Are Individuals Profit Maximising in Network Formation? Some Experimental Evidence*

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Abstract

We run a computerised experiment of network formation, where all connections are beneficial and only direct links are costly. The game-theoretic basis for the experiment is the model of Goyal and Joshi (2004) where players simultaneously submit link proposals and a connection is made only when both players involved agree. We provide an analysis both at the macro and the micro level. From a macro perspective, in accordance with the exsisting literature, we find that convergence to the stable network architecture is made problematic by the presence of multiple equilibria. At the level of the individual, we estimate the probability of a link through a probit model that includes both best-response and behavioural variables. We find strong evidence that both play a role in network formation.

Keywords: network formation, experiments, social interaction

JEL classification: C91, C92, L140

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1 Introduction

The role of social networks in shaping economic outcomes has received increasing attention in recent years. Network externalities have been extensively studied both in industrial organisations and, more recently, within the theory of social capital and development economics. Most of this literature however takes the

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structure of the social network as given and analyses the consequences of network externalities on outcomes.

In this paper we take the view that social linkages are often voluntarily formed and hence the architecture and membership of social networks are part of the economic outcome that one aims to explain. The literature on endogenous network formation stems from two seminal contributions by Jackson and Wolinsky [19] and Bala and Goyal [1]. Both papers follow a game-theoretic approach to the formation of social ties where the main idea is that players earn benefits from being connected both directly and indirectly to other players and bear costs for maintaining direct links.

The process of forming a network is extremely complex. The main difference between a network and a series of bilateral interactions lies in the value that accrues to agents though indirect connections: any two economic agents who have to decide whether to establish a social tie take into account not only their own characteristics and the characteristics of the prospective partner, but also the position of the prospective partner in the social network.

Given that the process of network formation is so complex, predicted outcomes are typically not unique. Even for those cases where the stable network architecture is unique (for example, the star network in information communication models a la Bala and Goyal or Jackson and Wolinsky), the coordination problem of which agent occupies which position in the network still remains.

In presence of multiplicity of equilibria, agents playing simultaneously face strategic uncertainty. The way in which agents cope with such uncertainty might result in some network architectures being more likely to achieve than others. We believe that interesting questions to address from an experimental perspective are the following: are there network configurations which are more likely to be achieved?; within such architecture, which role is played by which agent?; do subjects play best response strategies or do they also condition their actions on elements which do not affect directly their payoffs but help towards coordination?

The few existing experimental works on this topic have all highlighted the difficulty in obtaining convergence to a stable network architecture as predicted by the theory. More in detail, convergence is problematic in those framework where the prediction for the stable network is the center-sponsored star (Falk and Kosfeld [13], Berninghaus et al [3]); in those settings where the stable network architecture is the wheel convergence is more easily achieved (Callander and Plott [4], and Falk and Kosfeld [13]). Falk and Kosfeld [13] and Berninghaus et al [3] highlight the role of complexity and inequality aversion in preventing convergence to network architectures that are not "fairness compatible": they argue that a network architecture, such as the star network, which results in an uneven distribution of payoffs is less likely to be observed in the lab. Deck and Johnson [8] avoid coordination failures by introducing heterogeneity among agents and by constructing a framework where the stable network is indeed unique. Finally, Vanin [25] attempts to facilitate coordination by allowing cooperation and by preventing renegotiation among (skilled) subjects: he finds that, even under such favourable conditions, coordination is not achieved in all cases.

In this paper we adopt the notion of pairwise stable Nash networks, as in Goyal and Joshi [15] and we use a framework where any minimally connected network is a stable architecture according to the theory. This on the one hand potentially exacerbates the coordination problems due to multiplicity, but on the other hand mitigates the concerns as in [13] and [3] about the fact that convergence to the star network is prevented because of fairness considerations.

We run a large scale experiment involving a total of 90 subjects in groups of 6. Despite the severe multiplicity inherent to the model, we find some evidence of convergence to minimally connected networks, very often aided by the focalness provided by the alphabetical ordering of the subjects' labelling. We confirm these findings through an econometric analysis at the individual level where we cannot reject the hypothesis that both best response behaviour and framing effects (as provided by proximity in the graph and alphabetical order) matters in determining subjects' choices on link formation.

The paper is developed as follows. Section 2 contains the literature review, both theoretic and experimental. The experimental design is described in section 3. Section 4 presents the results and section 5 concludes the paper. The instructions, both in Italian and in their English translation, can be found in the appendix. The software utilised for the experiment is available from the authors upon request.

2 Related Literature

2.1 Theory

Seminal papers on the theory of network formation are Jackson and Wolinsky [19] and Bala and Goyal [1]. The two papers differ in the assumption underlying the process if network formation: Jackson and Wolinsky [19] assume that the process of network formation is two-sided: it takes two individuals to agree in order to form a link. Both individuals involved in a social tie bear the cost of their direct link and they both enjoy the benefits that come from it. In Bala and Goyal [1] the process of network formation is one-sided: players can unilaterally initiate links to any other player. The cost of the connection is maintained only by the player who initiates the link. As far as the benefits are concerned, Bala and Goyal distinguish between a one-way flow model and a two-way flow model. In the former, only the player who initiates the link enjoys the benefit from link formation; in the latter, both players receive the (same) benefit from network formation, even if only one of the two bears the cost.

The main advantage of assuming that links are initiated unilaterally, as in Bala and Goyal, is that the process of network formation can be formulated as a non-cooperative game where players' strategies are given by a tuple of 0's and 1's:

$$g_i = \begin{pmatrix} g_{i,1} & g_{i,2} & \dots & g_{i,n-1} & g_{i,n} \end{pmatrix}$$

and the binary variable $g_{i,j} \in \{0,1\}$ represents whether player i is linked to player j ($g_{ij} = 1$) or not ($g_{ij} = 0$). In a static setting, an appropriate solution concept for this game is the Nash equilibrium: a Nash network is the graph induced by a strategy profile such that each players' strategy is a best response to all other players' strategies.

The main advantage of the Jackson and Wolinksy's approach is that it captures the idea - which is realistic in many economic applications - that both agents have to agree in order for a link to be formed (and for information to be exchanged). A clear implication of this approach is that the process of network formation cannot be modelled as a purely non-cooperative game and the Nash equilibrium is no longer an appropriate solution concept. Jackson and Wolinsky introduce the notion of pairwise stability: a pairwise stable network is such that every link in the network is mutually agreed by the two agents involved and such that there is no other potential link that any two players would both agree to form. Unlike a Nash network, a pairwise stable network is robust to some, but not all, unilateral deviations (a single player is not allowed to delete more links at once, for example, nor to delete one link and at the same time initiate a new link with another player); on the other hand, a pairwise stable network is also robust to deviations which are not unilateral, in that they involve two players coming together to form a new link[1].

In more recent work Goyal and Joshi [15] have adopted an intermediate approach, by borrowing the notion of pairwise stability as a refinement of a Nash equilibrium. They consider a non-cooperative game, where players' strategies are vectors of intended links. As Bala and Goyal and unlike Jackson and Wolinksy, they allow for any unilateral deviation, so that each player can revise his vector of intended links in more than one entry at a time. As Jackson and Wolinksy and unlike Bala and Goyal, they assume that a link between any two players is formed if and only if both players agree on forming that link. Goyal and Joshi call a pairwise stable Nash network a Nash network that has the additional property that there is no potential link between any two players that are not connected, that both players would like to initiate.

Despite the different assumptions on the process of network formation, the models that the literature has proposed for two-way information flow predict very similar stable network architectures. When the cost of direct links is sufficiently high, there are no incentives to network formation and the equilibrium network is empty. When the cost of maintaining a link is such that network formation is profitable, the equilibrium network is minimally connected, i.e. there is one and only one path that connects any two individuals. An example of minimally connected network is the star: there is a central agent (the hub) who is connected to any other agent in the population (the spokes) and there is no other link.

If there is no decay in the quality of information as it flows through the graph, a minimally connected network is clearly a rather efficient way of organising information transmission: there are no redundant links. However there is a

[1] However more complicated multilateral deviations are not taken into account, so that the pairwise stability approach is indeed intermediate between cooperative and non-cooperative game theory.

tension between stability and efficiency. Link formation involves positive externalities: by linking to others, each agent also increases the payoff of his existing neighbours. As a result, underconnectedness might arise in equilibrium: there are levels of cost and benefits of link formation, such that the network that maximises aggregate value is minimally connected, but the only equilibrium network is the empty graph.

2.2 Experiments

Extensive literature exists on experiments that aim at testing individual behaviour for subjects who interact according to exogenously given networks. For a thorough review, see Kosfeld [22].

This paper contributes to the more tight literature on experiments on network formation. Recent economic experiments that examine endogenous network formation are Deck and Johnson [8], Callander and Plott [4], Kosfeld and Falk [13], Vanin [25], Berninghaus, Ott and Vogt [3], Corbae and Duffy [6].

Most of these studies build on the theoretical framework provided by Bala and Goyal [1]. In particular Callander and Plott [4] present an "exploratory" experiment aimed at discovering the evolution of information networks under different treatments. In the first treatment the experiment involves six subjects who interact repeatedly for a random number of rounds between 10 and 20. Each experimental subject can choose to link unilaterally to any of the others according to the Bala and Goyal [1] one-way flow model, where the circle is the unique efficient and strict Nash network. The second treatment involves different costs for different subjects leading to a different prediction for the prevailing network architecture. They find that networks often converge to the theoretical predictions under both treatments. In particular under the first treatment the prevailing network is a clockwise focal circle, which could result from both a best-response behaviour and a simple strategic behaviour based on focalness. They also detect forward looking behaviour that produces dynamic strategies where agents appear to "trade off short term profits in order to signal to, and teach, other agents the strategies required for long term profit maximisation" ([4]).

In this paper we consider a network formation process that differs from [4] in that we require links to be mutually agreed (and mutually sponsored) by each pair of agents involved. We also differ from [4] in the way in which convergence is claimed: in the case subjects form the same network for three consecutive rounds, Callander and Plott assume convergence to that particular network; in this paper subjects are allowed to change their choices of links in any round until the end of the session. On the other hand, the experimental design here is similar to theirs in that we also have 6 subjects by session and we adopt a random stopping rule (exceeding the 15th round).

Falk and Kosfeld [13] test both the one-way and the two-way flow model by Bala and Goyal [1], under several treatments. In all treatments they consider four subjects who decide simultaneously and independently. Their main finding is that convergence to the strict Nash network is obtained in the one-way flow model; however it is never achieved in the two-way flow model. They attribute this finding to the difficulty to coordinate in the two-way flow model, where the theoretical prediction is a center-sponsored star. Also, they suggest that fairness considerations might drive the result. In fact if subjects dislike unequal payoffs, they might be reluctant to form this kind of network unless some form of compensation is present.

Berninghaus et al [3] test a modified version of the two-way flow model by Bala and Goyal [1]. They run an experiment with 6 subjects and 15 rounds per session. They distinguish between active and passive connections and assume that each player obtains a benefit from his direct active connections and from all those indirect connections obtained through active links. In this modified framework the unique strict Nash network is the periphery sponsored star. They find a higher convergence rate to the Nash network than Kosfeld and Falk [13] and attribute this to the fact that the coordination problem is less severe in their framework and that there is less inequality in the payoffs of a periphery sponsored star than in a center sponsored star. They also find that an important determinant of network formation is played by agents that behave "inactively": less active groups earn higher payoff than active groups. This is due to the fact that "first they stop switching strategies after some rounds elapsed. Second, they open only few active links and try to fix one group member to serve as the potential center player rather early" (in [3]). Reference points in profits as benchmark on activity could be also a possible explanation of inactivity behaviours.

In this paper links are mutually agreed and mutually sponsored, so that there is less free-riding compared to the framework that both Falk and Kosfeld and Berninghaus et al. analyse. Moreover the theoretical prediction for our setup is any minimally connected graph, including - but not exclusively - the star network. As a result equilibrium payoffs are less unequal and fairness considerations should therefore be less important. As in [3] we find that less active groups are more likely to converge to a stable graph.

The network formation process in this paper is closer to one adopted by Deck and Johnson [8], Corbae and Duffy [6] and Vanin [25], who both test versions of the connections model by Jackson and Wolinsky [19], where links have to be mutually agreed. In particular, Deck and Jonhson [8] introduce the spatial cost topology of Johnson and Gilles [20] in the connections model by [19], where players are located on a line and the cost for a direct connection between two players is increasing in the distance between them. The parametrization that they adopt is such that there is a unique stable network for each treatment, so that coordination problems due to multiplicity of equilibria are avoided.

The focus of the paper by Corbae and Duffy [6] is not primarily on the network formation game, but rather on the comparison between the behaviour in a coordination game that subjects play when exogenously matched as opposed to matched with their endogenously chosen neighbours. The experimental design for the network formation game is similar to the one adopted here, even if made slightly less complex by the fact that it is based on groups of 4 rather than 6 participants. Some of their findings are replicated here: for example we also detect some learning in the fact that the ratio between actual and proposed links is increasing over time. However, given that the focus of their paper is on a different issue, they do not proceed to any econometric analysis of the determinants of individual behaviour.

Finally, Vanin [25] runs a pilot of the experimental test of both the connections and the co-author model by Jackson and Wolinsky [19], using 4 skilled graduate students who were allowed to cooperate throughout the experimental sessions. He observes that even under such favourable conditions, convergence to the stable network architecture is problematic and is obtained, but not in all cases.

3 The Experimental Design

The experiment involved 90 first year Economics and Law students from LUISS University in Rome. At the beginning of each experimental session, written instructions were distributed and read aloud by the experimenters. Subjects had then the opportunity to ask questions about their task in the experiment and the experimental sessions started only upon reassurance by the experimenters that both the instructions and the incentive structure had been well understood by the subjects[2]. After each experimental session, we asked for written (and anonymous) comments and feedback from the experimental subjects. Most of them gave feedback that suggest that they had fully understood the rules of the game and had some clear ideas on how to play in order to maximise their profits.

Subjects were paid immediately and in cash after the experiment, using a rate of conversion of their profits of 10% of the profits achieved in the overall session, in Euros.

We run 15 computerised experimental sessions, with 6 participants, each labelled A, B, C, D, E and F. Each experimental session consisted of a minimum of 15 rounds. We used a random stopping rule to determine the end of each session: participants were advised of the minimum number of rounds and that, after the end of round 15 (and of each rounds after that), a lottery administered by the computer would decide whether there was going to be another round or not. The probability of new rounds, after round 15, was fixed at 50%. The lottery was visualised on participants' screens as two flashing buttons, one red (with a NO sign) and one green (with a YES sign). At the end of each round, starting from the end of round 15, the two buttons would flash intermittently: if this ended with the red button being lit, a message box would signal that the session was over; if this ended with the green button being lit, a message box would signal that a new round had started.

In each round participants were given the opportunity to submit a new vector of intended links OR to maintain the previous one (inactivity was allowed). The number of links that each participant could suggest had to be less or equal to the maximum number of links that their current endowment could afford. A

[2] See the appendix for the instructions in Italian and their English translation.

message box would advise them whenever the budget constraint was binding. All relevant parameters (i.e. the initial endowment, the cost of each direct link and the revenue generated by each node to which the participant is connected through the realised graph) were equal across all participants. At any time the screen of each of the participants showed unitary costs and benefits to link formation, current endowment, past wins and losses and current graph of overall existing links. The screen of experimental subject A is depicted in figure 1.

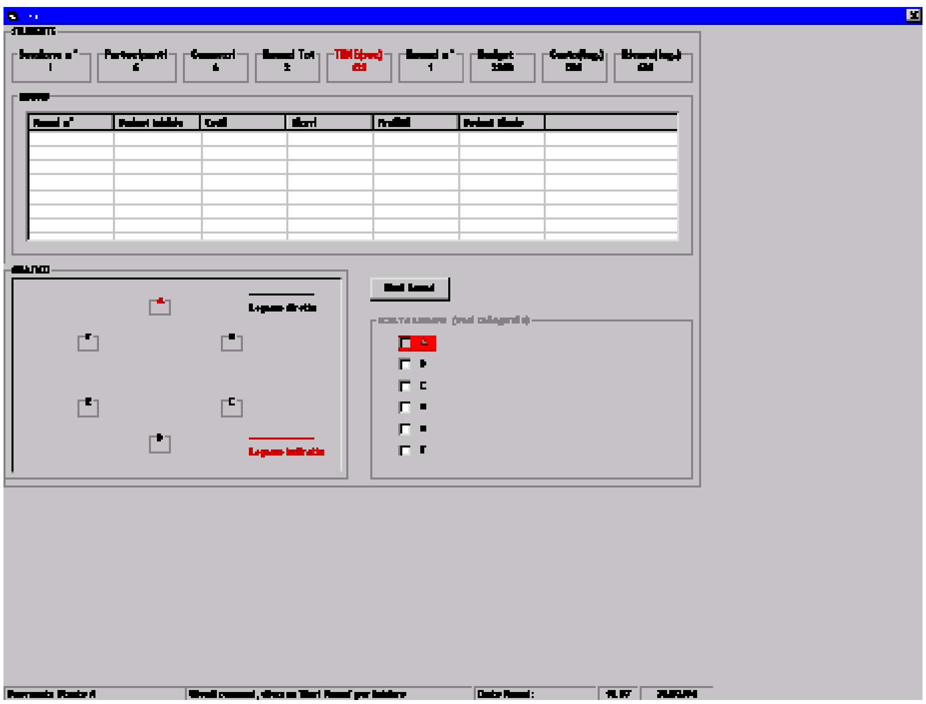


Figure 1

We run 3 different treatments, with parameters as follows:

	Participants	Endowment	Cost	Revenue
Treatment 1 (sessions 1 - 6)	6	500	90	100
Treatment 2 (sessions 7 - 12)	6	500	120	100
Treatment 3 (sessions 13 - 14)	6	500	220	100

In treatment 1 the budget constraint never binds. In treatments 2 and 3 the budget constraint binds in the first round (participants can suggest a maximum of 4 links and 2 links respectively in treatments 2 and 3), and may clearly bind, and more severely, at any time in subsequent rounds.

4 Results

In our analysis of the experimental results we focused on the outcomes of the first 15 rounds in each session, even when the random stopping rule adopted allowed for further rounds. This was done in order to obtain a more meaningful comparison between the outcomes of alternative sessions.

We distinguish between two different levels of analysis: macro and micro aspects. In the macro analysis we mainly look at the overall resulting network of established links, and at its evolution over time. The number of potential network configurations with 6 agents is more than one million (1.073.741.824): in our macro analysis we focus on whether there is any particular network architecture, among the very many that are possible, that emerges as stable in our experimental sessions and, if it does, on how it compares with the one predicted by the theory. When we move to consider the micro aspects we mainly focus on an analysis of the determinants of individual behaviour regarding the proposals of links. In particular we estimate through a probit model the likelihood of link proposals as a function of both best response determinants and behavioural (mainly framing) factors.

We know from the theory that a rational (best response) behaviour in this setting would require individuals to always delete any direct link they may have with any other subject to whom they are at the same time connected indirectly, through other subjects. Moreover, under parameter set 1, a best response behaviour would require subjects to propose a link to any other individual to whom they are not (indirectly) connected.

Under parameter sets 2 and 3 the theoretical assumption of myopic behaviour becomes crucial. The only stable network is the empty graph (with no links ever being proposed) if agents act myopically. In fact, if the cost of forming a link is higher than the benefits obtained by a single connection, then proposing a link to an isolated node results in negative profits. If, on the other hand, agents are forward looking, then they might anticipate that other players might also follow their lead and form ties: if this happens then by supporting the cost of one or two direct connections, each of the players might indeed receive the benefits that result from more than two (direct and indirect) connections. Under treatment 2 the minimum number of connections that one needs to achieve in order to find it worthwhile to invest in two direct links is three: this yields a strictly positive profit ($\geq 3 \times 100 - 2 \times 120 = 60$). Under treatment 3 the only possibility of achieving strictly positive profits is by making 5 connections through a maximum of 2 links ($5 \times 100 - 2 \times 220 = 60$). The star, for example, is not viable under treatments 2 and 3: the hub would incur in a loss of 100 (600) under treatment 2 (treatment 3). The chain, on the other hand, is viable under both treatments, with each of the agents making strictly positive profits. However a chain can only be sustained in equilibrium by players who are sufficiently forward looking. If agents act myopically there would be no incentive for the second and the last but one agent in the chain to maintain a link respectively to the first and the last agent in the chain: if, for example, the second agent in the chain deletes his link to the first agent, his payoff increases from $500 - 240 = 260$ to $400 - 120 = 280$

under treatment 2 and from $500-440=60$ to $400-220=180$ under treatment 3. If agents are forward looking, then in an infinitely repeated game (here the game is finite, but agents are uncertain about the terminal date), the chain might be stable. Under treatment 2, the second player in the chain will know that if he deviates in any particular round, he increases his payoff by 20 (from 260 to 280), but then faces a payoff of zero for the rest of the (uncertain) duration of the game. Deviating will not be profitable for sufficiently forward looking players. Under treatment 3, the stability of the chain is more problematic: the increase in the payoff from deviating is in fact very high. Only extremely patient players would not deviate under treatment 3.

4.1 Macro Aspects

Tables 1a and 1b show the number of proposals between any two experimental subjects in each of the sessions and over the 15 rounds. Table 2 shows the average number of proposals in each session: on average experimental subjects have made 2.64 proposals per round in sessions 1-6 and 2.33 proposals per round in sessions 7-12[3]. The lower number of proposals in sessions 7-12 is certainly due to the fact that direct links are more expensive under the second parameter set.

Session 1

i, j	A	B	C	D	E	F
A		15	2	10	6	6
B	14		13	5	2	6
C	1	14		8	10	6
D	9	11	8		11	10
E	11	2	12	6		14
F	10	2	5	1	8	

Session 2

i, j	A	B	C	D	E	F
A		4	13	13	9	4
B	3		4	9	3	11
C	10	6		6	4	8
D	12	7	4		4	5
E	7	11	6	11		11
F	9	8	11	8	10	

Session 3

i, j	A	B	C	D	E	F
A		3	15	6	8	11
B	9		15	6	4	4
C	5	16		6	6	16
D	11	2	12		14	4
E	3	5	7	11		11
F	12	3	16	8	15	

Session 4

i, j	A	B	C	D	E	F
A		11	6	15	7	5
B	14		13	8	7	4
C	12	12		9	9	9
D	15	0	12		12	4
E	3	6	2	10		14
F	14	12	11	10	8	

Session 5

i, j	A	B	C	D	E	F
A		6	6	5	2	5
B	6		9	9	4	5
C	6	5		2	3	4
D	11	3	7		5	10
E	8	9	8	4		10
F	8	8	15	9	8	

Session 6

i, j	A	B	C	D	E	F
A		11	7	9	10	9
B	15		13	6	9	5
C	9	10		8	9	0
D	6	3	6		7	5
E	9	7	7	7		10
F	11	3	2	0	5	

Table 1a - Number of proposals of *i to j*

[3] The data for the control sessions 13-15 are omitted here because not particularly meaningful. In each of the control sessions under treatment 3 very few proposals were made and only in the first few rounds. No proposals were made at all in the later rounds of each session.

Session 7

i, j	A	B	C	D	E	F
A		14	8	13	9	8
B	13		4	3	0	12
C	5	9		6	5	4
D	13	4	1		6	4
E	6	3	1	8		15
F	5	13	6	4	13	

Session 8

i, j	A	B	C	D	E	F
A		10	13	10	11	13
B	5		12	2	4	12
C	3	11		5	7	4
D	6	7	7		8	7
E	6	12	10	3		14
F	0	10	0	2	11	

Session 9

i, j	A	B	C	D	E	F
A		4	0	13	0	14
B	5		8	6	1	2
C	1	7		15	0	1
D	14	12	15		2	2
E	2	1	1	4		15
F	14	0	1	0	15	

Session 10

i, j	A	B	C	D	E	F
A		12	0	3	0	15
B	11		15	8	3	5
C	2	14		14	0	5
D	6	5	12		7	6
E	9	2	1	11		9
F	15	0	0	1	5	

Session 11

i, j	A	B	C	D	E	F
A		10	12	14	13	15
B	7		7	10	9	11
C	9	13		13	5	3
D	6	4	9		4	9
E	12	7	2	5		11
F	14	11	1	11	7	

Session 12

i, j	A	B	C	D	E	F
A		15	2	3	1	15
B	14		12	0	1	4
C	1	13		10	4	5
D	1	1	10		10	3
E	1	1	0	14		14
F	9	3	5	0	13	

Tab 1b - Number of proposals from *i to j*

Session	Proposals	Proposals per round
1	39.67	2.64
2	38.50	2.57
3	44.00	2.93
4	45.67	3.04
5	33.33	2.22
6	36.33	2.42
AVG	39.60	2.64
7	35.83	2.39
8	37.50	2.50
9	29.17	1.94
10	32.67	2.18
11	44.00	2.93
12	30.83	2.06
AVG	35.00	2.33

Tab 2 - Average number of proposals per session

Table 3 shows the total number of established links (matched proposals) per experimental session. The average number of links in sessions 1-6 was 69.67, or 4.64 links per round; the average number of links in sessions 7-12 was 71.67, or 4.78 links per round; the average number of links in the control sessions 13-15 is 14, i.e. 0.93 per round. As expected, there is very little link formation in the control sessions. Moreover, interestingly, the average number of established links under treatment 2 is not significantly different from the average number of established links under treatment 1 (in fact, if anything, the former is higher than the latter).

	1	2	3	4	5	6	AVG	7	8	9	10	11	12	AVG	13	14	15	AVG
AB	14	2	1	11	4	11	7.17	12	2	2	8	5	14	7.17	3	3	3	3
BC	13	4	15	10	4	10	9.33	2	9	7	14	6	12	8.33	1	1	2	1.33
CD	4	4	4	8	1	6	4.50	1	3	15	12	8	10	8.17	2	0	4	2.00
DE	5	2	10	7	1	3	4.67	5	2	0	6	2	10	4.17	1	1	4	2.00
EF	7	9	11	8	6	3	7.33	12	11	15	2	6	13	9.83	1	1	4	2.00
AF	2	3	8	5	4	7	4.83	1	0	13	15	14	9	8.67	0	1	5	2.00
AC	0	9	4	5	2	7	4.50	2	3	0	0	7	1	2.17	0	0	2	0.67
BD	3	5	0	0	0	1	1.50	2	1	6	5	1	0	2.50	0	0	0	0.00
CE	9	3	2	0	1	4	3.17	0	4	0	0	2	0	1.00	0	0	0	0.00
DF	0	1	3	1	7	0	2.00	1	1	0	1	8	0	1.83	0	0	1	0.33
BF	1	5	0	1	3	0	1.67	11	9	0	0	8	3	5.17	0	0	0	0.00
AD	6	11	4	15	4	3	7.17	11	5	12	2	5	1	6.00	0	0	0	0.00
AE	5	7	3	3	0	7	4.17	4	6	0	0	12	0	3.67	0	0	0	0.00
BE	0	1	0	2	2	4	1.50	0	4	0	0	6	1	1.83	0	0	2	0.67
CF	3	7	16	7	4	0	6.17	1	0	1	0	0	5	1.17	0	0	0	0.00

Table 3 - Number of links by session.

In table 4 we show the number of direct links and total connections (both direct and indirect links) achieved by each of the experimental subjects in each of the sessions[4], on average; we also compute the ratio between total connections and direct links. Such a ratio captures an important feature of the network architecture: the larger its value, the larger the number of the agents that the experimental subject has managed to reach indirectly. The smallest value for this ratio is 1 (no other agent is accessed indirectly: the subject has to bear the entire cost of his/her connections); the largest value for this ratio is 5 (the subject is connected to the five others, through a single direct link).

In sessions 1-6 we find that on average each subject has established 3.3 connections through 1.53 direct links: as a result, for each (costly) direct link, subjects have enjoyed the benefits of 2.16 connections on average. The statistics are very similar for sessions 7-12.

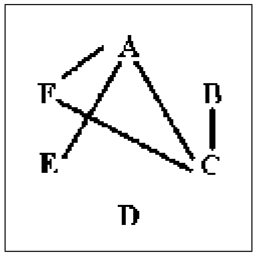
As an example of treatment 1 (sessions 1-6), we show below the macro outcome of experimental session 3. The graph presented for each round displays the actual links formed and it is the same diagram that experimental subjects would have seen on their screens, before making their decision on proposals of links for the following round. We notice that there is a tendency to establish a minimally connected graph. This typically occurs through the formation of repeated links. For example the link between C and F is always active (for 15 rounds). Also, the links between C and B, D and E, and E and F are very frequent (respectively for 14, 9 and 10 rounds).

[4] The data for the control sessions is omitted here, but is not particularly meaningful.

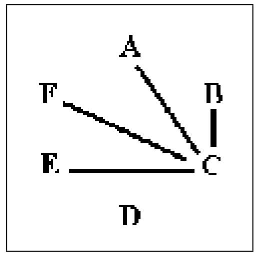
Ses.	Subject	Connections	Links	Ratio	Ses.	Subject	Connections	Links	Ratio
1	A	3.93	1.87	2.11	7	A	3.07	2.00	1.53
1	B	4.13	2.20	1.88	7	B	3.40	1.73	1.96
1	C	3.93	2.00	1.97	7	C	1.20	0.40	3.00
1	D	3.27	1.27	2.58	7	D	3.33	1.33	250
1	E	3.87	1.87	2.07	7	E	2.87	1.33	215
1	F	3.27	1.07	3.06	7	F	3.33	1.67	200
2	A	3.60	2.13	1.69	8	A	2.00	1.07	1.88
2	B	3.13	1.13	2.76	8	B	2.73	1.67	1.64
2	C	3.47	1.80	1.93	8	C	2.40	1.27	1.89
2	D	3.60	1.53	2.35	8	D	2.13	0.80	267
2	E	3.47	1.47	2.36	8	E	3.33	1.80	1.85
2	F	3.13	1.67	1.88	8	F	3.13	1.40	224
3	A	3.81	1.13	3.39	9	A	4.07	1.80	226
3	B	4.31	1.00	4.31	9	B	4.07	1.00	4.07
3	C	4.44	2.56	1.73	9	C	4.33	1.53	283
3	D	3.44	1.31	2.62	9	D	4.33	2.20	1.97
3	E	4.31	1.56	2.76	9	E	4.20	1.00	4.20
3	F	4.44	2.44	1.82	9	F	4.20	1.93	217
4	A	4.33	2.53	1.71	10	A	3.40	1.67	204
4	B	3.80	1.60	2.38	10	B	3.73	1.87	200
4	C	4.00	2.00	2.00	10	C	3.73	1.73	215
4	D	4.20	2.07	2.03	10	D	3.73	1.80	207
4	E	3.73	1.47	2.55	10	E	2.00	0.53	3.75
4	F	3.53	1.47	2.41	10	F	3.40	1.20	283
5	A	1.56	0.88	1.79	11	A	4.27	2.87	1.49
5	B	1.25	0.75	1.67	11	B	3.40	1.73	1.96
5	C	1.00	0.69	1.45	11	C	3.73	1.53	243
5	D	1.25	0.75	1.67	11	D	4.00	1.60	250
5	E	1.06	0.63	1.70	11	E	3.67	2.00	1.83
5	F	1.63	1.44	1.13	11	F	4.27	2.53	1.68
6	A	3.60	2.33	1.54	12	A	4.25	1.69	252
6	B	3.67	1.73	2.12	12	B	4.25	2.00	213
6	C	3.80	1.80	2.11	12	C	4.38	1.88	233
6	D	3.20	0.87	3.69	12	D	3.75	1.44	261
6	E	3.33	1.40	2.38	12	E	3.93	1.60	246
6	F	2.40	0.67	3.60	12	F	4.38	2.00	219
AVG		3.30	1.53	2.16	Average		3.51	1.60	219

Table 4 - Direct and indirect connections

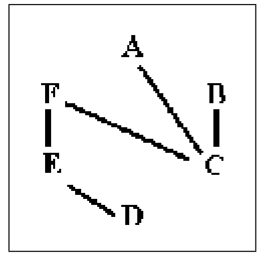
In all sessions under treatment 1 we do not find a definite convergence to a minimal architecture, however the number of isolated nodes and redundant links is generally quite small. For example, in session 3, in rounds 3, 4, 6, 9, 10, 11, 13 and 14 the resulting graph is connected, with no agent excluded from the network of links. In rounds 2, 3, 6, 7, 11, 14 and 15 the resulting graph has no redundant links: i.e. any two agents who are connected are reached through a single path. Finally in rounds 3, 6, 11 and 14 the resulting graph is minimally connected and hence it corresponds to a Nash network as predicted by the theory. The star architecture (the only strict Nash network) is never reached. However in rounds 2, 6 and 11 the resulting graph is quite close to a star.



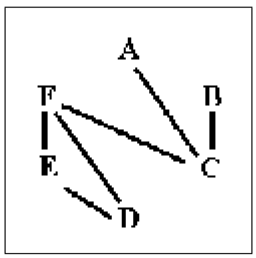
Session 3, round 1



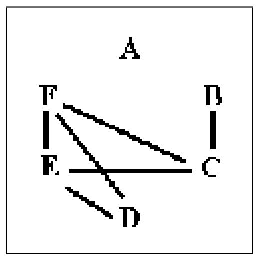
Session 3, round 2



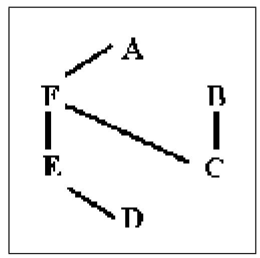
Session 3, round 3



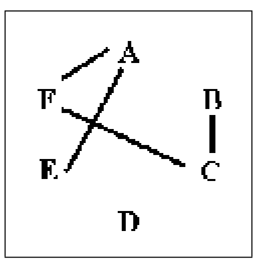
Session 3, round 4



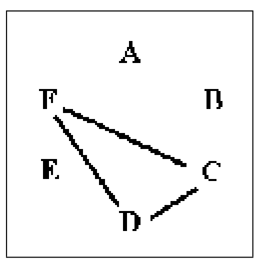
Session 3, round 5



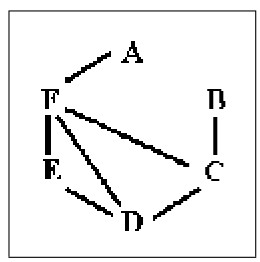
Session 3, round 6



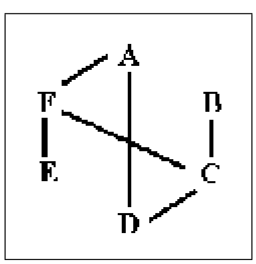
Session 3, round 7



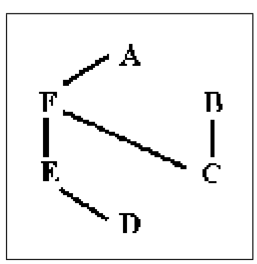
Session 3, round 8



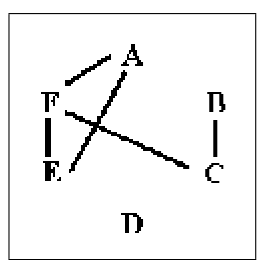
Session 3, round 9



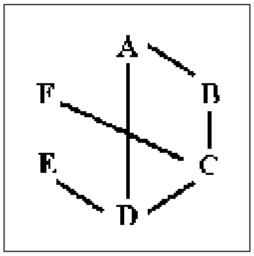
Session 3, round 10



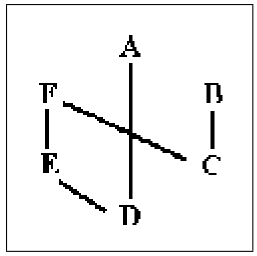
Session 3, round 11



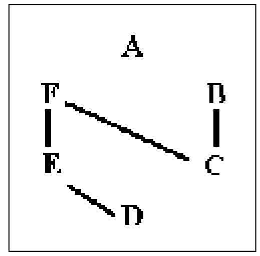
Session 3, round 12



Session 3, round 13



Session 3, round 14

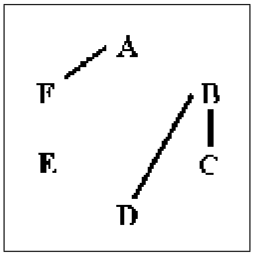


Session 3, round 15

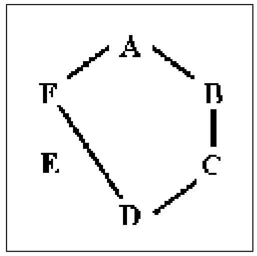
As an example of treatment 2, we show below the network formation process for session 10. A theory of myopic network formation would have predicted an empty graph: the cost of a direct link is higher than the benefits which are obtained from a single connection. Hence starting from a situation of no connections at all (an empty graph), individuals should simply not propose to form any new link. That is, unless they are forward looking and anticipate that others will attempt to link up as well. Session 10 showed as an example here is rather typical of treatment 2 in that all experimental subjects show clear forward looking behaviour.

We believe that this result is reinforced by what we observed under treatment 3. The parameter set for treatment 3 is such that the only network compatible with individual rationality is an empty graph. Through these sessions we wanted to filter away any activity between experimental subjects that was driven merely by the desire to participate in the game and take some action during the experiment. Sessions 13-15 confirm that the network formation activity under treatment 2 is indeed driven by forward looking behaviour, and not by the fact that experimental subjects cannot resist the temptation to input data and generate some activity. Through the control parameter set we find that when the incentives are such that link formation is too costly, even for forward looking players, there is indeed a very quick convergence to no activity at all and to an empty graph.

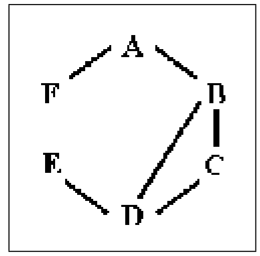
As far as convergence to a stable minimally connected graph is concerned, under treatment 2 the outcome is marginally better than under treatment 1. In particular, under treatment 2, there is some evidence of the fact that players tried to coordinate themselves along a line.



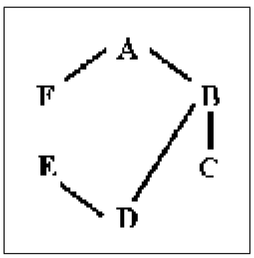
Session 10, round 1



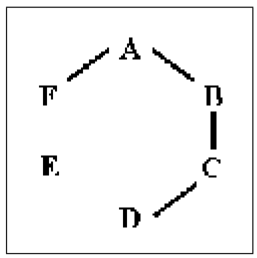
Session 10, round 2



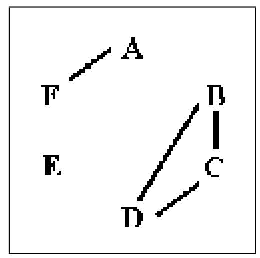
Session 10, round 3



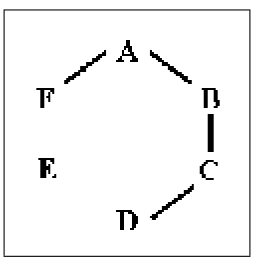
Session 10, round 4



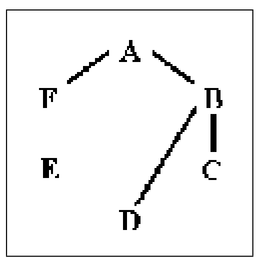
Session 10, round 5



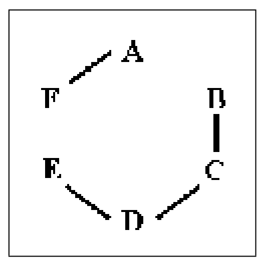
Session 10, round 6



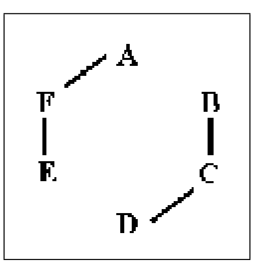
Session 10, round 7



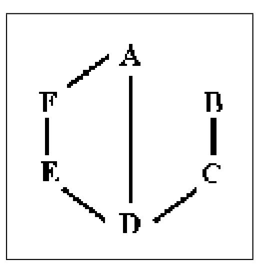
Session 10, round 8



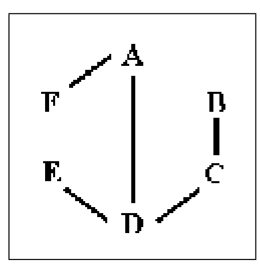
Session 10, round 9



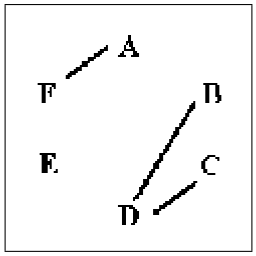
Session 10, round 10



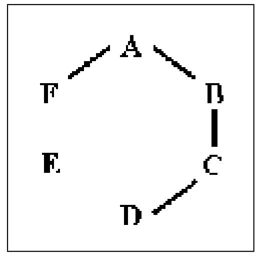
Session 10, round 11



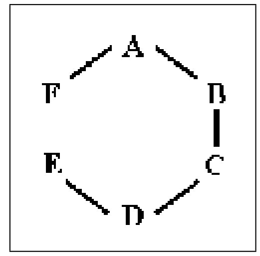
Session 10, round 12



Session 10, round 13



Session 10, round 14



Session 10, round 15

We believe that convergence to a minimally connected graph is made very difficult by two main factors. First of all, as it has been often remarked above, the game that agents play has multiple equilibria and players find it very difficult to coordinate on the same Nash equilibrium (clearly communication was prevented during the experiment). Secondly, subjects display some aversion to inertia and, whenever a minimally connected graph is reached in early rounds, it is often later abandoned (in same cases to be reached again) by subjects who cannot resist to experiment new strategies.

Whenever coordination - and hence convergence - is achieved, this is often on a focal network. One coordination device that was available to the experimental subjects is the alphabetical order. In the next section we show how this has in fact played an important role in determining individual link proposals. We speculate that other framing effects, such as proximity, also played a role here.

4.2 Micro aspects

We move next to a micro analysis of the determinants of individual behaviour in link formation. Such an analysis is particularly valid in this context where because of coordination problems, macro convergence is difficult to observe. In fact, even in presence of mis-coordination, we still ought to be able to determine whether at the individual level subjects are behaving as the theory predicts and what are he main drives to link formation.

We estimate through a probit model the probability of each subject i proposing a link to each other subject j. We treat proposals as independent and this allows us to estimate our model over 6300 observations across the three different parametric treatments. We estimate the probability of proposing a link as a function of: total revenues obtained and total costs incurred in the previous round by the proponent; and number of links of the recipient. Moreover we include as regressors several binary variables that denote whether the proponent and recipient were already linked in the previous round; whether proponent and recipient were indirectly linked through other agents in the previous round; whether proponent and recipient are close in alphabetical order or face each other in the diagram (so that the link appears as a vertical or horizontal line). Finally dummy variables for the different parametric treatments. The results of our estimates are in table 5.

Total revenues obtained and total costs incurred in the previous round by the proponent capture both the budget that each subject has available to spend in new links and the success of past attempts to link up. In fact total profits are a direct function of direct and indirect connections effectively established in the previous round. We find that total revenues are significant and with a negative sign: subjects who scored low revenues in the past are more likely to propose new links. We interpret this finding as a way of catching up on profits. Strategic uncertainty implies that subjects do not know how many of their proposals will be reciprocated; if they have not been successful at establishing links in the past, they ensure themselves by proposing a larger number of new links.

Rationality requires agents to respond to the present network by establishing direct links to those who have a larger number of connections and never to propose a direct link to those that they can otherwise reach through indirect connections. Our estimates show that the likelihood of proposing a link is not significantly affected by the number of links of the recipient in the previous round. Moreover we find only mildly significant evidence (p-value 0.17) of the fact that those agents who have no links (i.e. are isolated) in the previous round are less likely to be the recipients of a link proposal. On the other hand, we find strong evidence of the fact that whenever the proponent and the recipient are indirectly linked in the previous round, a link proposal is much less likely. Hence costly link formation is indeed directed to increase the profits that accrue to agents when they establish connections to those nodes that they are not able to reach otherwise. These findings show that experimental subjects have become aware of the presence of externalities in link formation and have, to an extent, considered the position of every other agent in the network, as one of the determinants of their choice. Given that what distinguishes a network from a series of bilateral interactions is the role played by indirect connections, we consider this finding as particularly interesting.

Other determinants of link formation do not have a clear theoretical counterpart, at least not within a static network formation game. Other significant determinant in the probability of proposing a link are: past play and framing effects (in particular, alphabetical proximity). We find strong positive evidence of the fact that links established in the past are more likely to be confirmed. Habit has an important role in determining how a network is formed. This is particularly understandable in a framework where there is strategic uncertainty about which link proposals will be reciprocated so that the proposed links will actually be formed.

Similarly we find that proximity matters and is a clear drive to link formation: subjects are more likely to propose a link to those who are close to them in alphabetical order which, in our framework also coincides with physical proximity in the diagram that subjects observe on their screens (but not necessarily physical proximity in the lab). On the contrary, we find no evidence of the fact that proposals that would result in links between subjects that face each other in the diagram (such as: A and D, E and C, F and B) are more likely. These findings seem to confirm that the alphabetical ordering provided subjects with a coordination device. The network formation game that we analyse has multiple equilibria. Hence, in absence of information about the other players' moves and of a clear coordination device, it would have been unlikely to observe equilibrium behaviour. In Deck and Johnson [8] a spatial structure is introduced where further away agents are more costly to connect to, precisely to reduce the coordination problem facing agents and "affording a greater likelihood that the desired architecture is formed" (p. 361, [8]). Our results show that, even in absence of a cost topology and hence among identical agents, proximity acts as a coordination device and is relevant in reducing the ambiguity and in limiting the number of equilibria that may arise.

Finally, as expected, we find solid evidence of the fact that link proposals are more likely when the cost of direct links is lower. The probability that an agent might propose a link is lower in treatment 2 (and even more so in treatment 3) than in treatment 1.

Dependent Variable: i proposes a link to j

	Coefficient	Std. Error	P-Value
Treatment 2	-0.09	0.04	0.02
Treatment 3	-1.33	0.07	0.00
Revenues of i in (t-1)	-0.28	0.12	0.03
Costs of i in (t-1)	-0.29	0.25	0.24
Links of j in (t-1)	-0.03	0.03	0.19
i no links in (t-1)	-0.08	0.06	0.17
i and j linked in (t-1)	0.38	0.06	0.00
i and j indirectly linked in (t-1)	-0.87	0.05	0.00
i and j close in alphabet	0.38	0.04	0.00
i facing j in diagram	-0.02	0.05	0.69
constant	0.47	0.07	0.00

Number of observations: 6300

LR CHI2(8) 2149.18

Prob > CHI2 0.000

Table 5 - Probit model

In the feedback forms distributed to experimental subjects at the end of each session, most of them described the strategy that they had adopted during the experiment in terms that are easy to relate to one of the determinants outlined above. In particular many of them reported to have tried to: establish repeated links; link up with those with many links; propose many links if they were isolated in the previous round. We also found evidence of the fact that many proposed links to their "neighbours" both in an alphabetical and visual sense.

4.3 Dynamic Aspects

We next turn to analyse some dynamic aspects, with the aim of detecting the extent of learning taking place. In table 6 we look at the ratio between accepted and proposed links over rounds in each session. What we typically observe is that subjects learn over time who are the players that are more likely to reciprocate their proposals. The ratio between accepted and proposed links declines over time. In figure 2 we display the ratio of accepted to proposed links for an average subject over time. In sessions 1-6 it increases from 0.36 to 0.63; in sessions 7-12 the ratio is uniformly higher and increases from 0.58 to 0.75. This shows that over time there is a smaller number of proposals which are not reciprocated. Moreover the effect is stronger under treatment 2, when the cost of links is higher.

	1	2	3	4	5	6	AVG	7	8	9	10	11	12	AVG	13	14	15	AVG
1	0.38	0.50	0.47	0.59	0.22	0.00	0.36	0.36	0.50	0.60	0.46	0.56	1.00	0.58	0.50	0.67	1.00	0.72
2	0.29	0.50	0.53	0.60	0.22	0.36	0.42	0.47	0.50	0.46	0.71	0.53	1.00	0.61	0.86	0.33	0.55	0.58
3	0.38	0.59	0.63	0.50	0.40	0.64	0.52	0.62	0.67	0.77	0.71	0.50	1.00	0.71	0.67	0.80	0.67	0.71
4	0.63	0.47	0.61	0.31	0.50	0.75	0.55	0.31	0.53	0.77	0.71	0.63	1.00	0.66	0.33	0.00	0.45	0.26
5	0.75	0.47	0.73	0.77	0.20	0.31	0.54	0.57	0.47	0.92	0.62	0.72	1.00	0.72	0.00	0.33	0.91	0.41
6	0.71	0.67	0.56	0.65	0.25	0.59	0.57	0.83	0.67	0.80	0.57	0.59	0.71	0.70	0.00	0.00	0.75	0.25
7	0.59	0.47	0.50	0.60	0.43	0.43	0.50	0.71	0.53	0.83	0.67	0.44	0.55	0.62	0.67	0.00	1.00	0.56
8	0.56	0.36	0.43	0.25	0.43	0.77	0.47	0.75	0.40	0.83	0.54	0.84	0.62	0.66	0.00	0.40	0.00	0.13
9	0.67	0.83	0.76	0.67	0.40	0.53	0.64	0.67	0.55	0.73	0.67	0.82	0.57	0.67	0.00	0.00	0.00	0.00
10	0.57	0.67	0.67	0.54	0.27	0.78	0.58	0.67	0.57	0.83	0.62	0.81	0.71	0.70	0.00	0.00	0.50	0.17
11	0.59	0.80	0.63	0.36	0.43	0.71	0.59	0.62	0.53	1.00	0.86	0.81	0.57	0.73	0.00	0.00	1.00	0.33
12	0.57	0.92	0.59	0.78	0.36	0.75	0.66	0.59	0.50	0.80	0.71	0.63	1.00	0.70	0.00	0.00	0.00	0.00
13	0.74	0.67	0.59	0.73	0.67	0.75	0.69	0.67	0.63	0.83	0.50	0.80	1.00	0.74	0.00	0.00	0.00	0.00
14	0.62	0.50	0.67	0.67	0.59	0.67	0.62	0.71	0.50	1.00	0.67	0.56	1.00	0.74	0.00	0.00	0.00	0.00
15	0.64	0.75	0.53	0.78	0.56	0.53	0.63	0.50	0.40	1.00	0.83	0.78	1.00	0.75	0.00	0.00	0.00	0.00
AVG	0.58	0.61	0.59	0.59	0.39	0.57	0.56	0.60	0.53	0.81	0.66	0.67	0.85	0.69	0.20	0.17	0.46	0.28

Table 6 - Ratio of accepted to proposed links by session and round.

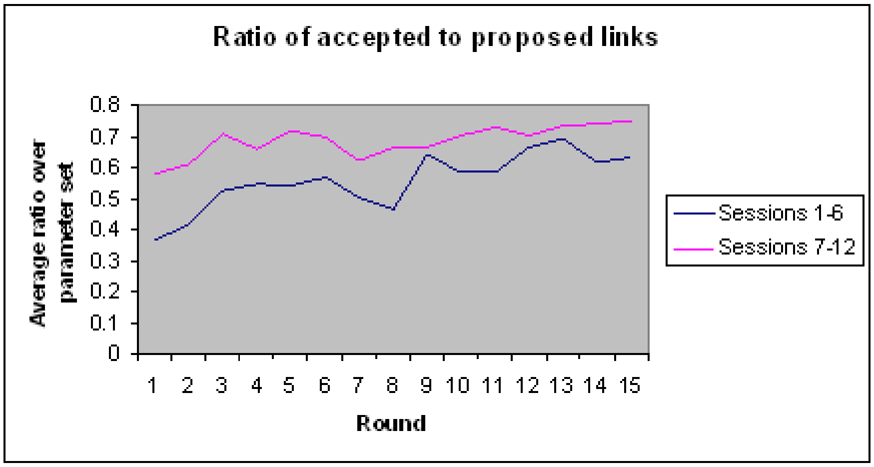


Figure 2

We also look at the number of isolated nodes over time, in table 7. It is decreasing on average: from 2.83 to 0.67 for sessions 1-6 and from 1 to 0.50 for sessions 7-12. On average there was just below one isolated node (0.91) per round in sessions 1-6; and 0.53 isolated nodes per round in sessions 7-12. Optimality requires all agents to be connected: these results show that fewer and fewer agents remain isolated as interaction is repeated over time and that the learning effect is stronger under treatment 2 than under treatment 1. Again, a higher cost of link formation helps towards optimality. The diagram in figure 3 summarises this information.

	1	2	3	4	5	6	AVG	7	8	9	10	11	12	AVG	13	14	15	AVG
1	3.00	2.00	1.00	1.00	4.00	6.00	2.83	1.00	1.00	1.00	1.00	2.00	0.00	1.00	4.00	1.00	0.00	1.67
2	2.00	0.00	1.00	0.00	3.00	3.00	1.50	0.00	1.00	1.00	0.00	0.00	0.00	0.33	1.00	4.00	1.00	2.00
3	1.00	0.00	0.00	1.00	2.00	0.00	0.67	0.00	1.00	0.00	0.00	0.00	0.00	0.17	1.00	3.00	1.00	1.67
4	0.00	0.00	0.00	2.00	2.00	1.00	0.83	2.00	0.00	0.00	0.00	0.00	0.00	0.33	4.00	6.00	1.00	3.67
5	0.00	0.00	1.00	0.00	4.00	2.00	1.17	1.00	2.00	0.00	1.00	0.00	0.00	0.67	6.00	4.00	0.00	3.33
6	0.00	1.00	0.00	0.00	4.00	1.00	1.00	0.00	1.00	0.00	1.00	0.00	0.00	0.33	6.00	6.00	1.00	4.33
7	1.00	0.00	1.00	0.00	1.00	2.00	0.83	1.00	1.00	0.00	1.00	1.00	2.00	1.00	4.00	6.00	2.00	4.00
8	0.00	2.00	2.00	2.00	1.00	1.00	1.33	0.00	2.00	0.00	1.00	0.00	0.00	0.50	6.00	4.00	6.00	5.33
9	0.00	0.00	0.00	0.00	1.00	1.00	0.33	0.00	2.00	1.00	0.00	0.00	1.00	0.67	6.00	6.00	6.00	6.00
10	1.00	1.00	0.00	0.00	2.00	0.00	0.67	1.00	0.00	0.00	0.00	0.00	0.00	0.17	6.00	6.00	4.00	5.33
11	0.00	0.00	0.00	0.00	2.00	0.00	0.33	1.00	1.00	0.00	0.00	0.00	2.00	0.67	6.00	6.00	6.00	6.00
12	1.00	0.00	1.00	0.00	2.00	1.00	0.83	2.00	0.00	0.00	0.00	1.00	0.00	0.50	6.00	6.00	6.00	6.00
13	0.00	1.00	0.00	0.00	1.00	0.00	0.33	1.00	1.00	0.00	1.00	0.00	0.00	0.50	6.00	6.00	6.00	6.00
14	1.00	1.00	0.00	0.00	0.00	0.00	0.33	0.00	1.00	0.00	1.00	2.00	0.00	0.67	6.00	6.00	6.00	6.00
15	2.00	0.00	1.00	0.00	0.00	1.00	0.67	1.00	2.00	0.00	0.00	0.00	0.00	0.50	6.00	6.00	6.00	6.00
AVG	0.80	0.53	0.53	0.40	1.93	1.27	0.91	0.73	1.07	0.20	0.47	0.40	0.33	0.53	4.93	5.07	3.47	4.49

Table 7 - Number of isolated nodes by session and round.

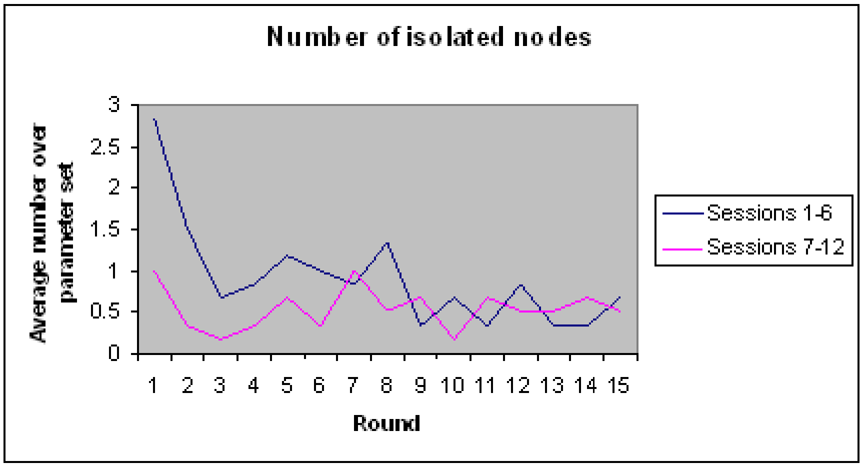


Figure 3

Finally we look at the number of redundant links over time (table 8). These are links that rational players should delete: a redundant link is present when a player is connected to another one both directly and indirectly. Since direct links come at a cost, it would be optimal to delete all those links to players that can be reached indirectly through other nodes. On average there was less than a redundant link per round both under treatment 1 (0.67) and under treatment 2 (0.59): agents are clearly more parsimonious when the cost of link formation is higher. Figure 4 depicts the number of redundant links over rounds. We expected that learning would have helped to reduce the number of redundant links over time, however we did not find such evidence. We explain this with lack of coordination. Subjects are uncertain about what the other players will do and insure themselves against remaining isolated by overconnecting. This effect is particularly strong within this parameter set where the cost of forming a link is not too high and in any case is lower than the benefit from a direct connection. This implies that by overconnecting a subject incurs lower profits, but never losses.

	1	2	3	4	5	6	AVG	7	8	9	10	11	12	AVG	13	14	15	AVG
1	0.00	0.00	1.00	1.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	1.00	1.00	0.33	0.00	0.00	1.00	0.33
2	0.00	0.00	0.00	1.00	0.00	0.00	0.17	0.00	0.00	0.00	0.00	1.00	1.00	0.33	0.00	0.00	0.00	0.00
3	1.00	0.00	0.00	1.00	0.00	0.00	0.33	0.00	1.00	0.00	1.00	0.00	1.00	0.50	0.00	0.00	0.00	0.00
4	2.00	0.00	1.00	0.00	1.00	3.00	1.17	0.00	0.00	0.00	0.00	0.00	1.00	0.17	0.00	0.00	0.00	0.00
5	1.00	0.00	1.00	4.00	0.00	0.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00	0.67	0.00	0.00	0.00	0.00
6	1.00	1.00	0.00	2.00	0.00	1.00	0.83	1.00	1.00	1.00	1.00	0.00	1.00	0.83	0.00	0.00	0.00	0.00
7	1.00	0.00	0.00	1.00	0.00	0.00	0.33	1.00	1.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
8	1.00	3.00	1.00	0.00	0.00	1.00	1.00	1.00	0.00	0.00	0.00	2.00	0.00	0.50	0.00	0.00	0.00	0.00
9	1.00	1.00	2.00	2.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	4.00	0.00	0.83	0.00	0.00	0.00	0.00
10	0.00	1.00	1.00	0.00	0.00	2.00	0.67	1.00	0.00	0.00	0.00	3.00	0.00	0.67	0.00	0.00	0.00	0.00
11	0.00	1.00	0.00	0.00	0.00	0.00	0.17	1.00	1.00	0.00	1.00	4.00	1.00	1.33	0.00	0.00	0.00	0.00
12	0.00	1.00	1.00	2.00	0.00	0.00	0.67	1.00	0.00	0.00	0.00	1.00	1.00	0.50	0.00	0.00	0.00	0.00
13	2.00	0.00	1.00	1.00	0.00	1.00	0.83	1.00	1.00	0.00	0.00	2.00	1.00	0.83	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	1.00	0.00	1.00	0.33	0.00	0.00	0.00	0.00	2.00	1.00	0.50	0.00	0.00	0.00	0.00
15	2.00	2.00	0.00	2.00	1.00	0.00	1.17	0.00	0.00	0.00	0.00	2.00	1.00	0.50	0.00	0.00	0.00	0.00
AVG	0.80	0.67	0.60	1.20	0.13	0.60	0.67	0.53	0.40	0.13	0.20	1.53	0.73	0.59	0.00	0.00	0.07	0.02

Table 8 - Number of redundant links by session and round.

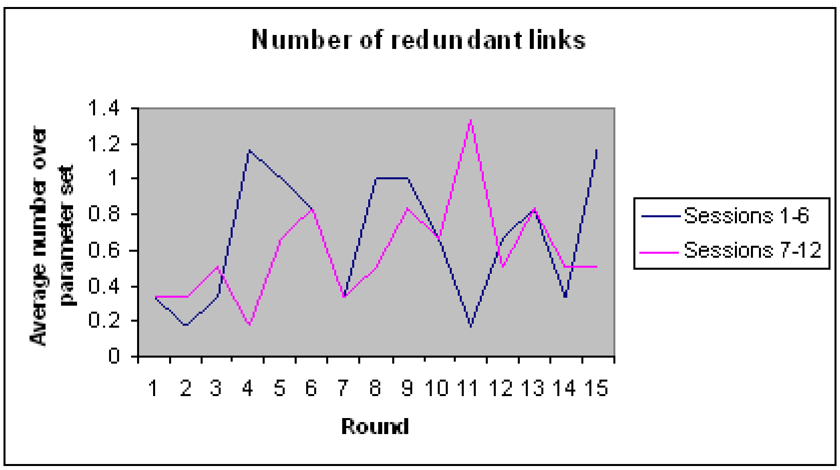


Figure 4

4.4 Earnings

Table 9 shows total revenues, costs and profits scored by the experimental subjects in each of the sessions. It is meaningful to compare these values to the maximum obtainable profits under each of the two treatments. In each of the rounds in sessions 1-6 the highest obtainable profit corresponds to the situation whereby an agent is connected to all other five (hence scoring a revenue of 500) through a single direct link. Hence in sessions 1-6 the maximum obtainable profit is 6650 (including the initial endowment of 500). The average actual profit over sessions 1-6 was 3442, equal to approximately 52% of the potential. Under treatment 2, the maximum obtainable profit is 6200 (i.e. 380 x 15 + 500). The average actual profit over sessions 7-12 was 2879, equal to approximately 46% of the potential.

Ses.	Subject	Tot. Rev.	Tot Cost	Profit	Session	Subject	Tot Rev.	Tot Cost	Profit
1	A	5900	2520	3880	7	A	4600	3600	1500
1	B	6200	2970	3730	7	B	5100	3120	2480
1	C	5900	2700	3700	7	C	1800	720	1580
1	D	4900	1710	3690	7	D	5000	2400	3100
1	E	5800	2520	3780	7	E	4300	2400	2400
1	F	4900	1440	3960	7	F	5000	3000	2500
2	A	5400	2880	3020	8	A	3000	1920	1580
2	B	4700	1530	3670	8	B	4100	3000	1600
2	C	5200	2430	3270	8	C	3600	2280	1820
2	D	5400	2070	3830	8	D	3200	1440	2260
2	E	5200	1980	3720	8	E	5000	3240	2260
2	F	4700	2250	2950	8	F	4700	2520	2680
3	A	6100	1620	4980	9	A	6100	3240	3360
3	B	6900	1440	5960	9	B	6100	1800	4800
3	C	7100	3690	3910	9	C	6500	2760	4240
3	D	5500	1890	4110	9	D	6500	3960	3040
3	E	6900	2250	5150	9	E	6300	1800	5000
3	F	7100	3510	4090	9	F	6300	3480	3320
4	A	6500	3420	3580	10	A	5100	3000	2600
4	B	5700	2160	4040	10	B	5600	3360	2740
4	C	6000	2700	3800	10	C	5600	3120	2980
4	D	6300	2790	4010	10	D	5600	3240	2860
4	E	5600	1980	4120	10	E	3000	960	2540
4	F	5300	1980	3820	10	F	5100	2160	3440
5	A	2500	1260	1740	11	A	6400	5160	1740
5	B	2000	1080	1420	11	B	5100	3120	2480
5	C	1600	990	1110	11	C	5600	2760	3340
5	D	2000	1080	1420	11	D	6000	2880	3620
5	E	1700	900	1300	11	E	5500	3600	2400
5	F	2600	2070	1030	11	F	6400	4560	2340
6	A	5400	3150	2750	12	A	6800	3240	3800
6	B	5500	2340	3660	12	B	6800	3840	3200
6	C	5700	2430	3770	12	C	7000	3600	3640
6	D	4800	1170	4130	12	D	6000	2760	3480
6	E	5000	1890	3610	12	E	5900	2880	3520
6	F	3600	900	3200	12	F	7000	3840	3400
AVG		5044	2103	3442	AVG		5325	2910	2879

Table 9 - Earnings.

5 Conclusions

In this paper we explore the network formation behaviour in a laboratory experiment. Interesting insights stem from both a micro and a macro level analysis.

From a micro perspective, we find that agents are forward looking and clearly follow complex dynamic strategies where they trade off short term losses in order to signal to the other participants their intention to follow strategies that will ensure long term profits. We detect three main drives to link formation: best-response behaviour, focalness and habit. As best-response behaviour would predict, subjects are less likely to propose links to those who have no links themselves; also, subjects are less likely to propose a direct link to those to whom they are already indirectly connected. Focalness has a role because when choosing whom to link to, subjects display a preference for their neighbours, both in an alphabetical sense and in a graphical sense. As a result the alphabetical order provides agents with a coordination device that allows them to focalise on the same stable network. Finally, habit plays an important role: subjects are more likely to propose a link to those with whom they have already successfully established links in the past.

From a macro perspective, our main finding is that, despite the multiplicity of equilibria, subjects often succeed in identifying a focal stable network to converge to. We believe that this positive result is due to two main factors. First, in our experimental setting we require links to be mutually agreed and mutually sponsored. This has the important implication that the star is not the unique stable network architecture, but any minimally connected graph is stable. Moreover, given that both agents involved in a link have to bear the cost of the connection, there is less free riding here than in the typical institutional setup that most of the literature has so far considered. This greatly alleviates the concerns raised by some authors that it is very difficult to obtain convergence to a network that is not fairness compatible in the sense that payoffs are unequally distributed. A second factor that helps towards convergence is the focalness provided by the alphabetical ordering. We find that proximity matters in network formation even when it is not reflected in the cost parametrization (as it occurs in [8], where connecting to neighbours is cheaper than linking to those who are further away).

The most commonly observed deviations from stable networks are: overconnectedness and the fact that minimally connected graph reached earlier on in the session are later departed from. A possible explanation for overconnectedness is that, due to multiplicity of equilibria, subjects try to cope with strategic uncertainty by forming redundant links as a form of insurance. Some aversion to inertia may explain the latter phenomenon. Both explanations are consistent with the fact that convergence and efficiency are higher in the second treatment, where direct links are more expensive. Moreover, both explanations can be reconciled with the learning behaviour detected over time: both redundant links and isolation tend to decrease during the course of the sessions.

The results of our analysis suggest some directions for future research. It would be interesting to see what is the effect of providing subjects with additional information. In this paper subjects are not aware about unmatched proposals; by disclosing information on past willingness to link may help towards convergence. The important role played by focalness suggests that it should be ascertained further whether it is the alphabetical order or proximity that matters. If it is proximity, as we suspect, then it would be interesting to assess whether proximity in characteristics also matters. Therefore heterogeneity in costs, benefits and endowments could be used to detect whether agents sort according to similarity or diversity.

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Appendix: Instructions (English Translation)

Welcome.

This is an experiment on the formation of links among different subjects. If you make good choices you can earn money that will be paid to you in cash immediately at the end of the experiment.

You are one of the 6 participants in this experiment; at the beginning of the experiment the computer will randomly assign to you a label (A, B, C, D, E, or F) and an intial budget (that same for all). You will find your label denoted in red on your screen.

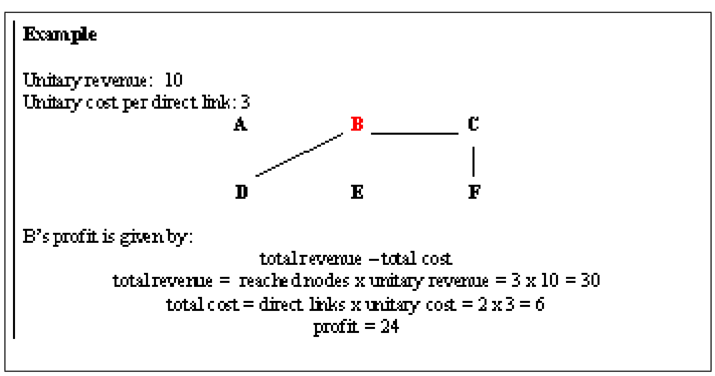
The experiment will last a random number of rounds: there will be at least 15 rounds and, after the 15th, a lottery will be administered by the computer in order to determine if the experiment will finish at that round or continue.

Each participant to the experiment represents a node. At the beginning of the experiment all nodes will be isolated. In each round you will be asked by the computer if you want to make some connections with the other participants and with whom. You will have the possibility to initiate one, two or more links The computer will receive all participants' proposals and will activate only the links that are mutually agreed. The graph of established connections will appear on your screen.

Each effective link has a cost (equal for all participants) which will reported on your screen. In each round the computer will refuse your links' proposals if the expenditure required for the links that your propose, when activated, is greater than the budget that you have available to spend for that round.

In each round the compute will calculate your revenues as the product between the unitary revenue (equal for all nodes and shown on your screen) and the number of nodes that you will be able to reach both through your own and other participants' connections.

For example, as you can see in the diagram below, subject B is directly linked to D and C and indirectly, that is through C, to F.



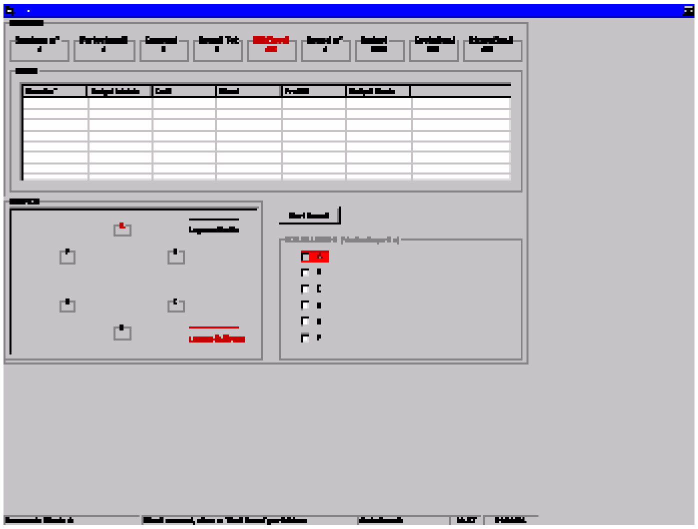
In each round the computer will calculate your profit and will display it on your screen. The overall profit from the experiment is given by the sum of your revenues in all rounds. At the end of the experiment you will be paid in cash an amount equivalent to the 10% of your total profit.

More in detail

At the beginning of the experiment please wait for instructions from the experimenters without touching any key.

When the experimenter will ask you to do so, please double-click only once on the "Link to Student" icon on your desktop.

The following screen will appear:



On this screen the first line indicates information relevant to the round you are playing.

Be careful: every round will last at most a number of seconds as indicated in red in the first line on the screen. If you fail to make any choice before the given time, the computer will move you automatically to the next round.

The table will show the results you scored in each round. At the end of each round, the diagram will show the links that you and other participants have successfully established.

When the key "Start Round" is active, you can start to play.

Press "Start Round" and make your choice. When you are done, press "Stop Round". The computer automatically calculates on shows on the scree the result of your choice.

The last line on the screen shows messages that are relevant to your session.

At the end of each round, the computer will initiate a new round and the key "Start Round" will become active again. Be careful: after the 15th round, your screen will show two flashing lights. If they stop on green, you will have the chance to play another round; it they stop on red the experiment is over.

It is very important that you make choices independently and that you do not communicate with other participants during the experimental session.

For any problem, please contact the experimenters.

Have a good session.

April 2004.