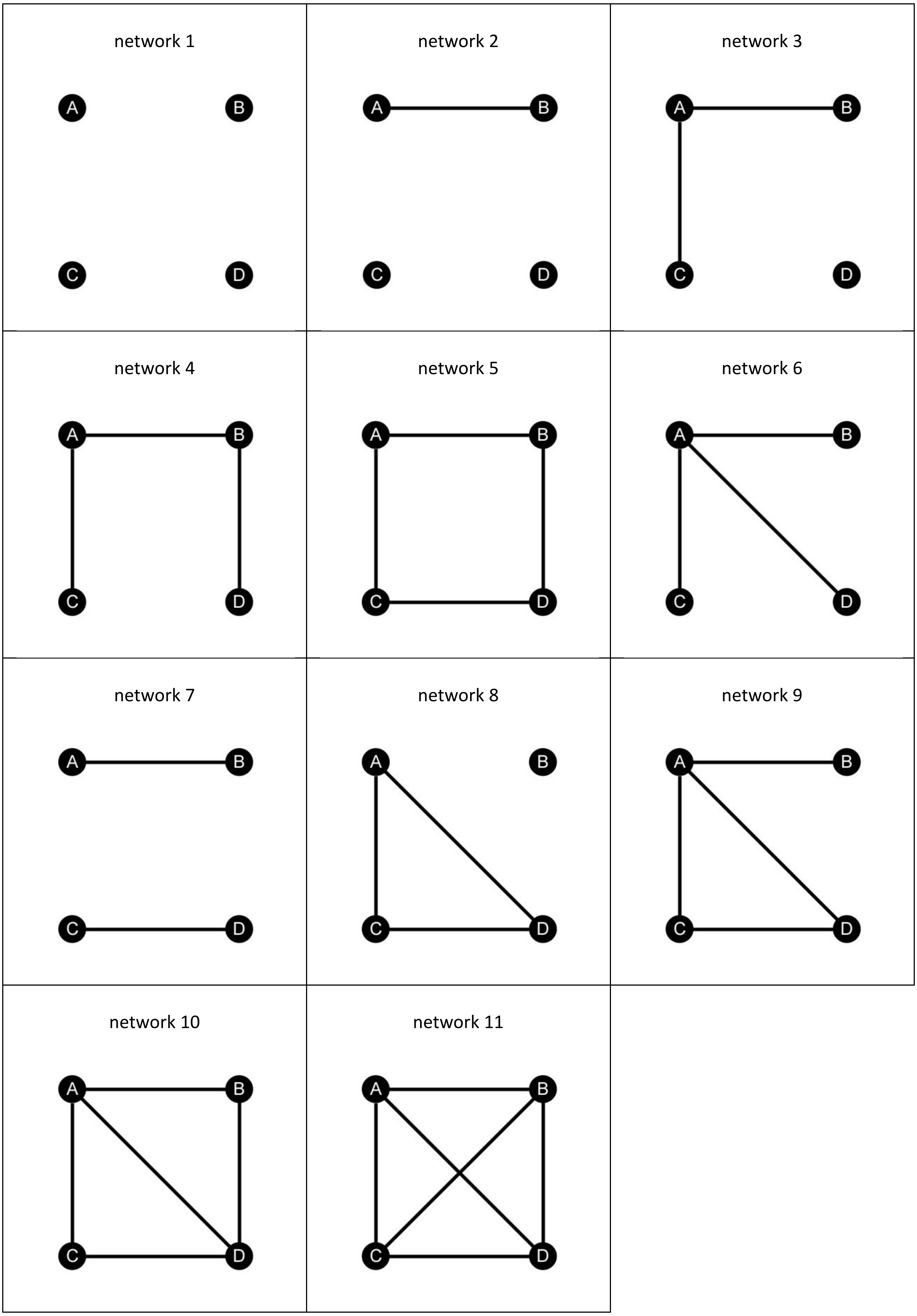


Figure 2: Potential networks in Part 2 of the experiment