The Formation of Social Capital: An Experiment *

Markus M. Mobius
Harvard University and NBER

Tanya S. Rosenblat
Wesleyan University

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Abstract

We study the formation of social capital in an environment where specialized agents have frequent diverse needs. This limits the potential of purely bilateral cooperation because the interaction frequency between any two particular agents is low. Such interactions usually invite defection by both sides unless agents are altruistic, or there exist information aggregation institutions that facilitate the use of group punishments. In a companion paper Gentzkow and Mobius (2002) develop a theory of how agents can cooperate even in a limited information environment as long as they can *relay* requests for help. This mechanism creates networks with long-term relationships which are continuously recombined to satisfy short-term needs. We test the theoretical predictions by conducting an experiment with two treatments: in the first treatment, agents can only utilize *direct* 'favors' while the second treatment adds the ability to provide *indirect* 'favors' as well. Our results help us understand how agents form and sustain weak links.

1 Introduction

Can cooperation be sustained in environments where agents need help from each other only infrequently? X may want to give a talk at a conference, but can only

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do it at a certain time. She tries to get in touch with the conference organizer Z, whom she does not know. She gets no response. She then contacts Y, whom she met briefly before. Y happens to be friends with Z. X's presentation time gets re-scheduled. X is grateful to Y; Y is grateful to Z.

In the example above bilateral cooperation was difficult to initiate (Z does not help X directly). However agent Y, an acquaintance of X, who is unable to provide a favor himself can forward X's request to some other acquaintance of his, agent Z, who 'owes' Y a favor. This acquaintance can then in turn relay the favor to a third agent who owes him a favor and so on. When such a chain of direct and relayed favors 'clears' each intermediate agent basically trades one favor for another - therefore he does not lose by passing favor requests along.

Indirect favors effectively increase the frequency with which agents can help each other, and thus assist in stabilizing bilateral cooperation between agents. Initial favor provision can open a 'link' to the recipient who then owes a favor to the original provider. Indirect favors make such directed links more valuable because they give access not only to the recipient of the actual favor, but also to all his indirect links, potentially connecting the agent to a very large number of other agents. This interpretation of the value of a link is similar to Jackson and Wolinsky (1996) who analyzed the stability of links in locally connected graphs in a cooperative game theory setting.

Understanding how much indirect reciprocity can complement direct bilateral cooperation is useful for the analysis of many real life situations in which large groups of agents cooperate even though any particular pair of agents interacts only rarely with one another. For example, Granovetter (1974) showed that a majority of workers found new jobs through referrals provided by 'weak links'[1]with other agents. Such referrals often involve agents with whom the recipients of the recommendations interact only at a very low frequency.

We study the formation of social capital in environments with low-frequency interaction through a computer-based experiment with two treatments. Subjects play a repeated game in which they have needs in each period. On average there is at least player in the population who can satisfy the need at a cost to himself which is less than the utility enjoyed by the recipient of the good. Therefore, cooperation is always socially optimal. In our first treatment subjects can send direct requests to all other players. In our second treatment, players are restricted to communicate to a subset of agents who we call their 'neighbors'. However, we allow agents to relay requests of their neighbors. The network is designed in such a way that a relayed request can reach each agent in the population after at most on relaying. We play two consecutive repeated games with each group of players to check whether cooperation increases over time in the two treatments.

[1]See Granovetter (1973) for the analysis of 'weak links'.

Communication in the network seems less efficient than direct communication because (a) there are several paths between any two agents which leads to duplication of messages; and (b) messages do not reach all agents if there is imperfect relaying. However, we find that there is significantly more cooperation in the network treatment. First of all, in the network treatment more than 50 percent of all needs are satisfied versus about 30 percent in the direct treatment. Second, we find that cooperation in the network treatment increases over time while it decreases over time in the direct treatment. Finally, the players who receive most favors in the network treatment are also the ones who provide most favors. In contrast, the players who do best in the direct treatment are the 'free-riders' who consume but do not provide favors.

This paper is organized as follows. Section 2 discusses related theoretical work on enforcement of cooperation and reviews existing experimental evidence on cooperation and indirect reciprocity. Section 3 develops a formal model of indirect exchange. Section 4 introduces experimental setting in which we can meaningfully study indirect exchange. Experimental results are presented in section 5. Section 6 provides concluding remarks.

2 Related Work

2.1 Theoretical Work on Enforcement of Cooperation

When agent X needs something she does not have and has something she can easily give away, mostly likely she will not miraculously run into agent Y who has exactly what agent X wants and desperately desires what agent X has in her possession. It is quite possible that even if X and Y succeed in meeting each other, X does not currently have what Y wants, but Y does possess the object of X's desire. X could claim that whenever she obtains what Y wants she would give it him; in the meantime, Y should just trust her and give her his endowment. Y might choose to agree to X's proposal or he might not. Unless he knows that he will be able to force X fulfill her promise in the future, he has no reason to trust her. We are faced with a situation closely resembling a Prisoner's dilemma game. The main question addressed in this paper is when and how society can sustain cooperation between its members in the long run.

Kandori (1992) provides the most general analysis of this question so far. His environment is closely related to ours. Agents play a Prisoner's Dilemma with their partner at each point in time and they are randomly rematched each period. As in our model, agents can therefore 'help' each other only infrequently. Kandori finds that if agents are sufficiently patient, cooperation can be sustained through contagious punishment schemes. If X cheats Y then Y will cheat every future partner. Cheating will therefore spread at an exponential rate and eventually reach X. Therefore X does not want to cheat in the first place. However, for fixed discount factors and as the population size becomes large this equilibrium breaks down eventually.[2] This impossibility result depends on agents having access to only 'local' information (i.e. information about personal encounters). Kandori (1992) shows that if society provides institutions to aggregate information and make it accessible to all agents cooperation can be sustained even in arbitrarily large populations. Access to aggregate information allows group punishments. For example, assume that X and Y live in a small village where 'everybody knows each other'.[3] Note, that if X knows about Y's past conduct this does not entail that X and Y interact frequently - it simply means that there is a lot of gossiping and information exchange within our hypothetical village. If X decides to forfeit on her debt to Y, she faces two types of punishments, individual and group: first, Y will never transact with her again, and, second, the rest of the village is not likely to treat her well either. However, when a village grows into a large city, informational requirements needed for group punishments increase substantially and Kandori (1992) impossibility result becomes pressingly relevant.

Recent research has focused on looking at one particular type of institution that allows for group punishments - image scoring (see Nowak and Sigmund (1998a) and Nowak and Sigmund (1998b)). Following Alexander (1987), the authors suggest that individuals constantly access and re-assess each other to arrive at image scores that are indicative of their past behavior. They study evolution of indirect reciprocity in a population of individuals with the option to help or not help one another.[4] Helping is costly to the donor, but it increases her image score, known to every player in the game. Because image scores are public knowledge, cooperation is effectively achieved using group punishments: the authors show that a stable level of cooperation can persist only if there is a sufficient number of individuals who are prepared to refuse help to those with a low score. Nowak and Sigmund (1998b) relax the assumption that individuals walk around with their image scores displayed on their foreheads and allow for incomplete information about image scores because not all acts can be publicly observable. However, since the agents are always matched randomly, the informational requirements on the knowledge of image scores increase with population size, even if each individual only observes a small fraction of image-enhancing deeds by others. In contrast, in our environment, agents make their own decision about whom to ask for help and

[2]The equilibrium could only be sustained if agents' discount factor δ increases simultaneously with the population size.

[3]Another example are diamond traders who put up pictures of non-trustworthy individuals in trading rooms. Traders can then identify defectors easily and punish them by refusing to do further business with them.

[4]A lively summary of results can be also found in Nowak and Sigmund (2000).

therefore can focus on obtaining and maintaining image scores for a small group of chosen friends. Cooperation in our world can be achieved not because individuals are interested in preserving their public image, but because they care about their appearances in close bilateral relationships. We will subsequently refer to standard image scoring as *global*, and our private information image scoring as *local*.

Is is worth pointing out that in the sphere of market exchange cooperation can be enforced by introduction of money, an anonymous universal medium of exchange. Y will be delighted to swap his good for a dollar bill provided he is certain that he can use that bill to purchase his consumption good from agent Z. Extensive literature on the origins of money has documented its welfare-improving role in facilitating exchange (see for example Townsend (1980), Kiyotaki and Wright (1989) among others). Kocherlakota (1998) has emphasized the origin of money in the systems of gift exchange and has shown that money is technologically equivalent to memory. In fact, money can be viewed as an example of a *global* image score. When Y sees X present him with a dollar bill, he assumes that X must have 'helped' somebody before to obtain that piece of paper. Money then becomes a sufficient statistic for a particular type of image-scoring. It does not provide any detailed information about X's helping history, but it is enough for Y to give X his good, since he obtains "Have helped before" certificate that he can use to obtain goods from Z.

The view taken in this paper is complementary to the literature on group punishments. We suggest a way of overcoming Kandori (1992) low information impossibility result by allowing for indirect favor provision. Our agents maintain *local* image scores of the individuals in their circle of friends and since these circles are interconnected, they gain access to a larger community of favor donors.

2.2 Experimental Analysis of Cooperation and Reciprocity

An extensive experimental literature has documented that a) the levels of cooperation observed in laboratory far exceed those predicted by strategic self-interested behavior predicted by standard theoretical models and b) cooperation is often sustained by players displaying reciprocal behavior towards each other. Standard environments in which reciprocity has been observed include prisoner's dilemma (Andreoni and Miller (1993) and Cooper, DeJong, Forsythe, and Ross (1996)), centipede game (McKelvey and Palfrey (1992), public goods game (Croson (1998)) and investment game (Berg, Dickhaut, and McCabe (1995)) among others. Fehr, Gächter, and Kirchsteiger (1997) and Fehr and Gächter (1998) show the importance of reciprocity in employer/employee relationships. In contrast to the emerging literature on indirect reciprocity, most of the above research focuses on the maintenance of bilateral links.

Since in real life people often receive favors in one-time random encounters without any possibility for repeated interactions, researchers have looked at the prevalence of indirect reciprocation. Dufwenberg, Gneezy, Güth, and van Damme (2000) and Buchan, Croson, and Dawes (2001) study indirect reciprocity in the Berg, Dickhaut, and McCabe (1995) investment game environment. Indirect reciprocity is viewed as rewarding not the original donor but somebody else. Dufwenberg, Gneezy, Güth, and van Damme (2000) find no significant difference in giving between direct and indirect treatments, while Buchan, Croson, and Dawes (2001) observe a decline in giving. Our analysis of indirect exchange is significantly different from such studies because we are not looking at success of indirect giving alone, but only in conjunction with already established networks of direct exchange. In our setup agents are not randomly matched, but rather choose their partners in exchange. In contrast to one-shot nature of the investment game, our subjects are involved in repeated interactions which allow them to learn about others by keeping track of history of their personal encounters.

Several recent experimental studies explore the potential for cooperation based on global image scoring. Wedekind and Milinski (2000) study a game in which players have an opportunity to repeatedly give money to others and receive from others. However, they are never matched with the same person twice. Prior to making her decision each donor receives information on the past giving of her recipient. The authors show that donations are higher to those receivers who were generous to others in earlier interactions. Seinen and Schram (2000) and Bolton, Ockenfels, Katok, and Huck (2001) conduct more careful experiments in which they vary the amount of image score information available to donors to distinguish basic image-score-independent giving from strategic reputation building. While there is some baseline altruism, they find strong evidence for strategic indirect reciprocity. Subjects tend to give less when the cost of giving increases and towards the end of the experiment (Bolton, Ockenfels, Katok, and Huck (2001) reveal the actual number of rounds in the game to see if subjects would rationally reduce their donations when image protection is no longer important).

Our experiment is conducted in a limited information environment: subjects are only able to keep track of their personal encounters, and thus are restricted to local image score information. Because they choose their partners themselves, they are able to accumulate more information about a subset of players than in the 'no information' treatments of the above experiments. The basic structure of our helping game is also more complicated. Our subjects are not always physically able to help. When a request for help goes unanswered, the initiator of the request does not know whether his target could not help or chose not to help. In light of the baseline altruism findings above, we expect to see some untargeted giving in both direct and indirect treatments. However, we are likely to see more structure in the indirect exchange because given the parametrization of our model (low frequency of help provision abilities), the returns to effectively increasing the network of 'verified' friends are high.

3 Model

The model follows Gentzkow and Mobius (2002). For this paper we use the the *cursed equilibrium* concept of Eyster and Rabin (2001) which simplifies the analysis considerably. In Gentzkow and Mobius (2002) we use the standard sequential equilibrium concept. Interested readers should consult this companion paper for proofs and technical details.

3.1 Demand and Production of Favors

There is an infinite number of agents $A = \{1, 2, 3, ..\}$. Time is continuous and agents discount the future at rate r. Each agent i develops needs for some good $f_{i,t} \in [0, 1]$ at some random time t at rate 1. If some other agent $j \neq i$ provides this good agent i enjoys utility b and j has to bear a cost $c < b$. Providing goods is therefore always socially optimal.

Any agent in the economy can independently provide a particular good $f_{i,t}$ with probability $0 < p < 1$. The interesting case for us is the limit $p \to 0$ when bilateral relationships always break down even though could continue to match up each need for a favor with a potential sender since a share $p > 0$ of all agents are able to provide some favor $f_{i,t}$.

3.2 Social Network

Each agent has n acquaintances who are randomly selected from A. The acquaintance relationship is symmetric, i.e. if i is an acquaintance of j then j is also an acquaintance of i. The acquaintance relationship defines a random graph $G \subset A \times A$ where each link $l = (i, j) \in G$ represents the relationship between two acquaintances. Since there is a continuum of agents the random graph G has no 'loops' , i.e. a finite chain of indirect links starting from some agent i never includes i herself.[5]

Each link $l = (i, j)$ can be 'open' (state 0) or 'closed' (state 1). Formally, a function $B : G \to \{0, 1\}$ describes the state of each link and makes the graph G directed. If agent i has an open link to agent j, then agent j's link to i is closed. We interpret an open link between agent i and j as agent i 'owing' a favor to agent j. Graphically an open link between agent i and j is represented by an arrow

[5]More precisely, each agent almost surely belongs to no finite loop.

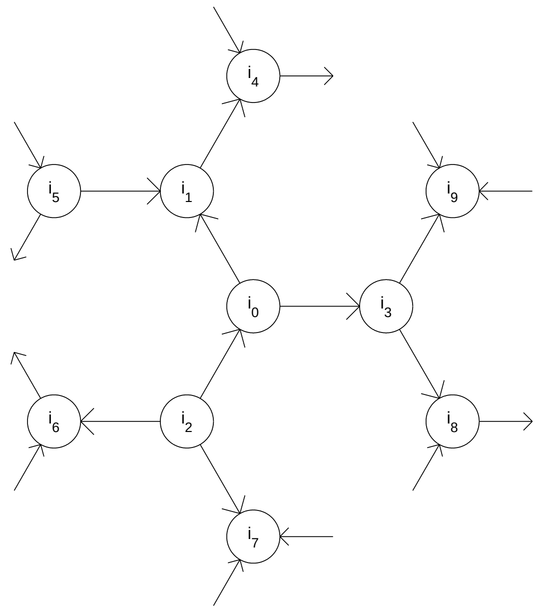

Figure 1: Graph with acquaintance number $n = 3$

which points away from agent i towards agent j. In figure 1, for example, agent i_0 owes a favor to agent i_2 and is owed favors by agents i_1 and i_3.

A path ϕ between two agents is said to be an open path if it is a path and each successive link is open. The set of open paths originating from some agent i is denoted with $\Phi(i)$. Although each agent is connected to only n acquaintances he can be indirectly connected through open paths to infinitely many agents. To see this, consider a graph where for every agent i each of her n links are open and closed independently with probability $\frac{1}{2}$. The probability that a particular open link (i, j) connects agent i to infinitely many agents is q. Neighbor j has $0 \le k \le n-1$ open links with probability $\begin{pmatrix} n-1 \\ k \end{pmatrix} 2^{1-n}$. The following recursive equation can be used to calculate q:

$$q = \sum_{k=0}^{n-1} \begin{pmatrix} n-1 \\ k \end{pmatrix} 2^{1-n} \left[1 - (1-q)^k\right] = F_n(q) \tag{1}$$

Then $F(0) = 0$, $F(1) < 1$ and

$$F'(0) = \sum_{k=0}^{n-1} \begin{pmatrix} n-1 \\ k \end{pmatrix} 2^{1-n} k \tag{2}$$

which is greater than 1 for $n > 3$. Therefore, agents in a random bond network have indirect access to infinitely many agents with probability $q > 0$ for $n > 3$. A simple intuition for this observation is that each open link gives access to $\frac{n-1}{2}$ open links in expectation. Hence, for $n > 3$ the number of open paths increases exponentially which ensures that the agent is connected to infinitely many other agents through open links.

3.3 Messages and Transfers

Agents have to inform other agents about their needs, and request assistance. We think of communication to happen fast compared to the arrival of new needs. To keep the model as simple as possible we assume lexicographic time: whenever an agent has a need the clock stops at time t and a *message phase* starts. The message phase has a discrete sub-timing $t.0$, $t.1$, etc. In each subperiod an agent can send messages or transfer goods.

Formally, a message sent by agent i to j asking for f is defined as:

$$m = (i, j, f) \in A \times A \times [0, 1] \tag{3}$$

A message can only be observed by the sender the and receiver of the message. Similarly, an action involves a transfer from agent i to agent j of good f:

$$a = (i, j, f) \in A \times A \times [0, 1] \tag{4}$$

We allow agents to *relay* requests for goods. If agent i requests good f from agent j through a message $m = (i, j, f)$, then agent j can send a new request $m' = (j, k, f)$ to agent k in some future sub-period and so on. Therefore, indirect favors travel along the set of open paths $\Phi(i)$ (which is potentially infinite as we have seen above). If an agent j at the end of an open path $\phi = (i, i_1, .., i_k, j)$ starting from agent i grants an indirect request from i and agent i has *not* yet received the good from another agent the good travels along the chain immediately to i. If two or more agents can provide a specific favor f at the same time a tie-breaking rule applies in which each agent provides the favor with equal probability. Note, that agents cannot distinguish between direct and indirect messages.

We assume that a message phase can end with some positive probability $w > 0$ in each subperiod. This ensures that every message phase will end eventually with probability 1.[6]

[6]Because we assume that each agent has only finitely many image scores, requests for favors will require an increasing number of sub-periods to get fulfilled as $p \to 0$ assuming that we keep the social network fixed. It is therefore undesirable to assume a fixed exit probability w for each

3.4 Strategies

When an agent j receives some message $m = (i, j, f)$ from some agent i she can take three possible actions:

$$s = \begin{cases} \emptyset & \text{ignore the message} \\ a = (j, i, f) & \text{send good } f \text{ to agent } i \text{ provided she can provide it} \\ m = (j, k, f) & \text{relay message to agent } k \end{cases} \tag{5}$$

A strategy of an agent i consists of the following elements:

1. subset of neighbors who receive requests for help from agent i when she has a need f
2. actions an agent i takes when she receives a message from some neighbor j

The following result is immediate.

Proposition 1 *Without indirect relaying there is no equilibrium for any $\frac{b}{c}$ in which favors are granted with positive probability as $p \to 0$.*

As $p \to 0$ direct favors take longer and longer to be reciprocated. For this reason direct favor provision becomes unprofitable and it is always better to ignore requests.

3.5 Equilibrium with Indirect Requests

The picture changes radically if we allow indirect requests. Although direct favors become increasingly rare as $p \to 0$ the frequency of indirect links does not decline as long as there are enough open paths. We describe an equilibrium whose strategies are simple and intuitive.

Definition 1 *In the indirect favor equilibrium (a) agents provide favors whenever possible, and (b) both send and relay all favors which they cannot provide through as many open links as possible according to the following rules:*

1. *An agent i who needs a favor f immediately sends requests for help through all his open links.*

p because cooperation would always break down as $p \to 0$. We therefore 'scale' w appropriately and assume that $w = f(p) = O(p)$. This ensures that communication is always sufficiently frictionless to not impede cooperation.

2. *An agent j who receives a message (i, j, f) from agent i and can provide a favor will do so.*

3. *An agent j who receives a message (i, j, f) from agent i and cannot provide a favor will resend it through each of his open links (if he has any).*

4. *If agent i provides a favor to agent j then agent i the orientation of the link between i and j becomes 'open' (i.e. i 'owes' a favor to j).*

Note, that indirect favor provision essentially creates trade in favors. When a favor is finally provided by some agent i_k and clears along some open path $(i_0, i_1, .., i_k)$, each intermediate agent i_h $(0 < h < k)$ essentially trades his open favor to agent i_{h+1} for an open favor to agent i_{h-1}. She is therefore no worse off after the trade in terms of number of favors she is owed by others.

The next theorem shows that these strategies form in deed a *cursed equilibrium* (see Eyster and Rabin (2001)). In a cursed equilibrium agents assume that the state of their neighbors is a random draw from the population-wide distribution of states (i.e. they ignore local correlation between their own states and those of their neighbors). Although agents are not fully rational in this equilibrium simulations demonstrate that the degree of local correlation between agents' states is in fact small (see Gentzkow and Mobius (2002)).

Theorem 1 *The network equilibrium is a cursed equilibrium for $n > 3$ and $\frac{b}{c}$ sufficiently large even as $p \to 0$.*

Proof: see appendix A

Expanding the action space and allowing the relaying of favors therefore enables cooperation along weak links.

4 Experimental Design

We first establish an experimental framework in which we can meaningfully analyze cooperation in the direct and indirect exchange environments.

4.1 Subjects

Eighty-nine subjects from the University of Tucuman (Argentina) participated in the experiment. The university is one of the top universities and Argentina and offers a wide variety of undergraduate education as well as master programs in economics and other subjects. Subjects included both undergraduate and graduate students but we excluded economics students from our sample. Student participants were recruited through posters and email announcements that promised compensation based on performance in an economic decision-making experiment of up to two hours in length. Participants were also paid a flat show-up fee of 12 Pesos (the average hourly wage in Tucuman is between 6 and 10 Pesos). Interested students were asked to reply to an email address and indicate their time preference and whether they were friends with other students who were planning to participate in the experiment. The latter was to ensure that friends were not scheduled to be in the same experimental session. Students were instructed to arrive to a computer-enabled classroom 5 minutes prior to the start time of their session.

4.2 Procedure

The experiment was entirely web-based and we used Microsoft Internet Explorer 6 (IE) on the client side. On the server side we used PHP scripts to serve the dynamic HTML and Javascript content. The data was stored in a MySQL relational database. As another safety precaution, all the tools bars were removed from the interface of IE. Each person was assigned a fixed login password. At the login screen players were asked to provide some basic information about themselves such as their major, their age and gender.

After login each player was assigned a computer-generated random player from 1 to 10. Player numbers could not be easily deduced and remained private information to each subject throughout the experiment. In order to preserve anonymity, players were seated at every other computer and were instructed to keep their eyes on their own screen. We had each group of player play the game repeated game twice and their player numbers were independently assigned in both sessions. However, the fixed password allowed us to later trace the identity of players between sessions and connect to the information they provided at the login.

The game consisted of a random number of discrete time periods. After each round the game continued with probability $\delta = 0.92$. Our experimental economy had 50 different goods. In each time period every player had a need for one of these 50 goods which was randomly chosen. At the same time each player could give 8 out of the 50 goods in a time period which were also randomly and independently chosen in each time period.

All players started initially with a balance of 1500 credits (puntos) and the exchange rate between puntos and pesos was

$$100 \quad \text{Puntos} = 0.40 \quad \text{Pesos} \tag{6}$$

The players' screens during the experiment were subdivided into four windows and a status bar on the top of the screen (see figure 2). We refer to these four screens in counter-clockwise direction starting from the top right as the message window, the status window, the exchanged messages history window and the exchanged goods history window.

The status bar showed the player number and name, the current round and the duration of the current round. Each player could think for 60 seconds before sending a message. If he exceeded that time limit he was warned that he would becomes 'inactive' for the current round within 15 seconds. If he did not acknowledge this, he was set to 'inactive status' and could only participate again in the next round. A new round started when all player had either sent all their messages or were inactive.

The status window showed the current money holdings of the player, the current need and the goods he could give in this round. It also indicated who (if anyone) had fulfilled his need. An 'N' indicated that his need was as yet unfulfilled. Providing a good had a cost of 100 Puntos, while consuming a good had a benefit of 300 Puntos. The social surplus from one successful transaction was therefore 200 Puntos. Sending a message had a cost of 2 Puntos.

The exchanged messages window showed the number of messages which the player had so far sent to his neighbors. Figure 2 shows this window for the indirect treatment where each player had three neighbors. The exchanged goods window similarly summarized the history of goods exchange.

The message window could show two basic types of messages:

1. At the beginning of the period the player could send requests to his neighbors.

2. After the player had sent his initial requests he had to work through the queue of received messages. There were cases: (I) he received a messages from a player for whom he could provide a good; (II) he received a message from a player whose need he could not fulfill. In the first case in the direct treatment the subject could decide between granting the request or rejecting it. In the second case the subject could only acknowledge the request and move on to the next message. In the indirect treatment the subject could in both cases relay the request. Relaying implied that the player could send a new round of messages to all his neighbors informing them about the request *except* to the player from whom he had received the request in the first place.

Whenever somebody provided a good a message would appear informing the player about this event. The player could also deduce it from the status window, but we wanted to keep the game as transparent as possible to all participants.

The instruction were read aloud to players. They consisted of 34 steps in the direct game and 53 steps in the indirect game. To make the instructions as

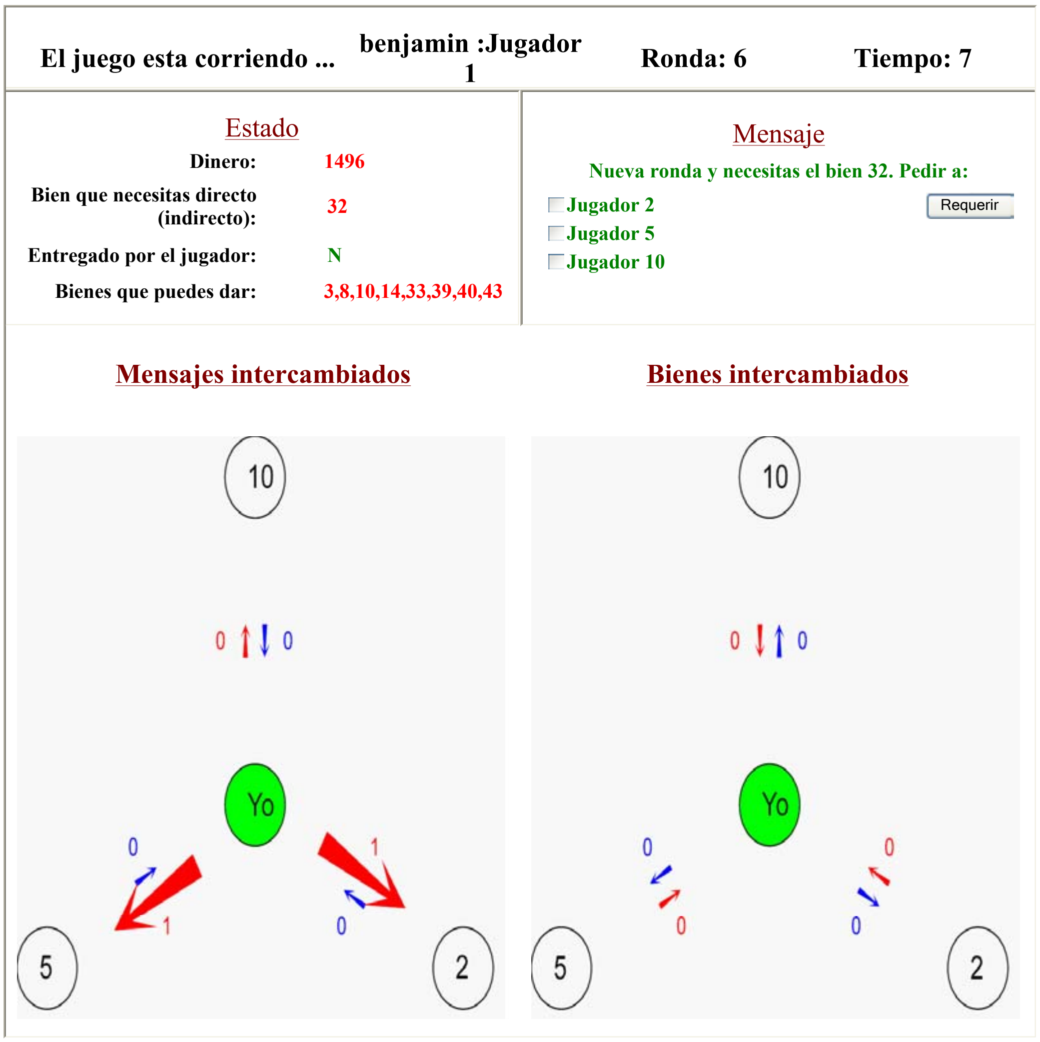

Figure 2: Sample screen with status window, message window, message history window and exchanged goods history window

intuitive as possible the players were asked to read the step-by-step instructions on their screens: each step explained the impact of their and other players' actions on the way the program updated their screen. The part of the instructions which corresponded to a particular step were displayed next to the corresponding window (see figure 3).

4.3 Direct Game

In the direct game each player could send messages to nine neighbors. The parameter we chose allowed it in principle to sustain bilateral relationships, because any neighbor could provide a good with probability $p \approx 15$ percent, social surplus was $b - c = 200$ puntos and $\delta = 0.92$. Hence the bilateral cooperation constraint

$$\frac{p\,(b-c)}{1-\delta} > c \tag{7}$$

was fulfilled. However, in practice we did not see any significant degree of bilateral cooperation between pairs of players.

The information about givable goods was private information to all players. Therefore, a player could not deduce whether a request was denied because the neighbor could not give the good, or was unwilling to provide it. We also did not allow for communicating the performance of players which would allow all subjects to construct global image scores. The aim of our experiment was to analyze the formation of social capital in the absence of any such group communication.

We played the direct game with four groups of subjects: three groups contained 10 subjects and one group 9 subjects. Each group played the game twice (two sessions).

4.4 Indirect Game

The indirect game was very similar to the direct game. However, agents could now also relay requests to their neighbors. An agent could not distinguish between direct and indirect messages.

We played the indirect with five groups of subjects each containing 10 people. Each group participated in two consecutive sessions.

5 Experimental Results

We started with four basic hypothesis which we wanted to test in the data:

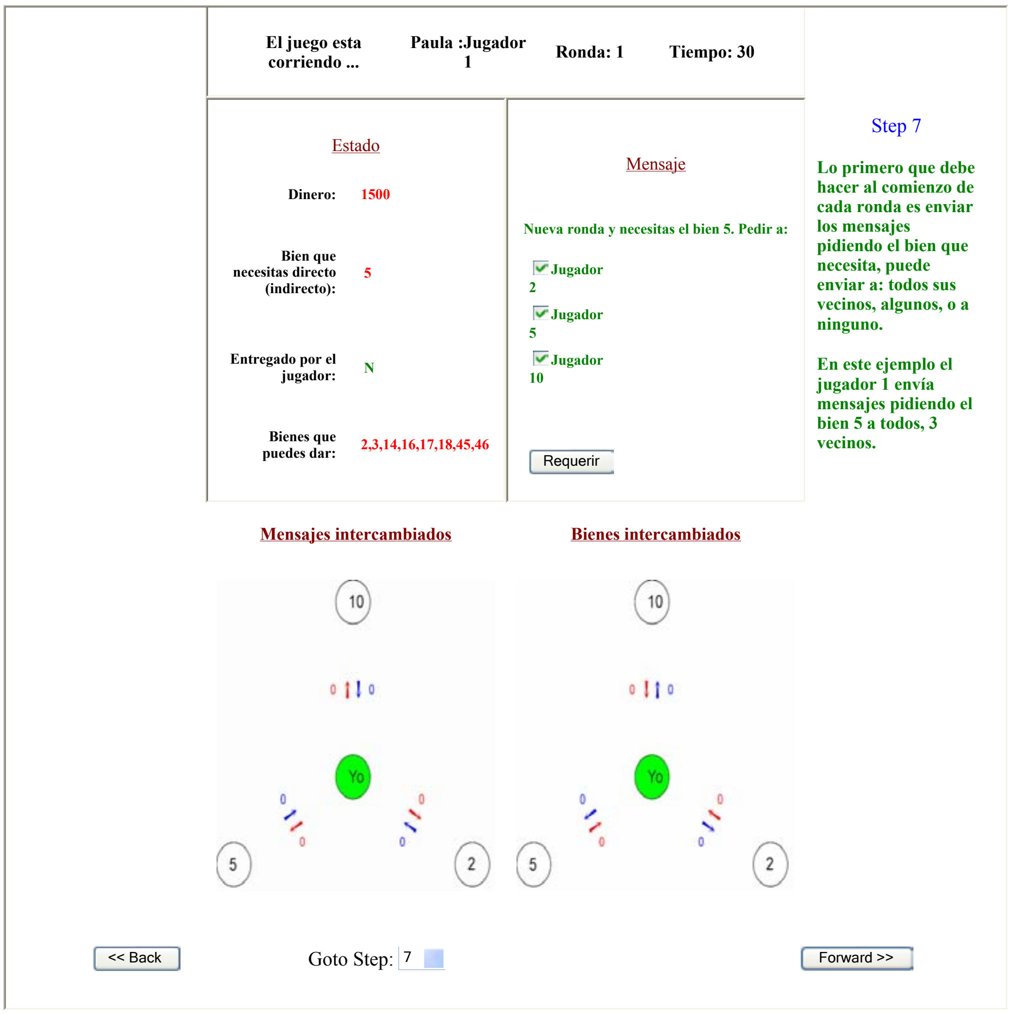

Figure 3: Sample instruction screen showing step 7 in the instructions to the indirect game.

Table 1: Variable Means and Standard Variations of Network Experiment

Variable	Mean	SD	Variable	Mean	SD
MATYEAR	1997.19	3.51	TEAMSPORT	0.58	0.50
MALE	0.64	0.48	AGE	23.53	5.93
INTERNET	0.62	0.49	PREVJOBS	1.31	1.26
N=89					

MATYEAR indicates the matriculation year of students. MALE, TEAMSPORT and INTERNET are indicator variables for sex and whether the subject plays team sports and has internet at home, respectively. PREVJOBS indicates how many jobs the subject has held.

H1: The probability that a need is fulfilled in the indirect treatment is larger than the probability that a need is granted in the direct treatment. This means that average winnings should be higher in the indirect treatment.

H2: The probability that a givable request is granted is greater in the indirect treatment. Notice, that hypothesis **H2** is different from **H1** because messaging is less efficient in the indirect game. Therefore, it is possible that more givable requests are granted in the indirect game but average winnings are nevertheless lower because relaying is incomplete and each agent can only reach a subset of fellow subjects (directly and indirectly).

H3: The probability of granting a givable request increases between sessions in the indirect game and decreases between sessions in the direct game.

H4: In the indirect game agents who receive a lot of favors should be also the agents who grant a lot of favors. In the direct game there is no correlation between receiving favors and granting them.

Hypothesis **H4** relies on the intuition that with only three neighbors an agent quickly runs down his stock of goodwill with his neighbors. In contrast in the direct game an agent can cheat many neighbors before he has to start reciprocating.

5.1 Description of the Data

Table 1 summarizes the basic characteristics of our subject population. The average age was 23 years, about two thirds of the subjects were male and most had some work experience. More than half used the internet at home: we asked for internet usage at home to proxy for family wealth since not all university students in Tucuman have a home PC.

5.2 Testing Hypothesis H1: Winnings

In the indirect treatment the average probability of a need being fulfilled is 52 percent while in the direct treatment it is 30 percent. Therefore, winnings are indeed higher in the indirect treatment.

5.3 Testing Hypothesis H2 and H3: Givable Requests

If agents can indeed build more stable long-term relationships in the indirect treatment we would expect that the propensity to grant a request which is givable to be higher in the indirect treatment. To test this, we extracted all givable requests from the messaging data and constructed and plotted the resulting message ID on the x-axis and the propensity to grant a request on the y-axis. Since in our data each request is either granted or rejected we used a moving average over the preceding 20 givable messages to calculate the average propensity to grant a request at any point in time. We separately compare the first sessions in the direct and indirect treatment and the second sessions in both treatments. Figure 4 compares the first and second session propensities for all four direct treatment and the indirect treatments 1-3. Figure 5 compares the first and second session propensities for all four direct treatment and the indirect treatments 4 and 5.

In the first session the average propensity to grant requests is higher in the indirect treatment for groups 1-3 but not for groups 4-5. However, in the second session the picture changes. While the level of cooperation remains either unchanged or increases in the indirect treatment it falls very strongly for the direct treatment. We take this as evidence that agents learn to cooperate in the indirect game but free-ride on each other in the direct game.

A within group comparison of the first and second sessions shows the same picture. Figure 6 compares the propensities to grant requests in the first and second session of the direct treatment for groups 2 and 3. Figure 7 compares the propensities to grant requests in the first and second session of the indirect treatment for groups 2 and 3. While in the latter case cooperation in the second session increases or remains unchanged it decreases in the direct treatments (strongly so for group 3).

5.4 Testing Hypothesis H4: Free-riding

To test whether subjects who receive a lot of favors are also the ones who give a lot we counted the number of received and sent favors for each subject over all direct and indirect treatments and then plotted 39 data points for the direct treatment and 50 data points for the indirect treatment on a scatter plot. Figure **??** compares the scatter plots in the direct and indirect game. In the direct treatment there is a

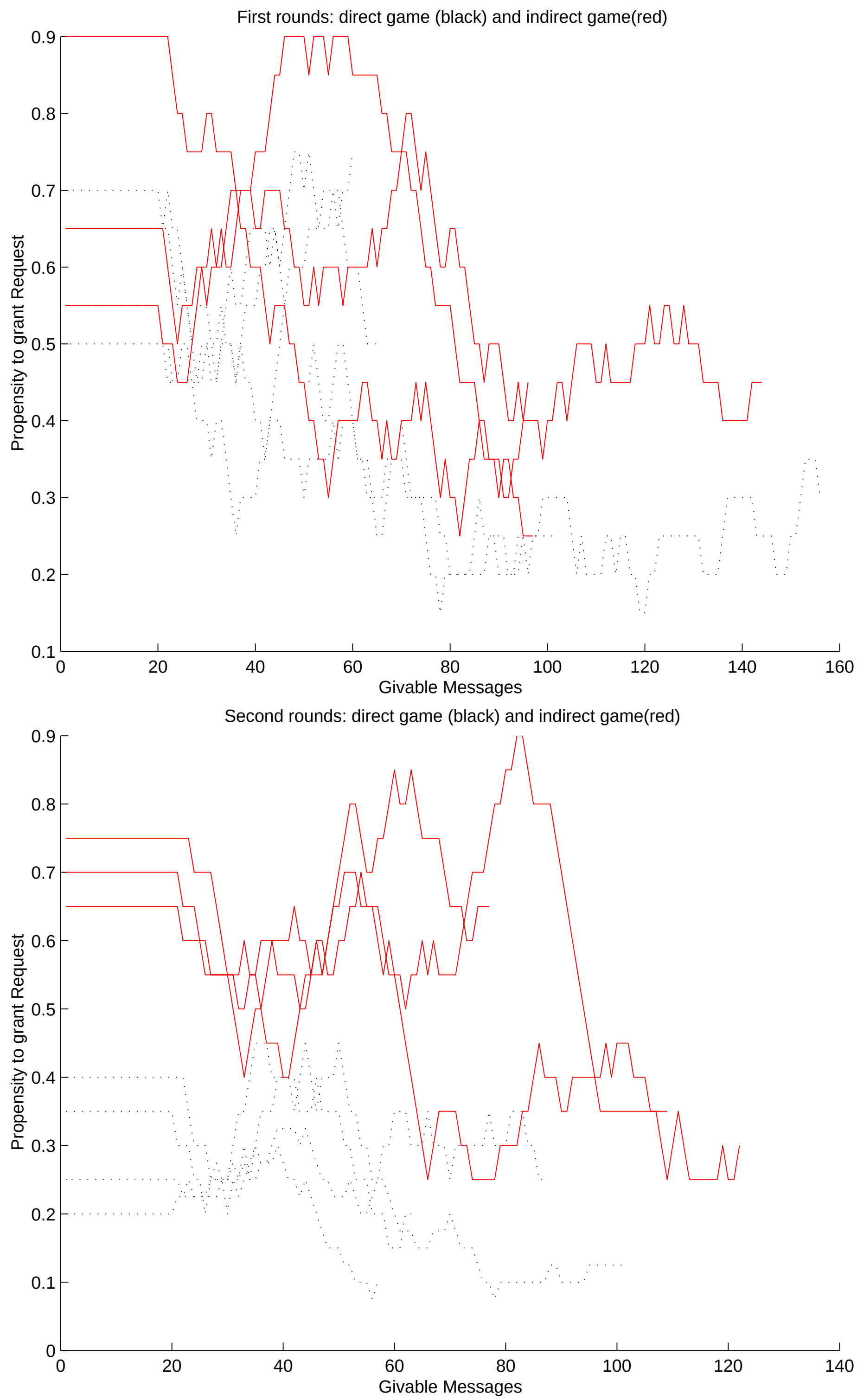

Figure 4: Comparing first and second sessions for all direct games and indirect games 1-3 (direct games are dotted lines)

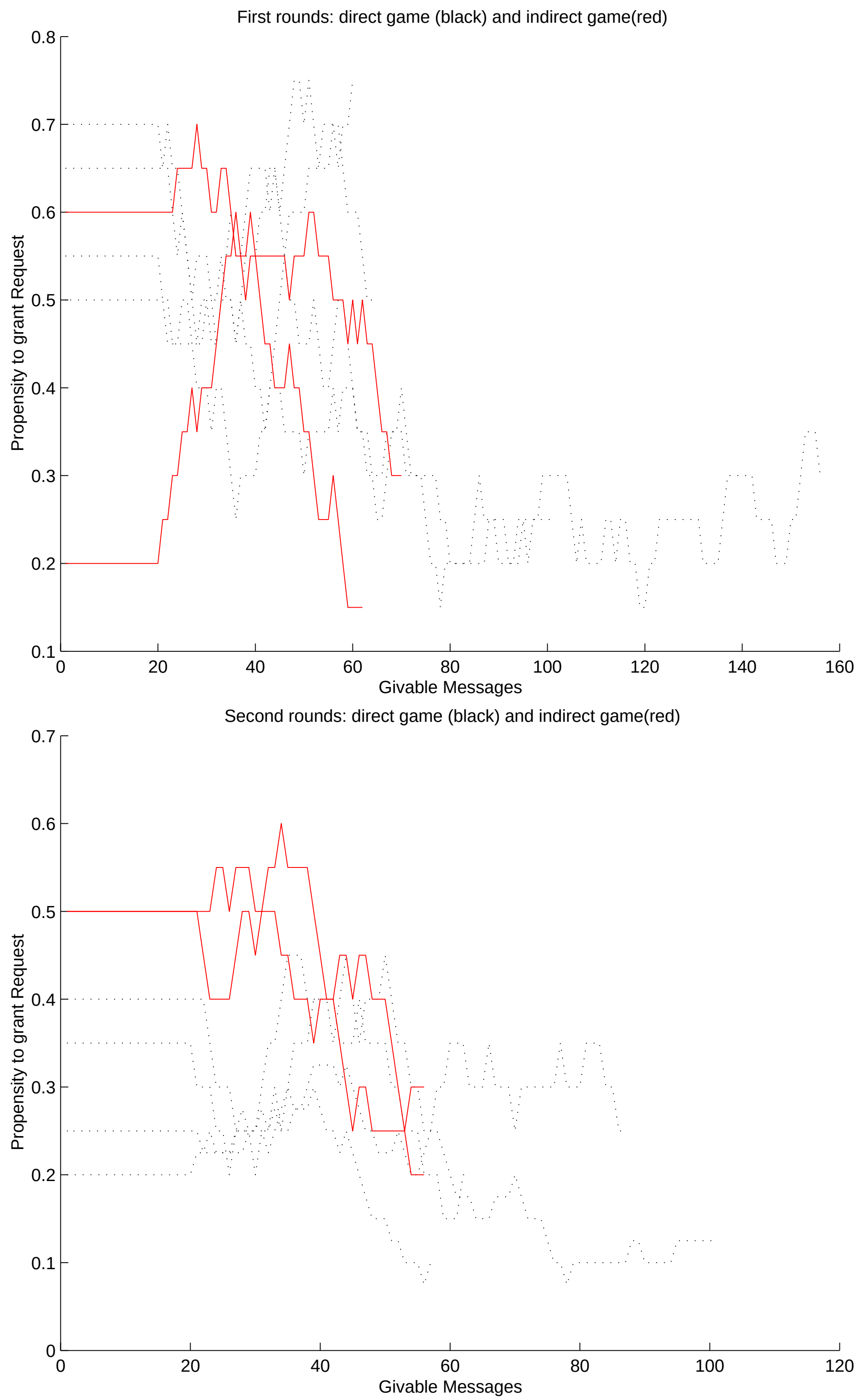

Figure 5: Comparing first and second sessions for all direct games and indirect games 4 and 5 (direct games are dotted lines)

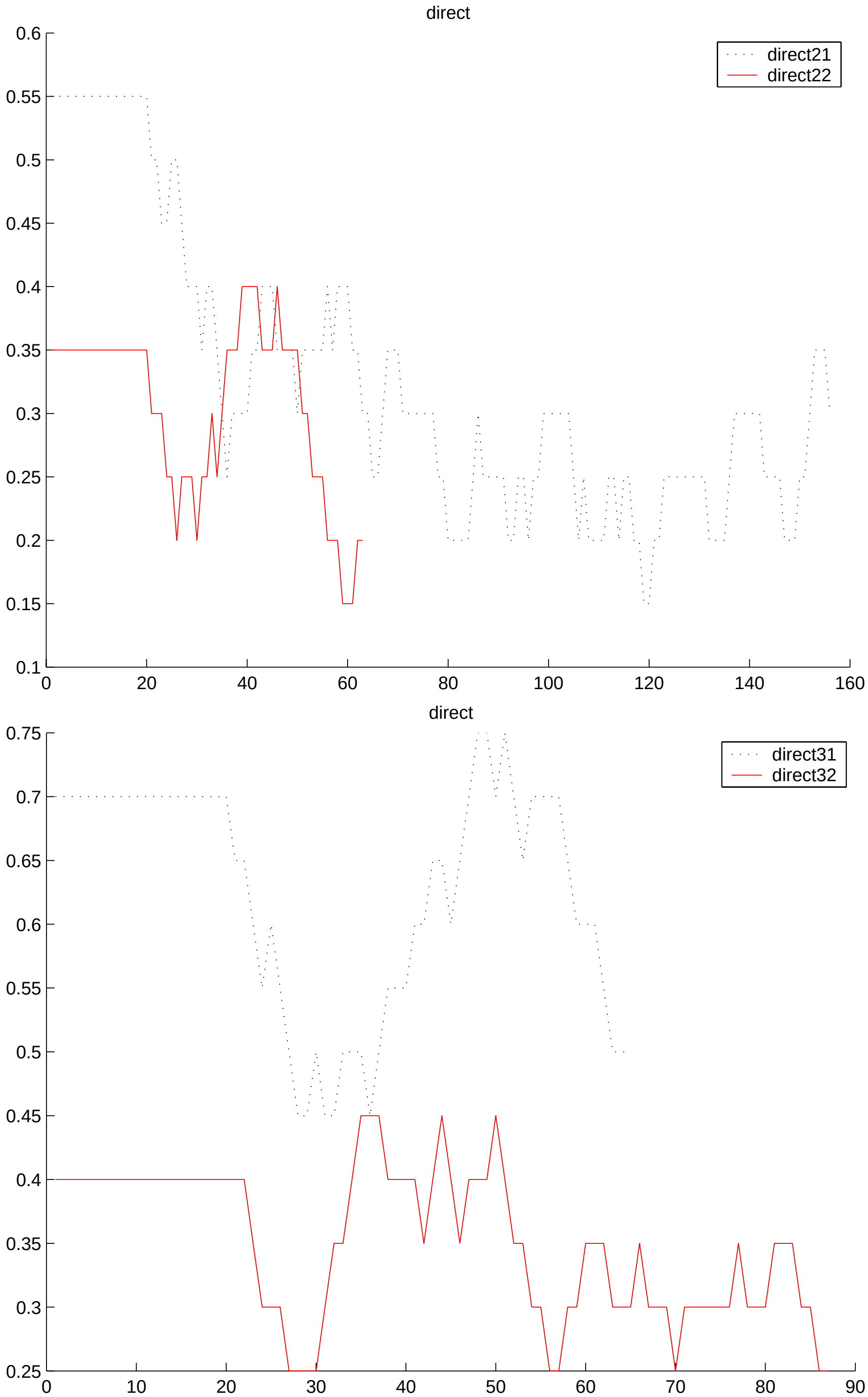

Figure 6: Comparing first and second sessions for direct treatments with groups 2 and 2 (first session is black dotted line)

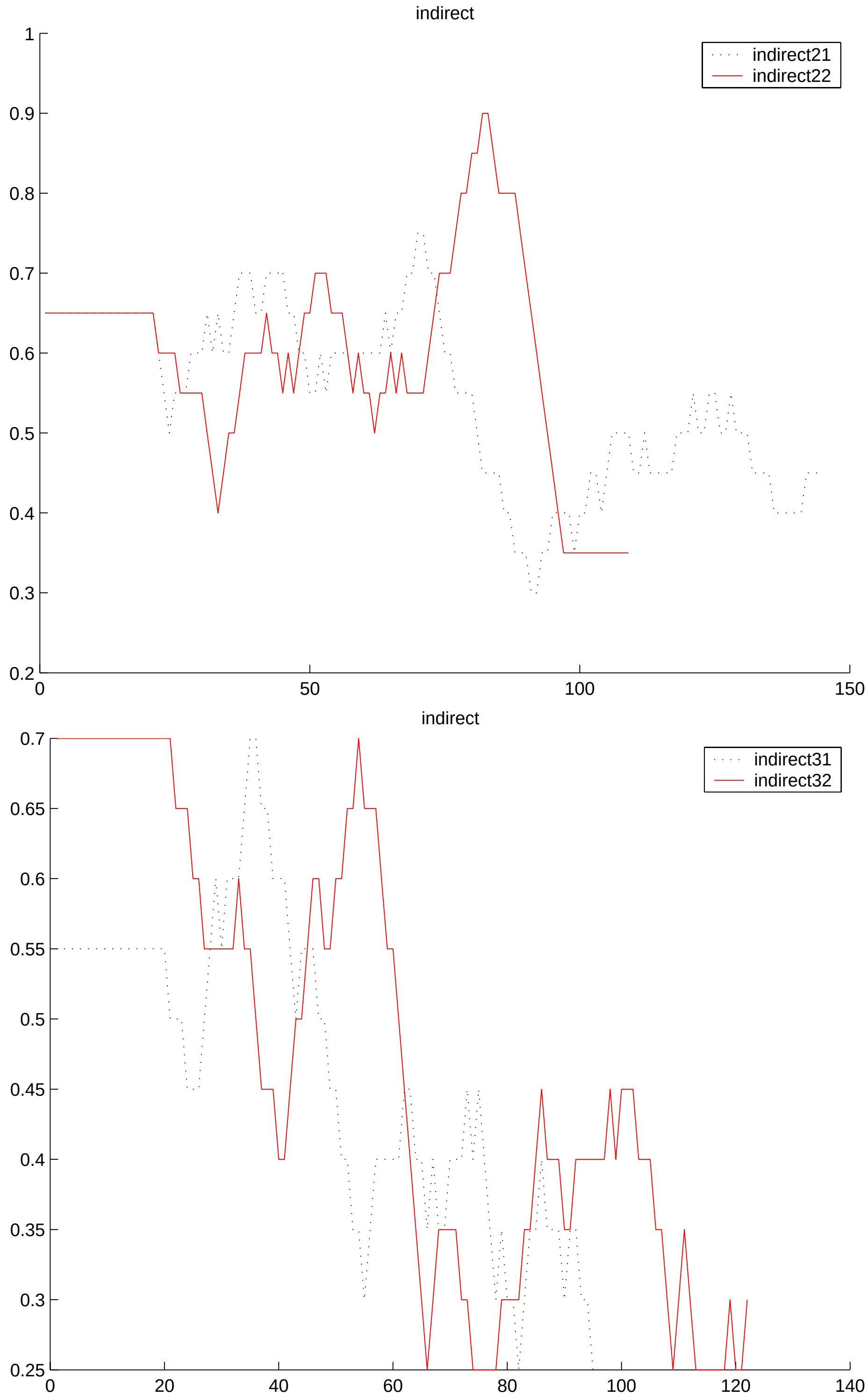

Figure 7: Comparing first and second sessions for indirect treatments with groups 2 and 2 (first session is black dotted line)

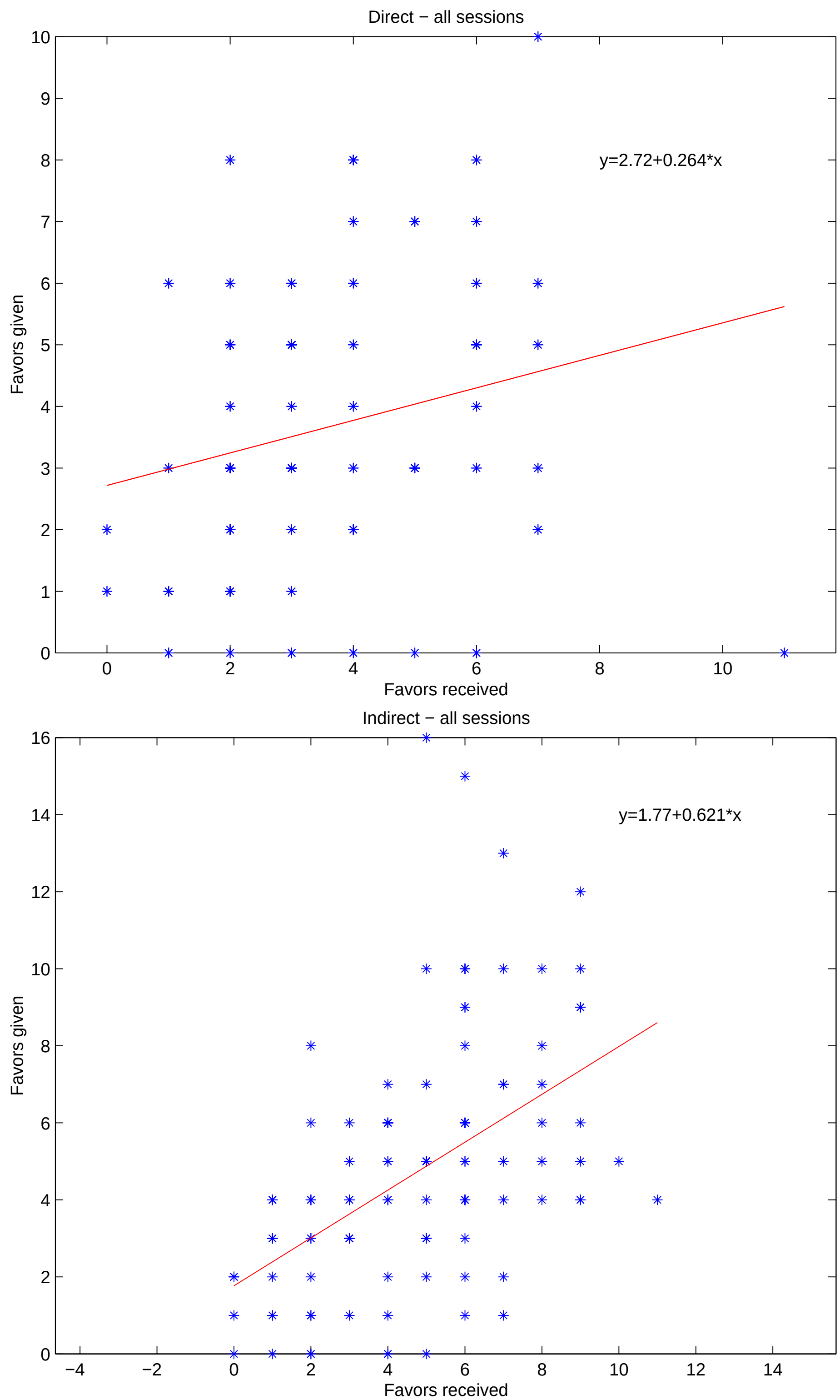

Figure 8: Comparing given and received favors in the last round for all subjects in the direct and indirect treatments respectively

weak positive relationship between favors given and favors received. In contrast in the indirect treatment the relationship is stronger: the agents who win the most in the indirect treatment also give more on average. We interpret this as evidence that the incentive to free-ride is stronger in the direct treatment.

6 Conclusion

We have introduced a model where the ability to relay requests allows agents to sustain low frequency cooperation. Our experimental results conform quite nicely with this model.

We believe that variants of our model can help to shed light on the internal functioning of the firm as well the role of networks in labor markets. On a more theoretical level, the question of exchange through anonymous markets versus exchange through networks is intriguing. Prendergast and Stole (1999) estimate that up to half of all economic transactions are not conducted through markets. Our model can help to explain which types of goods and services are exchanged through networks. Since networks operate by building long-term relationships we would expect that goods whose quality is costly to verify are exchanged through networks while goods of homogenous quality are more efficiently exchanged through markets.

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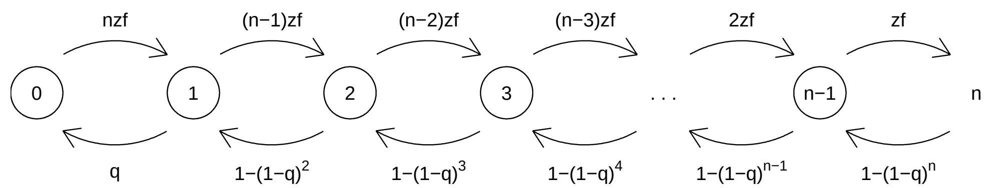

Figure 9: Markov transition matrix when open links give access to infinitely many agents

A Proof of Theorem 1

Assume that the equilibrium share of agents in state m is x_m. The parameter q denotes the probability that an open link gives access to infinitely many favors while the parameter z denotes the probability that infinitely many agents have access to an agent's closed link. The agent receives requests through his closed links at some rate f and asks favors from his open links at rate 1. The state of an agent then changes according to the Markov transition matrix in figure 8: each agent i in some state m_i develops needs for favors at rate 1. Effectively, she will only be able to satisfy these needs when at least one of her links gives her access to infinitely many agents (in this case she will receive a favor for sure). In state m_i she will have access to infinitely many agents with probability $1-(1-q)^m$.

We need three more equations to calculate all unknowns in the model:

$$(1-x_n)\,q = \sum_{m=0}^{n-1} x_m \left[1-(1-q)^m\right] \tag{8}$$

$$(1-x_0)\,z = \sum_{m=1}^{n} x_m \left[1-(1-z)^{n-m}\right] \tag{9}$$

$$\sum_{m=0}^{n} m x_m = \frac{n}{2} \tag{10}$$

Equation 8 simply states that the probability q of being connected to infinitely many agent through some open link to neighbor j equals the sum of probabilities $\frac{x_m}{1-x_n}$ that neighbor j is in state m $(0 \le m < n)$ times the probability that none of the m links gives access to infinitely many open paths.

It is easy to check that for $n > 3$ the above equation system has a solution with $q > 0$. This is enough to make sure that there is an equilibrium with favor provision. Essentially, providing a favor at cost c gives access to a future favor with benefit b. If we denote the value of being in state m with V_m we can write the following Bellman equation:

$$\begin{aligned} rV_m &= (n-m)\, zf\,(V_{m+1} - V_m - c) + \\ &+ \left[1 - (1-q)^m\right](V_{m-1} - V_m + b) \quad \text{for } 0 < m < n \qquad (11) \\ rV_n &= \left[1 - (1-q)^n\right](V_{n-1} - V_n + b) \qquad (12) \\ rV_0 &= nzf\,(V_1 - V_0 - c) \qquad (13) \end{aligned}$$

The resulting value function can be shown to satisfy both the IC constraint and the IR constraint for sufficiently large benefit-cost ratio $\frac{b}{c}$:

$$\begin{array}{ll} \text{(IC)} & V_{m+1} - V_m > c \quad \text{for } 0 \leq m < n \\ \text{(IR)} & V_0 > 0 \end{array} \qquad (14)$$

This proves the result. QED