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Bargaining and network structure: An experiment

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Abstract

We consider bargaining in a bipartite *network* of buyers and sellers, who can only trade with the limited number of people with whom they are connected. We perform an experimental test of a graph-theoretic model that yields unique predictions about equilibrium prices for the networks in our sessions. The results diverge sharply depending on how a connection is made between two separate simple networks, typically conforming to the theoretical directional predictions. Payoffs can be systematically affected even for agents who are not connected by the new link, and we find evidence of a form of social learning.

JEL classification: B49; C70; C78; C91; C92; D40

Keywords: Bargaining; Experiment; Graph theory; Network; Social learning

1. Introduction

In institutions such as financial markets, people make independent and anonymous decisions that interact through a central clearing mechanism that matches buyer and seller.[1] However, in other environments, individual agents are only in contact with a small number of other agents, and transactions can only take place if there is a direct 'link' (e.g., a social or business relationship) connecting two agents. In this sense one can talk about a *network*, which summarizes the structure of linkages among people. Intuitively, some connections may be better than others.

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[1] Nevertheless, there are still human agents in this system. Professional traders and market makers may strongly prefer to transact with others of their cohort, so that links may still play a role.

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Network structure has economic implications for a wide range of situations that feature a limited number of agents and connections. A market may be inherently thin, as with exclusive dealers, airplane or arms sales, or international relations. Even where there are many players, useful information may be transmitted only through private channels, as is often the case for job openings, business opportunities, and confidential transactions. A network is a non-market institution, with important market-like characteristics. It can be seen to represent an intermediate case between bilateral bargaining and matching in a large centralized market. [2]

Social networks may play an important role where there is little effective external regulation. For example, Lamoureaux [38, p. 648] states that “the operation of New England banks [in the first half of the nineteenth century] was shaped primarily by kinship networks,” and attributes the successful industrialization of the region to these networks. Guseva and Rona-Tas [30] find that social and business networks ameliorated problems in the emerging Russian credit-card market in the early 1990s, which suffered from both difficulties in screening applicants and a lack of effective punishment or sanctions for violations.

While theoretical work on network structure has been progressing rapidly, there have been few empirical tests; however, the stylized theoretical environment lends itself to laboratory experiments. In this paper, we assume that the basic network structure is exogenously given. While this is clearly not the case in many environments, here the imposed network structure could be seen as representing social, legal, or cultural trading restrictions. This abstraction allows us to focus on the issue of the resulting bargaining allocations once the network has reached the form we consider.

We extend the infinite-horizon Corominas-Bosch [18] graph-theoretic model of buyers and sellers to a finite-horizon experimental game. The model allows us to decompose any countable number of agents into relatively simple subgraphs (plus some extra links). This decomposition (and the associated equilibrium payoffs) is unique for the networks we study, (although it is not unique for general bipartite networks) and determines whether any particular link is relevant to the local equilibrium price. The process of price formation is central in economics, and there are many applications for which the traditional Walrasian approach seems inadequate; Rubinstein and Wolinsky [45], Gale [27], and others model price formation as an outcome of decentralized bilateral bargaining. Pairs of traders who reach agreements leave the market, and those remaining (and re-matched) continue to bargain, as in our design.

The crucial question that this paper investigates is how the network ‘architecture’ affects the outcomes and dynamics of bargaining. We perform a test on whether it matters how a simple link is added between two small groups of traders. One link is theoretically irrelevant, while the other should have dramatic effects. We find that the manner in which the link is added has a major impact on the bargaining outcome, as the results diverge sharply across treatments and broadly conform to the theoretical predictions. Payoffs can be systematically affected even for agents who are not connected by the new link.

Most of the discrepancies between the data and theoretical predictions seem to be attributable to two behavioral phenomena: First, we find that people receive significantly less when they have only one connection, even where the theory predicts no difference in outcomes. Perhaps having only a single connection makes one nervous, or inspires perceived bargaining weakness. Second, we see strong evidence that shares (publicly) allocated in the past to others in one’s current position

[2] Roth et al. [43] highlight the effect of competition, demonstrating that results are very different for an ultimatum game, with one-to-one matching, and a ‘market game’, where a single agent on one side can agree to a proposal from any of nine agents on the other side.

substantially and significantly affect what one is willing to accept, suggesting that a form of *social learning* [22] is taking place.

2. Background

There are two strands to the network literature in economics. One branch of research examines the process of network formation; see for instance Jackson and Wolinsky [34], Jackson and Watts [33], Bala and Goyal [2] or Kranton and Minehart [37]. The second strand considers the impact of exogenously specified network structures on outcomes; examples include Bala and Goyal [3], Glaeser et al. [28], Morris [40], Chwe [15], and Calvó-Armengol [10]. Our study relates to the second strand, as we do not consider the issue of how networks were formed, or which networks we might expect to form if there are modest costs to forming (or severing) links. Our motivation for considering exogenously specified networks is that we are primarily interested in isolating the effect of a small change in network structure on bargaining behavior and prices. We simply presume that the links are already in place due to some relationships that have (or had) value, and that the cost of (endogenous) change is prohibitive. In this sense, the networks we use are effectively stable and have immediate economic application.

Although economics experiments on networks are recent, there are now several such papers, all with a very different focus than ours. [3] Corbae and Duffy [17] study 2×2 games, where participants play all of their 'neighbors' in the network. Cassar [11] finds that play in a coordination game typically converges to the efficient Nash equilibrium less frequently with local interaction or a random network than with a 'small-world' network. Deck and Johnson [19] examine the effect of cost-sharing institutions in endogenous networks, obtaining slightly better efficiency when players can bid between zero and the full cost of a direct link. Riedl and Ule [41] find stable cooperation in a prisoner's dilemma when people can choose their own partners. Falk and Kosfeld [24] find that the Bala and Goyal [3] model predicts outcomes fairly well with one-way flows, but does quite poorly with two-way flows. [4] While all of these studies consider network-related issues, none directly address the asymmetrical nature of many networks, how network structure affects bargaining outcomes, or the value of different links.

Also related is the social-learning literature, which generally considers the effect of dynamic aggregation of social information on equilibrium outcomes. Ellison and Fudenberg [22, p. 612] use the term social learning to describe contexts where "agents base their decisions, at least in part, on the experience of their neighbors," listing (p. 613) three features for such learning environments, all of which are satisfied here. [5] Ellison and Fudenberg [23] find that word-of-mouth communication may lead to superior choices and socially efficient outcomes. Jackson and Kalai [32] study recurring games, where a stage game is played repeatedly, but each stage is played by a new group of players. This set-up seems closest in spirit to our game, but involves signals that shed light on the distribution of types in the population. [6]

[3] Kosfeld [36] offers an excellent survey of this embryonic field.

[4] Kirchkamp and Nagel [35] study a prisoner's dilemma game with local interaction. Berninghaus et al. [4] use a three-person game; participants are either connected to neighbors on a circle or play within closed three-person groups.

[5] (1) Agents observe both their neighbors' choices and the payoffs that these choices generate; (2) agents periodically reevaluate their decisions, as opposed to making a once-and-for-all choice; and (3) players may be sufficiently heterogeneous that under full information they would not all make the same choice. In our case, one's neighbors are in a sense temporal.

[6] See also Jackson and Kalai [32] and Bala and Goyal [2,3].

In our environment, a link can have an important impact or no impact at all depending on which subnetworks it connects. In a sense, this result is reminiscent of the concept of 'structural holes' in the sociology literature. Burt [8] contends that people have a competitive advantage if they are at bottlenecks in partially connected networks. In terms of power, being adjacent to a link between two groups that are each internally well-connected but are largely separate is more valuable to the people at the nodes than are links within a fully connected group. See Willer [47] and Burt [9] for discussions of the literature and issues in this field.

3. The model

Corominas-Bosch [18] provides a method for decomposing a network of buyers and sellers into relatively simple subgraphs, plus some extra links. Our adaptation to the laboratory is a two-sided market, with two types of agents (e.g., buyers and sellers) who engage in sequential bargaining–alternating offers over a shrinking pie, with multiple possible rounds.

Suppose there are n sellers and m buyers of a homogenous good for which all sellers have reservation value 0 and all buyers have reservation value 1. Each buyer desires only one unit of the good, and each seller can supply only one unit. Is the price dependent only on the relative sizes of n and m, and will all trades take place at the same price? Here buyers (sellers) bargain with a pre-assigned subset of all sellers (buyers); links are non-directed, which means that A is linked to B if and only if B is linked to A. Any buyer may be connected to multiple sellers and *vice versa*. The network structure is common information, as are all proposals and acceptances. [7,8]

Our analysis incorporates the following intuition: Some networks are 'competitive', so that the short side of the market receives all surplus. On the other hand, other networks are 'even' (neither of the sides is stronger), and agents split the payoffs nearly evenly. This structure generalizes to any network, and we can decompose any network into a union of smaller networks, each one either a competitive or an even network, plus some extra links.

Consider three types of particular bipartite graphs (G^S, G^E, and G^B); in the graphs below we arbitrarily have *sellers reside at the top nodes* and *buyers reside at the bottom nodes*. Let graphs G^S be those with more sellers than buyers, such that any set of sellers can be 'jointly matched' with buyers if the number of sellers in this set does not exceed the number of buyers. [9] In Fig. 1, G_1 is of type G^S since it has more sellers than buyers (3 versus 2), and since we can find a joint matching involving any set of 1 or 2 sellers. Graphs G^B are the complement, substituting sellers for buyers and *vice versa*. Finally, graphs G^E have as many sellers and buyers and are such that there exists a joint matching involving all of them.

Not every graph is one of these three types, as is illustrated by the graph in Fig. 2.

[7] One might object that it is unrealistic for a seller to simultaneously advertise the availability of a good to many parties when there is only one unit available. Indeed, we might expect somewhat different behavior if an agent could only make an offer to one other specified agent in each round, even where the theoretical predictions are the same. Nevertheless, there do exist markets where this practice occurs and where it is understood that there is only one unit available. For example, when one wishes to publish a paper in law journals, one may simultaneously submit the paper to all law journals, even though it can only be published in one of them. Similarly, stores (e.g., car dealerships) may send out flyers to 'linked' buyers advertising a product of which there is only one unit available for purchase. We feel that our game should be viewed as a reduced form that abstracts from many aspects of real-word negotiations.

[8] Of course, bargainers maintain personal anonymity in the laboratory.

[9] Intuitively, a set of sellers can be jointly matched if there exists a collection of pairs of linked members such that each agent belongs to at most one pair. See Appendix A for more detail and the formal definitions.

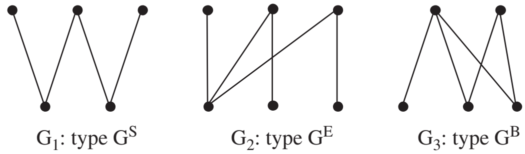

Fig. 1.

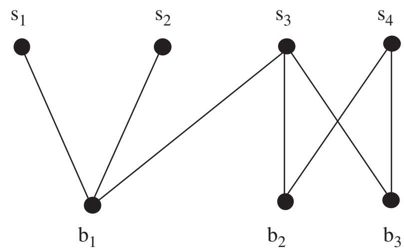

Fig. 2.

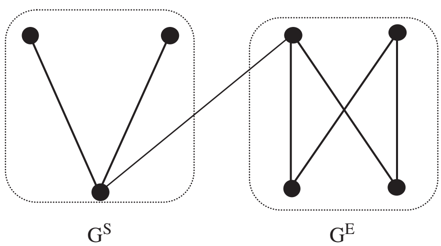

Fig. 3.

Nevertheless, we can decompose this graph into two subgraphs, one of type G^{S} and one of type G^{E}, plus an extra link as shown in Fig. 3.

Theorem 1 (shown in Appendix A) shows that any graph decomposes as a union of subgraphs which are of one of these three types, plus some extra links which will never connect a buyer in a subgraph G^{B} with a seller in a subgraph G^{S}. As in Corominas-Bosch [18], a simple iterative algorithm for decomposing countable bipartite networks is at the heart of the process. [10]

The graph in Fig. 4 is an example of the decomposition process; it decomposes into two subgraphs of type G^{S}, one of type G^{E} and one of type G^{B}.

[10] An outline: We first remove the subgraphs that have a set of sellers of size t collectively linked to less than t buyers. We do so starting with the subgraphs in which multiple sellers are collectively linked to only one buyer. Then we remove the subgraphs in which more than two sellers are collectively linked to only two buyers. When we have exhausted all the possibilities we then remove the subgraphs that have a set of buyers of size t, collectively linked to less than t sellers. The subgraphs removed in the first case, will be type G_i^{S}, the ones removed in the second case will be type G_i^{B} and the remaining subgraphs will be type G^{E}.

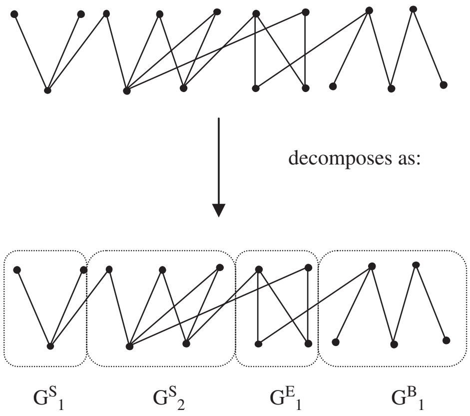

Fig. 4.

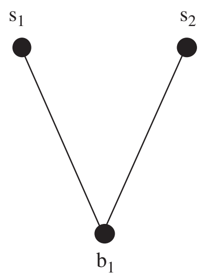

Fig. 5.

The decomposition we have defined above directly allows us to characterize equilibrium outcomes. The subgame-perfect equilibrium payoff will give all the surplus to the short side in the subgraphs that are G^{S} or G^{B} (competitive networks), while the surplus will be split relatively evenly (taking into account the first mover advantage) in G^{E} subgraphs (even networks). We demonstrate below precisely how this works for the particular networks and procedures used in our experimental design.

3.1. Implementation

Before describing the details of the bargaining game, it may be helpful to show the particular networks that we use in our experiment; see Figs. 5–7.

Network (1) is analogous to the Roth et al. [43] market game, but with only two proposers (instead of nine) for each responder. In both networks (2) and (3), there are two buyers and two sellers; in network (2) each buyer is connected to each seller, while in network (3) there is no link between b_2 and s_4. In these networks, nodes represent traders and arcs represent trading possibilities.

We begin our experimental sessions with one network (1) and one of either network (2) or (3). We later introduce a connection between the two networks, linking either the bottom of (1) to

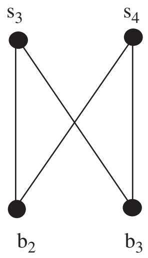

Fig. 6.

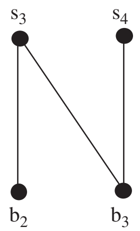

Fig. 7.

the top of the other network, or the top of (1) to the bottom of the other network. The discerning reader might also notice that the prediction of different behavior resulting from these different links would also hold with network (1) and a separate dyad, a simpler case. However, we chose the seven-person structure to provide a bit more richness in the environment; as it happens, the number of links in the four-person network becomes behaviorally relevant, as we find some differences depending on whether this network is fully connected. To the best of our knowledge, we are the first to experimentally compare behavior in a N versus a |X| structure. In addition, one of the strong predictions of the model is that people who are not directly involved with the added link can nevertheless be affected by it. By using a seven-person network, we have more possibilities for testing this prediction without increasing the complexity too much.

In the first round of bargaining, sellers simultaneously make proposals to divide 2500 with any of their linked buyers. [11] These offers are displayed, and buyers then simultaneously choose to accept at most one of the proposals made by linked sellers. If one or more responders accept the same share proposed by one or more proposers, the accepting player who is left unmatched after a coin flip is then matched with the other proposer who made the same offer. [12] This means that responders actually accept a proposal, but they do not care with which specific proposer they trade. If a buyer and seller trade, they and their links are removed from the network. If any linked buyers and sellers remain, the game proceeds to the second round, where now *buyers* propose divisions of 2400 to all of their linked sellers, who choose whether to accept. If a third round is

[11] Note that sellers and buyers are simply labels. We could have just as well called the first movers buyers and the results would be unchanged.

[12] We thank Matt Jackson and Tom Palfrey for pointing out that in fact this process is necessary for the equilibrium predictions to hold.

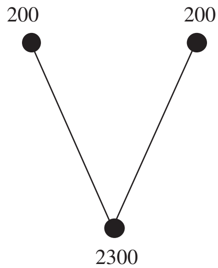

Fig. 8.

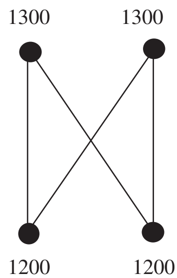

Fig. 9.

necessary, sellers propose divisions of 2300, etc. There are at most six rounds of bargaining; a coin is flipped in front of the group after round 4 to determine whether the period ends after round 5 or 6. [13] All unmatched players receive 200. [14]

Let us examine how to determine the subgame-perfect equilibrium payoffs (subsequently denoted by PEP). Our analysis begins with the study of the simplest possible cases: Networks with at most two sellers and two buyers. We start by considering triads in Fig. 8.

In the unique PEP of our game (see Proposition 1; all propositions and proofs are given in Appendix B), the buyer receives 2300, and the sellers receive 200. The result is intuitively clear: Competition is so strong that the agents on the long side are forced to yield all surplus to the agent alone on the short side. In this respect, it is worth noting that competition is much stronger than the ultimatum effect given by the last period. Even if it is the turn of s_1 and s_2 to propose in the last period, they are forced to yield all surplus to agent b_1.

A buyer and seller linked only to each other will split the surplus nearly evenly, with the initial proposer having a small advantage (Lemma 1), and we can extend this result to both networks feasible with two sellers and two buyers (Proposition 2); see Figs. 9 and 10.

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[13] We introduced this uncertainty in order to prevent unraveling effects, at least prior to round 5.

[14] We chose a non-zero reservation payoff to avoid having to give individual participants no money other than the show-up fee. This may serve to reduce any ‘fairness’ considerations, which are not the research question for this paper. We shall see that the passage of time seems to reduce their impact in any case. While we could have chosen a higher reservation payoff to reduce fairness considerations, doing so would have also reduced the power of our statistical tests to show the effect on behavior of adding a link.

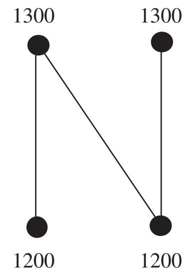

Fig. 10.

According to this theory there is no difference between the predictions for networks (2) and (3). One might initially suppose that the equilibrium should favor the agents having more connections, but a closer look tells us that the extra connection in (2) is actually irrelevant. Suppose the seller with two links offers a small share to the buyers. Clearly, the buyer with two links will reject such a proposal, since he has the other seller all to himself. If the other buyer also rejects the proposal, then the seller with two links will be forced to offer a larger share. This process continues until all buyers and sellers receive equal shares (subject to the slight inequality present from the asymmetric timing of offers).

When the number of players in each side is less than or equal to two, we have seen that either we have a network in which one side completely extracts the surplus from the other side (we will denote these networks as ‘competitive’ networks, like Network 1) or we have networks in which neither of the sides is stronger, with the surplus being split evenly with the proposer having a slight advantage (denoted as ‘even’ networks, as Network 2 or 3). Equivalently, we can also state that the theoretical joint payoffs received by agents always falls into one of only two categories: (1) When agents are in a competitive network, the agent on the short side receives 2300 (all the surplus minus the reservation value), while the agent on the long side receives 200 (the reservation value). (2) In an even network, agents making initial proposals receive 1300 (slightly more than half of the pie) and agents responding to these proposals receive 1200 (slightly less than half of the pie).

Interestingly, this property can be generalized to any network. Theorem 2 (see Appendix B) tells us that in each network, no matter how complex it may be, there exists an equilibrium in which agents either extract all the surplus, receive only the reservation value, or split the pie nearly evenly. This result uses the existence of a decomposition (see Theorem 1) that allows us to split any network into subgraphs that are either competitive or even, plus some extra links. Competitive subgraphs reproduce situations in which, as in Network 1, there exists an equilibrium in which the long side extracts all surplus. Even networks (like Network 2 or 3) reproduce situations in which there exists an equilibrium in which agents split the surplus roughly evenly. This PEP is not unique in all cases, but it is unique for the networks used in this experiment. Our derivation closely follows Corominas-Bosch [18], by adapting the model of the infinite-horizon game treated therein to our finite-horizon game.

Applying Theorem 2 to our networks, we get the following PEP for the seven-player networks, which we show is unique in Propositions 4 and 5; see Figs. 11–14.

It may be helpful to provide some intuition for the theoretically predicted differences between, for instance, networks (4) and (6), the seven-person groups that are formed by adding a link between the smaller networks. In network (6) the added link from s_2 to b_2 (hereafter, a top-to-

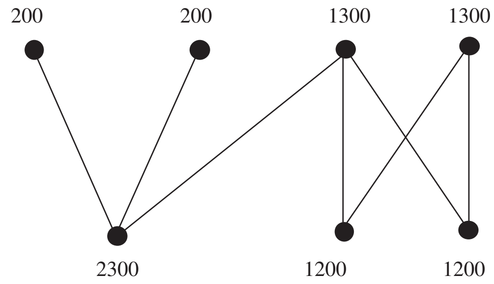

Fig. 11.

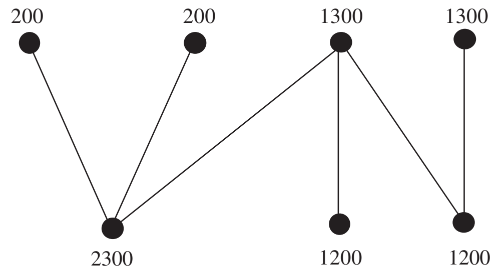

Fig. 12.

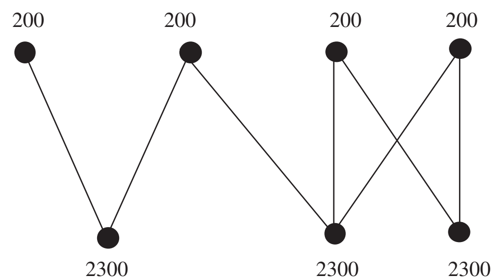

Fig. 13.

bottom link, or *tb*) serves as a propagation mechanism. We know that one of the sellers must receive the reservation payoff, since there is no way to match all sellers with all buyers. Assume it is s_1 (we can start with s_2, s_3, or s_4 and get the same result), then s_2 must also receive the reservation payoff, or else s_1 could make a proposal that would yield him a slightly higher payoff than the reservation value, a proposal that should be accepted by b_1. Similarly, it must be the case that s_3 proposes receiving the reservation payoff, otherwise s_2 could deviate. This leaves b_3 in a position to also extract surplus. Essentially, the buyers are jointly able to exploit the sellers; b_1, b_2, and b_3 receive full shares and s_1, s_2, s_3, and s_4 receive only the reservation payoffs.

On the other hand, in network (4) there is no propagation across the added link (hereafter, a bottom-to-top link, or *bt*). Seller s_3 knows that either s_1 or s_2 must get 0, so that b_1 will expect to

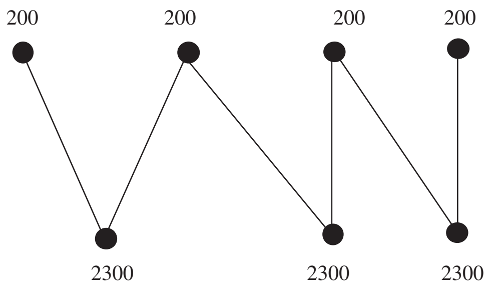

Fig. 14.

get a full share. This implies that s_3 eliminates b_1 from his bargaining plans, and the (s_3, s_4, b_2, b_3) network can be considered in isolation.

Thus, an apparently minor change in the network (differing by only one connection) may strongly alter the situation. A new connection can affect players who are not directly involved. On the other hand, some new connections are theoretically irrelevant.

4. Experimental design

This experiment was conducted at the Universitat Pompeu Fabra in Barcelona, Spain. Participants were recruited by posting notices at campus locations. A total of 105 people participated in our study (each person could only participate in one session). Most of these were students in economics or business, with a smaller percentage of students in the humanities. Session lasted about 100 min and average earnings were approximately 1600 Spanish *pesetas* (at the time, $1 = 140 pesetas), including a show-up fee of 500 pesetas.

Participants were given written instructions (an English translation of the instructions is presented in Appendix C) and these were read aloud.[15] We used a three-person network and one of two types of four-person networks in the initial phase of our experimental sessions. Thus, there were seven agents in each experimental session. These are the networks we used in the initial phase; see Figs. 15–18.

We conducted 15 sessions. There were four sessions for each type of network, except for Treatment 1, as one session was canceled due to an insufficient number of participants. Each session consisted of 10 separate bargaining interactions or 'periods'. Every participant received a sheet of paper that stated his or her letter assignment in the period.

The networks were drawn on the board and each proposal was written next to the player's letter. In the first half of the first round, agents s_1, s_2, s_3, and s_4 made proposals on sheets of paper. Blank sheets were also collected from agents b_1, b_2, and b_3, so that anonymity with respect to role was preserved. In the second half of this bargaining round, agents b_1, b_2, and b_3 indicated which one (if any) of the outstanding proposals they wished to accept.[16] Acceptances and rejections

[15] The instructions did not correctly reflect the specifications of the theoretical model when two agents simultaneously accept the same individual's offer, while there was another identical offer available (see footnote 12). However, this situation was rare in the laboratory and was in fact implemented in accordance with our model in three of the five cases where it occurred.

[16] In the second half of the first round, we collected responses from b_1, b_2, and b_3, as well as blank sheets from s_1, s_2, s_3, and s_4. In all subsequent rounds (if necessary), we continued to collect sheets from every player.

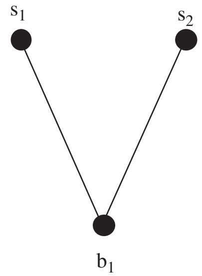

Fig. 15.

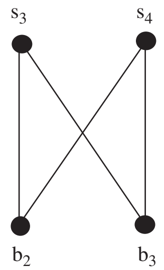

Fig. 16.

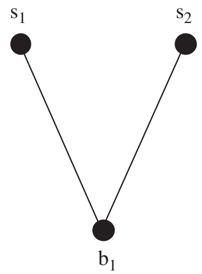

Fig. 17.

were indicated on the board and an ellipse was drawn around links between those agents who had reached agreements, removing them and their links from the network. Bargaining rounds continued as needed. In the second bargaining round, agents b_1, b_2, and b_3 made proposals and agents s_1, s_2, s_3, and s_4 indicated which one (if any) of the outstanding proposals they wished to accept. This pattern continued in odd and even rounds. Each period was comprised of up to five or six bargaining rounds (decided by a coin flip after round 4), with the total amount to be divided shrinking after each unsuccessful bargaining round.

The session then proceeded to the next period. We randomly changed positions for each individual in each period, subject to the constraint that each person remained in their original three- or four-person network. While it might seem more natural to keep the same letter assignments

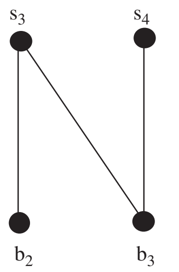

Fig. 18.

Table 1
Treatment summary

Treatment	Seven-person network	Sessions	Periods/Session
1	**V**/|**X**|	3	10
2	**V/N**	4	10
3	**V**\\|**X**|	4	10
4	**V****N**	4	10[a]

[a] There were only nine periods in one session of Treatment 4.

throughout the session and learning might well have been thereby accelerated, fixed roles in our multi-period design could lead to people deciding to invest in some form of reputation; in addition, role changing allows for 'smoothing' of the heterogeneity of individuals and minimizes arbitrary performance by a participant unhappy at being stuck in a disadvantageous role throughout the session. More importantly, as will be shown later, this does not lead to different results (for the basic networks in periods 1–4) from comparable studies without role changes. Finally, one of our findings, that subjects are influenced by others' behavior in their position, would not have been identifiable without this role rotation. [17] Nevertheless, it is possible.

We played four periods before adding a link between the two networks and six periods after the link was added. The number of periods to be played either before or after the link was added was not divulged to the participants, although they were told that there would be a change in the network at some point in time. The participants only learned the nature of the new network at the time that the change was publicly introduced.

People were told that one of the 10 periods would be chosen at random for implementation of actual monetary payoffs. At the end of the experiment, a 10-sided die was rolled to determine the period chosen for payment. [18] Participants were then paid individually and privately. Table 1 summarizes our treatments.

[17] Furthermore, Charness and Rabin [13] find no significant effects from role rotation in simple binary-choice games, and van der Heijden et al. [46] show how role rotation is qualitatively irrelevant in a sequential exchange-game experiment (note that we have role randomization, not role rotation). In fact, Binmore et al. [5] find that role reversal brings results *closer* to equilibrium in a bargaining game.

[18] This random-payment design avoids possible 'income effects' from participants having accumulated wealth in early periods.

5. Experimental results

In this section, we present our results and the performance of the theoretical predictions. Overall, we find that the maximum number of matches (three) was achieved in 139 of 149 periods, with 98% (437 of 447) of all potential matches made. Table 2 shows the distribution of the number of rounds needed to reach agreement in each session.

On average, participants received 96.2% of the possible surplus of 6300 for each seven-person group, and this was fairly consistent across treatments and pre- and post-link periods. [19] Three-quarters of all possible matches are made in the first round, while another 17% are made in the second round. Only 15 bargaining sessions go beyond round 4, and two-thirds of these never become agreements. [20] Thus, of the total inefficiency of 3.8%, 2.2% can be attributed to failed negotiations while the rest is due to agreements reached after round 1.

Table 3 summarizes the average payoffs for first-round agreements in each treatment, both before and after the introduction of the additional link after period 4. [21,22]

A non-parametric Wilcoxon–Mann–Whitney rank-sum test [48] on payoff changes, using fully independent session-level data (15 observations), confirms that the type of link added (*tb* or *bt*) strongly affects bargaining behavior. The changes in average (s_1, s_2) payoffs and the average

Table 2
Agreements reached, by round

Treatment	Round						
	1	2	3	4	5	6	None
1	64	19	3	0	2	0	2
	(71.1%)	(21.1%)	(3.3%)	(0.0%)	(2,2%)	(0.0%)	(2.2%)
2	93	19	2	3	1	0	2
	(77.5%)	(15.8%)	(1.7%)	(2.5%)	(0.8%)	(0.0%)	(1.7%)
3	99	14	1	1	1	0	4
	(82.5%)	(11.7%)	(0.8%)	(0.8%)	(0.8%)	(0.0%)	(3.3%)
4	79	24	5	6	1	0	2
	(67.5%)	(20.5%)	(4.3%)	(5.1%)	(0.9%)	(0.0%)	(1.7%)
Total	335	76	11	10	5	0	10[a]
	(74.9%)	(17.0%)	(2.5%)	(2.2%)	(1.1%)	(0.0%)	(2.2%)

[a] Two disagreements in N networks were the result of players s_3 and b_3 reaching an agreement, and leaving players E and F isolated. Thus, only eight disagreements reflect failed bilateral bargaining.

[19] The proportions range from 94.7% (periods 1–4 of Treatment 3) to 97.4% (periods 5–10 of Treatment 2).

[20] Although the numbers here are quite small, a similar result in time-decay bargaining is found in Charness [12]. This result shows that even a relatively large financial disincentive in the last period may not induce an agreement in a final dyad. However, these disagreements are rare, suggesting that even though there is some form of 'fairness' present in these dyads, it is not a major factor in our results.

[21] We only use first-round agreement data since bargaining behavior in later rounds may also be confounded by changes in the remaining network structure. In theory, all bargaining should end in round 1; recall that this occurs 75% of the time. This selection criterion will be used in tests throughout the paper, unless otherwise noted. For completeness, the average payoffs for all cases are shown in Tables D1–D4 in Appendix D.

[22] Data for periods 1–4 reveal two features. The V network has unequal divisions with the bottom extracting most of the pie. This is similar to the result observe in Roth et al. [43] market game. Second, in the "balanced" network |X|, both sides of the market obtain almost equal shares as in the standard two person pie shrinking game. We take both of these results as indication the role randomization did not have a substantial effect on our results.

Table 3
Average payoffs by network position (first-round agreements)

Treatment	Period	Network position						
		s_1	s_2	b_1	s_3	s_4	b_2	b_3
1	1–4	606	525	1569	1265	1260	1238	1229
V/|**X**|		(200)	(200)	(2300)	(1300)	(1300)	(1200)	(1200)
	5–10	396	331	1974	1264	1288	1217	1236
		(200)	(200)	(2300)	(1300)	(1300)	(1200)	(1200)
2	1–4	819	434	1443	1333	1082	1108	1279
V/**N**		(200)	(200)	(2300)	(1300)	(1300)	(1200)	(1200)
	5–10	400	386	1924	1327	1252	1175	1248
		(200)	(200)	(2300)	(1300)	(1300)	(1200)	(1200)
3	1–4	560	737	1403	1246	1262	1258	1229
V\\|**X**|		(200)	(200)	(2300)	(1300)	(1300)	(1200)	(1200)
	5–10	982	784	1482	934	757	1407	1374
		(200)	(200)	(2300)	(200)	(200)	(2300)	(2300)
4	1–4	442	725	1533	1261	1119	1122	1294
V**N**		(200)	(200)	(2300)	(1300)	(1300)	(1200)	(1200)
	5–10	839	839	1661	729	750	1537	1475
		(200)	(200)	(2300)	(200)	(200)	(2300)	(2300)

Equilibrium payoffs in parentheses.

difference in (b_2, b_3) and (s_3, s_4) payoffs are always highest when a *tb* link is added; this reverses for player b_1's payoffs (see Table D1). Each of these comparisons indicates a difference significant at $p = 0.002$.

Several implications of the theory can be tested; we first consider the point predictions, and then discuss the qualitative predictions. Table 4 breaks the average payoff per position down by link-type, and reports whether the payoff differs (at the 5% significance level) from the theoretical prediction. We pool all the (first-round agreement) data for s_1, b_1, and b_2, as the type of link does not affect the predicted payoffs for these positions.[23] For s_2, s_3, b_3, and b_4, the theory distinguishes between whether or not there is a *tb* link. The columns give the theoretical predictions, and in each cell the average amount is reported, accompanied by *r* if the theoretical prediction is rejected and *nr* otherwise. As can be seen, only two of the 11 predictions cannot be rejected. However, the relative magnitudes of the estimates seem to go in the direction suggested by theory.

To test the qualitative predictions, we first average the payoffs by subject (for each position and relevant link). Using these per-subject averages, we conduct sign tests. Each cell compares whether the column and row components are equal, with a one-sided test if there is a directional hypothesis (Table 5).

All but two of the theoretical predictions find support. Even for the two exceptions, the difference between actual average payoffs and predicted payoffs is never more than 100.[24] We will explore

[23] We note that the apparent differences in *A* and *B* payoffs in periods 1–4 in some treatments vanish when these are (appropriately) aggregated across treatments.

[24] The (s_3, s_4) average payoff with no *tb* link is only slightly larger than the (b_2, b_3) average payoff, (1248 vs. 1221), instead of being 100 larger, and the s_3 and s_4 payoffs with no *tb* link are different (1286–1211).

Table 4
Tests of the quantitative theoretical predictions

Type	Link	200	1200	1300	2300
s_1	All	641 *r*			
s_2	All	578 *r*			
b_1	All				1646 *r*
s_3	No *tb*			1286 *nr*	
s_3	*tb*	855 *r*			
s_4	No *tb*			1211 *r*	
s_4	*tb*	754 *r*			
b_2	No *tb*		1188 *nr*		
b_2	*tb*				1464 *r*
b_3	No *tb*		1255 *r*		
b_3	*tb*				1418 *r*

Table 5
Nonparametric tests of payoff comparisons[a]

Type	Link	Type s_1	s_2	s_3	s_4	b_2	b_3	s_3	s_4	b_2
		All	All	No *tb*	No *tb*	No *tb*	No *tb*	*tb*	*tb*	*tb*
s_2	All	*nr*, *t*								
b_1	All	*r*, *t*	*r*, *t*							
s_3	No *tb*				*r*	*nr*, *t*		*r*, *t*		
s_4	No *tb*			*r*						
b_2	No *tb*				*nr*		*nr*, *t*			
b_3	No *tb*					*nr*, *t*				
s_4	*tb*							*nr*, *t*		
b_2	*tb*					*r*, *t*		*r*, *t*		
b_3	*tb*									*nr*, *t*

r (*nr*) means we can (cannot) reject (at $p = 0.05$) the hypothesis that the payoffs are equal.
t means the result is consistent with the theory.
[a]All tests in this table are sign tests, except for the (s_3, s_4) vs. (s_3, s_4) and the (b_2, b_3) vs. (b_2, b_3) comparisons, which are Wilcoxon–Mann–Whitney rank-sum tests.

the causes for these deviations in our discussion. Generally the directional comparisons are very much in line with the theoretical predictions, at high levels of statistical significance.[25]

[25] While we do not focus on the networks remaining after the first round of bargaining, some summary statistics may be useful. There were 65 cases where only two connected bargainers remained after the first round. These were always members of the original four-person network, except for one case where s_1 and b_1 remained unmatched. There were also 24 cases where a set of three connected bargainers remained after the first round, with 15 of these being (s_3, s_2, b_1). All eight bargaining failures occurred in the dyads.

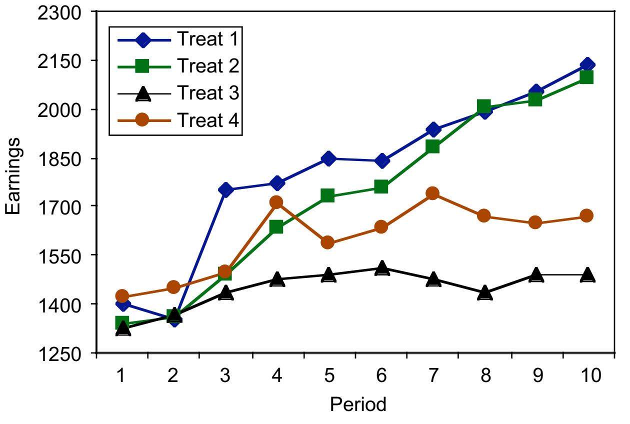

Fig. 19.

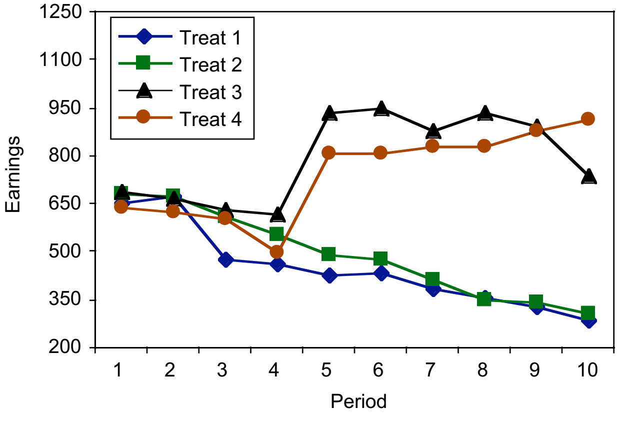

Fig. 20.

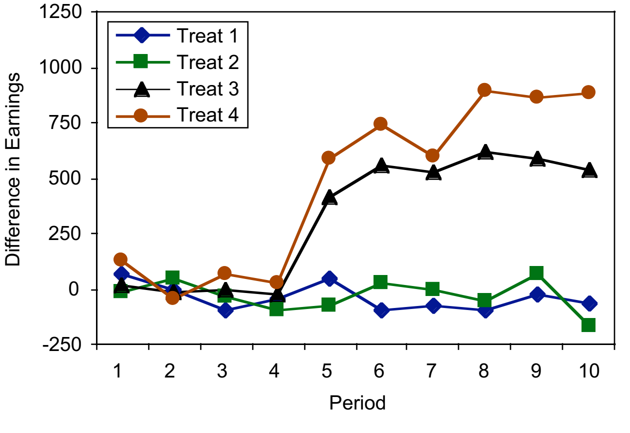

Fig. 21.

Although the theoretical point predictions generally fail, the evolution of play suggests that this might be in part remedied over time. The theory seems to fare poorly when it predicts a very uneven split. In most of these cases, however, payoffs either stabilize or move closer and closer to the predicted values. Figs. 19–21 illustrate how payoffs change over time for the top and bottom of each small network.

Fig. 19 shows that player b_1's earnings increase in all treatments prior to the addition of a link. When the new link connects b_1 and s_3, b_1's earnings continue to increase steadily. However, when the new link connects s_2 and b_2, b_1's earnings do not change as much after period 4.

Fig. 20 shows that the average earnings for players s_1 and s_2 decline in all treatments prior to the addition of the new link. This trend continues when the new link connects b_1 and s_3; however, when the new link connects s_2 and b_2, the average earnings increase somewhat.

Fig. 21 looks at the difference between the average payoffs for the top and the bottom of the four-person network. In the first four periods, there is very little difference between the average payoffs for b_2 and b_3 and the average payoffs for s_3 and s_4. However, behavior after the new link is added is very sensitive to whether the link connects b_1 and s_3 or b_2 and s_2. In the first case there is no change, but in the second case b_2 and b_3 payoffs increase dramatically.

Hence, all of these trends appear to bring the division of payoffs closer to the theoretical predictions, except in the case where a *tb* link is added. A possible reason for the latter behavior will be explored later.

6. Discussion

Thus far it seems fair to say that the model predicts the directions of the split rather well, and that the *tb* link has the expected effect. Yet questions remain concerning what makes behavior differ from the exact predictions of the theory and how to explain the few qualitative-prediction anomalies. Of course, to the extent that we find factors that contributed to these deviations, these may very well be due to our particular experimental environment.

The observed outcomes are the result of at least two decisions. On the one hand, people decide what they are willing to offer. On the other hand, people receiving these offers decide what they are willing to accept. We first attempt to identify the determinants of whether an offer is accepted or rejected. Table 6 presents probit estimates of the determinants of whether, in round 1, subjects accepted or rejected the best offer they received (when available offers differed, the lower one(s) were never chosen).[26] Two separate probit regressions are estimated for the responders, one for type b_1 and one for pooled types b_2 and b_3.[27]

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[26] In this case, a likelihood ratio test strongly rejects the random-effects specification for b_2 and b_3 types. Since the results are not markedly different for b_1, we only include the probit in the text. The random-effects probit estimates are available in a longer working-paper version. There were no significant period effects, so these are also omitted in the regression. The results were unaffected.

[27] Pooling data for positions b_2 and b_3 may seem incorrect since although they are predicted to be equivalent in equilibrium, they might not be in practice. The extent to which they differ is the number of connections. Thus, we control for the number of links even if these are not predicted to have an impact theoretically. Another (separate) issue is that, as shall be seen later, the added link between the two (originally) separate networks, *tb* and *bt*, may not *be* irrelevant in the laboratory. Hence we have also estimated the probit regressions interacting the share offered with a dummy for each type of link. We show that for type b_1, none of the three coefficient estimates differ statistically; for types b_2 and b_3, the cases with no link and with a *bt* link do not differ statistically, but the coefficient for the *tb* link differs from both of the others. This both confirms the theory and validates the specification choice for the probit regressions.

Table 6
Determinants for accepting an offer

	Type b_1	Types b_2 and b_3 (pooled)
Share offered (all link types for b_1 and no *tb* link for b_2 and b_3)	12.95***	11.79***
	(3.95)	(2.40)
Share offered with *tb* link (for b_2 and b_3)	–	8.92***
		(2.04)
Average share the position received in the past	−13.27***	−2.10***
	(4.10)	(0.77)
Two-link	–	0.54**
		(0.30)
Three-link	0.05	1.00**
	(0.62)	(0.46)
Constant	0.97	−2.76**
	(1.39)	(1.21)
Number of observations	132	264
Log likelihood	−37.93	−107.67

Period one omitted *,** ,*** indicates statistical significance at $p = 0.10, 0.05, 0.01$. Std. errors in parentheses.
Two-link is a dummy that has a value of 1 if the offerer is linked to two people, and is 0 otherwise.
Three-link is a dummy that has a value of 1 if the offerer is linked to three people, and is 0 otherwise.

As expected, the share offered is a significant factor with regard to acceptance or rejection—higher proposed shares are more likely to be accepted. However, note that b_2 and b_3 are generally willing to accept less money when there is a *tb* link. This is a bit surprising, as we have seen (Tables 3 and 4) that b_2 and b_3 receive a greater amount with a *tb* link. It would appear that this effect must be driven by higher *tb*-link offers being made. In fact, (s_3, s_4) round 1 offers average 1366 with a *tb* link, compared to 1180 with a *bt* link (the Wilcoxon–Mann–Whitney test gives $p < 0.001$). Since b_2 can reach an agreement with s_2 with a *tb* link, both s_3 and s_4 should be concerned with being left unmatched in this case, and so must compete.

We also observe the fact that the shares allocated in the past affect what one is willing to accept. Thus, people appear to be learning the 'social norm' for the group.[28] In an unfamiliar situation (either in the laboratory or in the field), where people may be uncertain about appropriate behavior, it is natural to consider that individuals update their beliefs about social norms on the basis of other observed outcomes. Here we see that the higher the average share previously received by a position, the less likely it is that a person in that position will accept any given offer.

We find that both b_1 and (b_2, b_3) decisions on whether to accept offers are sensitive to whether the subject is connected to only one person; this is not predicted by the theory. However, this factor seems quite plausible psychologically; perhaps people get more nervous when they only have one connection, and are correspondingly less aggressive. Also notice that the coefficient for a three-link is nearly identical to that of the two-link (it is not statistically different) for b_2 and b_3, and the coefficient for a three-link is effectively zero for b_1 decisions.[29,30]

[28] Note that this is not the usual form of learning, where agents learn from the agents to whom they are connected. Instead, since agents change positions, they see what other people do in the same position. We find that their behavior is influenced by what they observe.

[29] Note that b_1 is always connected to at least two people in the first round of bargaining, which is all we consider in our analysis.

[30] The analysis of the marginal effects is available in a longer working-paper version.

Table 7
Determinants of offers

Independent variable	Types s_1 and s_2[a]		Types s_3 and s_4[b]	
	Coeff.	Std. error	Coeff.	Std. error
Period 2	0.030	0.023	0.030	0.019
Period 3	0.075***	0.022	0.034**	0.015
Period 4	0.106***	0.023	0.013	0.019
Period 5	0.176***	0.025	0.012	0.021
Period 6	0.204***	0.024	0.034*	0.020
Period 7	0.214***	0.025	0.034*	0.020
Period 8	0.215***	0.024	0.040**	0.019
Period 9	0.238***	0.025	0.068***	0.018
Period 10	0.227***	0.025	0.056***	0.020
tb link	−0.101***	0.022	0.041***	0.016
Two-link	−0.052***	0.017	−0.031***	0.010
Three-link	–	–	−0.030**	0.014
# of observations	298		296	

Period one omitted *,** ,*** indicates statistical significance at $p = 0.10, 0.05, 0.01$.
Two-link is a dummy that has a value of 1 if the offerer is linked to two people, and is 0 otherwise.
Three-link is a dummy that has a value of 1 if the offerer is linked to three people, and is 0 otherwise.
[a]Pooling is justified both theoretically and empirically (see Table 5).
[b]Although pooling is justified theoretically, one might oppose this on the basis of the results in Table 4. Note, however, that the difference in payoffs between s_3 and s_4 only occurs if they are connected to a different number of buyers (see Table 8). By controlling for the number of links, this is taken into account in the regression.

We can also examine the determinants of the offers made in the first round by s_1, s_2, s_3, and s_4.[31] Our results for first-round offers by s_1 and s_2 (pooled) and by s_3 and s_4 (pooled) are shown in Table 7.

Here we see positive time trends for (s_1, s_2) offers, with significant t-statistics almost from the beginning. Perhaps these offers would approach the extreme level predicted with more time. In conformance with the payoffs displayed in Fig. 2, but in contrast with the predictions, it appears that s_1 and s_2 adjust their offers downwards when a *tb* link is added.[32] However, the negative coefficient for the *tb* link dummy is overwhelmed by the coefficients for the later periods. The reason for this seems to be that after the *tb* link is added, s_3 and s_4 do not increase their offers as much as is predicted by theory. This allows s_2 to undercut s_3 and also allows s_1 to decrease his offers.

Note that this also explains the anomalous jump in Fig. 2 for Treatments 3 and 4.[33] We should also expect s_3 and s_4 to adjust their offers, and this is exactly what is observed.

As with b_1 and (b_2, b_3) offer-acceptance decisions, we find that both (s_1, s_2) and (s_3, s_4) offers are sensitive to whether the subject is connected to only one person.[34] This may explain the surprising result (Table 4) that s_3's and s_4's payoffs are not equal. To see this, we will show that results for networks 2 and 4 (where s_3 and b_3 have more connections than s_2 and b_2) drive the

[31] These were estimated using fixed-effects regressions. We can reject the hypothesis that the fixed effects are not statistically significant.

[32] A sign test indicates that s_1 and s_2 payoffs are significantly lower before a *tb* link than after one is made.

[33] This is also consistent with the observation that b_1's payoffs are higher in treatments 1 and 2 than in treatments 3 and 4 (significant at the 1% significance level using a Mann–Whitney test).

[34] Note that for s_1 and s_2, this simply identifies the different impacts of the link on types.

Table 8
Sign tests on (s_3, s_4) and (b_2, b_3) payoffs

	Link category, network type					
	none, N	*tb*, N	*bt*, N	none, |X|	*tb*, |X|	*bt*, |X|
s_3 vs. s_4	*r*	*nr*	*r*	*nr*	*nr*	*nr*
b_2 vs. b_3	r^*	*nr*	*r*	*nr*	*nr*	*nr*

r (*nr*) means we can (cannot) reject the hypothesis that the payoffs are equal.
r^* means significant at $p = 0.10$, but not 0.05.

payoff inequality. Also notice that for s_3 and s_4, the coefficient for a three-link is nearly identical to that of the two-link (it is not statistically different). Table 8 presents some sign test results.

Our theory predicts that s_3 and s_4 payoffs should be the same, and b_2 and b_3 payoffs should be the same. While s_3 and s_4 payoffs are not different for the |X| network, they are significantly different in most conditions for the N network.[35] As the only real difference between these networks is the number of connections for s_4, it appears that having only a single connection inspires perceived bargaining weakness.

As in bilateral bargaining games, buyers and sellers payoffs are closer than predicted, a phenomenon often attributed to some form of social preferences. However, evidence from market games (e.g., Roth et al. [43]) indicates that bargaining agreements are quite lopsided when there are unequal numbers of buyers and sellers. Our evidence from the V network is consistent with this; for example, Fig. 1 shows that b_1 earnings begin to approach the full 2300 predicted in the final periods. It is worth noting that some prominent social-preference models (e.g., Fehr and Schmidt [25], Bolton and Ockenfels [7]) successfully predict (via heterogeneity) the lopsided payoffs in the market game, so that the presence of fairness is not inconsistent with lopsided payoffs in a multi-player environment. Finally, we note that our main result, the sharply divergent outcomes after *bt* versus *tb* links, occurs *despite* any existing social preferences, which might tend to diminish this divergence.

6.1. Some modeling and design concerns and issues

We have modeled bargaining as an alternating-offer process, with multi-lateral simultaneous bargaining. We begin with the long side of the market making offers, and we do not consider the simpler case of five-person networks with a *bt* or *tb* link between the triad and the dyad. Finally, we provide full information about the network structure, offers, and acceptances to every experimental participant; these characteristics are not completely general to bargaining environments. In view of these issues, we must consider whether our results are artifacts of our specific design.

The first issue is that a more unstructured bargaining protocol might lead to different outcomes, as alternating-offers models may make idiosyncratic predictions about the effects of outside options in bilateral bargaining and this could carry over to the network structure in the design.[36]

[35] Indeed, the only s_3 vs. s_4 comparison that is not significantly different in N networks occurs with a *tb* link. This is consistent with our explanation, as here s_3 is being directly undercut by s_2, and so needs to adjust more (in an immediate sense) than does s_4.

[36] We thank Vince Crawford for this observation.

While this is a reasonable concern, there is some evidence that the observed results are robust to the bargaining protocol. [37]

A second concern is whether our results are robust to which side of the market made the first offer (in round 1), even though there is no theoretical difference. We do have indirect evidence that allowing the short side to make the first proposal would not have affected the results greatly. There were nine cases in periods 1–4 where no agreement was reached in the unconnected V in the first round of bargaining, but an agreement was reached in the second round, where the short side made the proposal to the long side of the market. In all of these cases, the short side indeed received more than the matched agent from the long side. The average amount received by the short side was 1683 (out of 2400), or 70% of the total. This compares with 59% for agreements reached in the unconnected V in round 1; perhaps the divisions would be more extreme in the unequal case if the short side could move first. [38]

While we do not consider the simpler five-person network, we also have some evidence from those six instances where a connected five-person network remained after the first round of bargaining. In one of these cases, the remaining network was type *bt*, decomposing into a triad and a dyad; unsurprisingly, the dyad settlement was fairly even, 54% vs. 46%, while the short side of the V received 69% of the total. More interesting are the five cases where a *tb* five-person network remained; since this network cannot be decomposed, the theoretical predictions are for each agent on the short side to receive the lion's share. There were six agreements reached in the second round of bargaining, with the agent on the short side receiving an average of 72% of the total payoff (the range was 63–79%). If a dyad remained after the second round, the split was 50% for each agent, while if a triad remained, the agent on the short side received 77%. These data suggest that results would not have been dramatically different if we had used five-person networks in our design, although perhaps we would have observed more extreme splits in the *tb*.

Another issue is that it may be unrealistic to expect bargainers to have the full information that we provide, limiting the applicability of our results. One could reasonably argue that in practice one might not actually know details about transactions between parties with whom one cannot transact, so that the network must also determine the information flow in the group. We chose this information structure in part for practical reasons (public display in a hand-run experiment), but also to introduce the possibility of social learning. We recognize that eliminating imperfect information might well affect behavior and decision rules.

Nevertheless, in the small markets/networks mentioned earlier (airplanes, arms, etc.), the limited number of participants may well know the full information that we provide. [39] In addition, the Lovaglia et al. [39] test of the effect of restricting this information showed no discernible difference in (late-session) outcomes, although it took substantially longer to arrive at these outcomes. In line with these results, we conjecture that the public display of all information helped to accelerate the learning process, and perhaps served to minimize disagreements. This additional information may facilitate a common perception of the pertinent social norm. Clearly, since this allowed subjects

[37] Four students at Universitat Pompeu Fabra, A. Alsina, R. Fuertes, E. Moret and M. Planell, replicated our network and payoff structures in a couple of sessions for an undergraduate research project. They used a double-auction design instead of alternating offers. All subjects could submit bids in each round. To maintain anonymity, bids were written down on pieces of paper and an experimenter would copy them on the blackboard. Their results were close to ours, with respect to payoffs, treatment effects, and efficiency.

[38] Of course, there is also a selection-bias issue here, since agents at the bottom node of the V who make proposals in round 2 must have declined proposals in round 1.

[39] Alternatively, consider the academic job market. While a lower-ranked school might not be able to hire (or even interview) top candidates, it is still able to learn hiring information that is relevant to it's own actions.

to see what others in their current position obtained in the past, it might also have contributed to the deviations.[40] Perhaps one useful direction for future work would be to investigate how changes in the information structure affect bargaining behavior and outcomes.

7. Conclusion

We conduct an experiment to study the effect of network structure on bargaining outcomes in a bipartite market of buyers and sellers of a homogenous and indivisible good. In many markets, a buyer is connected to only a small subset of all sellers, and *vice versa*. Such an interaction can be modeled as a network, which describes the feasible links (trading possibilities) between agents.

We observe a high degree of bargaining efficiency, in that the total payoffs received are 96% of the maximum possible.[41] The public display of all bids and acceptances may accelerate learning with respect to both bargaining power and group norms about appropriate division.[42] While there are only 10 separate bargaining interactions for each individual in an experimental session, there is strong evidence of substantial changes in bargaining behavior even over this limited period of time.

In the laboratory, the payoffs often do not match the theoretical point predictions; this is the norm more than the exception in experimental economics (see Chapter 4 in Kagel and Roth [42]), which is why the focus is often on whether a model predicts the correct comparative statics with respect to changes in the key variables in the model. Here the central contribution of the theory, the decomposition, seems to capture the fairly strong differences in bargaining behavior depending on how a link is added between two groups. Payoffs are typically asymmetric where predicted so, and in the expected direction; we find these effects in a short time in a moderately complex environment, perhaps in part because we provide public information about transactions. We also find that subjects not directly connected to an added link are affected by its presence where the theory so predicts.

To the extent that behavior deviates from the theory, we see some explanations outside of the bargaining model and probably related to the specifics of our experimental environment, such as a significant decrease in earnings when an agent is connected to only one other agent, even where an extra connection (in the **N** network) should not make any difference. This indicates that what makes the results from the |**X**| network look so similar to what has been observed before in multilateral bargaining game is not simply the fact that there is the same numbers of buyers and sellers connected together, but also that they all have the same number of connections. Also, there is strong evidence of a form of social learning: The shares that have been allocated in the past to others in one's current position substantially and significantly affect what one is willing

[40] Of course, the ultimate effect of providing this information is an open empirical question. However, Blume et al. [6] find that providing a population history leads to an increase in the proportion of separating outcomes achieved in a sender–receiver game, and Duffy and Feltovich [20] find that observation of other players' actions and payoffs appears to affect the evolution of play. Armantier [1] finds that in a common-value auction, unless subjects learn the signals and bids of other players, their bidding behavior never approaches the behavior predicted by theory.

[41] It is true that the high degree of efficiency may be partially an artifact of the modest decline in payoffs with successive bargaining rounds. Nevertheless, efficiency would still be quite high (92%) with the same bargaining behavior and a (for example) 20% discount from round to round, since 75% of the possible agreements are reached in the first round, and 17% in the second round. A steeper discount rate could also induce more rapid agreement, partially compensating for the higher efficiency loss from round to round.

[42] Chatterjee and Dutta [14] find that public offers in thin markets lead to a unique subgame-perfect equilibrium in pure strategies, whereas private offers do not permit any efficient equilibria in pure strategies.

to accept. This phenomenon could be the result of people updating their beliefs about the success of different strategies, as in belief-based learning models [26]; it could also be a more general form of social learning, where subjects are trying to learn the acceptable norm by observing the behavior of others (see Ellison [21], for example).

We feel that the network framework is a useful metaphor for many market environments. Natural extensions of our work include changing bargaining timing and protocols, as well as considering endogenous link-formation with bipartite markets. For example, if we consider that it may be possible to add or subtract links in markets, we can predict the effect of such changes in the trading regime. [43] It is plausible that the lower payoffs experienced by people with few links could lead to over-connectedness, from a social standpoint. As network theory is still evolving and general solutions are often unobtainable, experimental study seems a very natural complement in this area.

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Appendix A. Graph theory notation and results

We now start introducing basic concepts in graph theory. All concepts are standard (excepting the definition of G^{S}, G^{B}, and G^{E}) and can be found in any graph theory textbook, e.g., Gould [29].

A non-directed *bipartite graph* $G = \langle S \cup B, L \rangle$ consists of a set of *nodes*, formed by n sellers $S = \{s_1, \ldots, s_n\}$ and m buyers $B = \{b_1, \ldots, b_m\}$, and a set of *links* L, each link joining a seller with a buyer. An element of L, say a link from s_i to b_j will be denoted as $s_i\colon b_j$.

A *subgraph* $G_0 = \langle S_0 \cup B_0, L_0 \rangle$ of $G = \langle S \cup B, L \rangle$ is a graph such that $S_0 \subseteq S$, $B_0 \subseteq B$, $L_0 \subseteq L$, and such that each link in L_0 connects a seller of S_0 with a buyer in B_0. When we speak of the *subgraph* G_0 *induced by the set of nodes* $S_0 \cup B_0$ *in* G we mean the subgraph formed by the nodes $S_0 \cup B_0$ and all the links that connect a seller in S_0 and a buyer in B_0 in G.

A *matching* in a bipartite graph $G = \langle S \cup B, L \rangle$ is a collection of pairs of linked members of B and S such that each agent in $S \cup B$ belongs to at most one pair. We say that a subset of agents can be matched if there exists a matching involving these agents.

[43] For example, suppose there is a *tb* link in existence and s_2 can sever it. b_2 and b_3 would pay s_2 to do so, but would be bidding against s_3 and s_4.

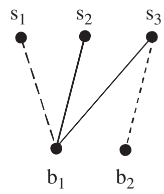

Fig. 22.

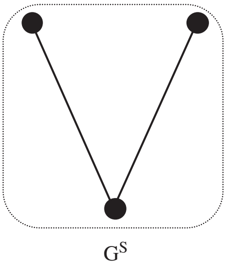

Fig. 23.

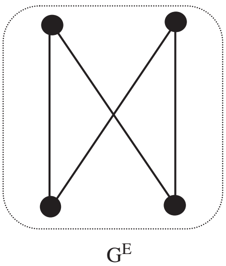

Fig. 24.

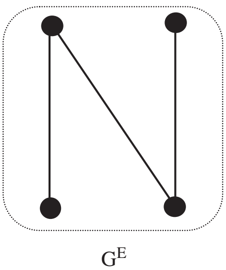

Fig. 25.

For instance, in the following graph there exists a matching involving agents s_1, s_3, b_1 and b_2 (depicted in Fig. 22 with the dotted lines), but there exists no matching involving s_1 and s_2.

We now define three different types of connected graphs, that we will denote by G^{S} (where 's' stands for a surplus of sellers), G^{B} (with a surplus of buyers) and G^{E} (with an equal number of buyers and sellers). For each of these graphs, one can construct a matching with a set of nodes in the long side at most equal to the short side.

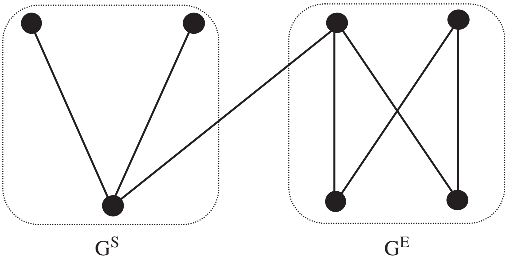

Fig. 26.

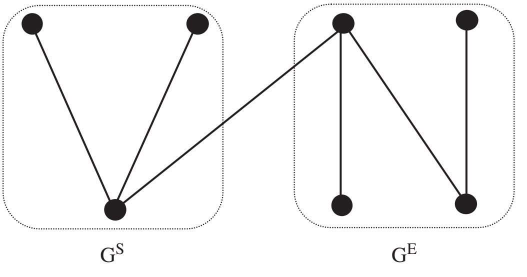

Fig. 27.

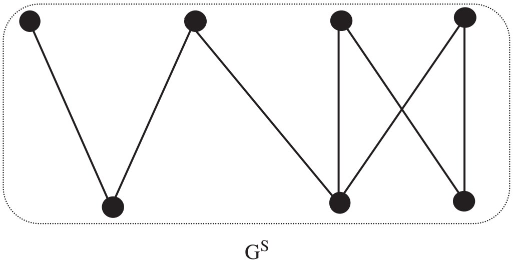

Fig. 28.

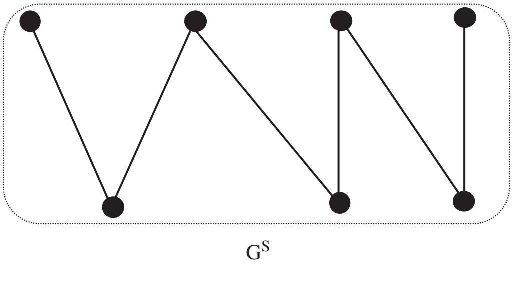

Fig. 29.

Definition. A graph $G = \langle S \cup B, L \rangle$ with more sellers than buyers ($|S| = n > m = |B|$) is a G^{S} *graph* if any subset of sellers of size smaller or equal than m can be matched.

Symmetrically, a graph with more buyers than sellers ($n < m$) is a G^{B} *graph* if any subset of buyers up to size n can be matched. Finally, a graph with as many sellers and buyers ($n = m$) is a G^{E} *graph* if there exists a matching involving all its agents.[44]

Theorem 1 shows that any graph decomposes as a union of subgraphs which are of one of these three types, plus some extra links which will never connect a buyer in a subgraph G^{B} with a seller in a subgraph G^{S}. A simple iterative algorithm for decomposing bipartite networks is at the heart of the process.

Theorem 1. *Every graph G can be decomposed into a number of subgraphs* $G_1^{\mathrm{S}}, \ldots, G_{nS}^{\mathrm{S}}$ (*of the* G^{S} *type*), $G_1^{\mathrm{B}}, \ldots, G_{nB}^{\mathrm{B}}$ (*of the* G^{B} *type*), $G_1^{\mathrm{E}}, \ldots, G_{nE}^{\mathrm{E}}$ (*of the* G^{S} *type*), *such that each node of G belongs to one and only one of the subgraphs and any seller* (*buyer*) *in a* G_i^{S} (G_i^{B}) *is only linked to buyers* (*sellers*) *in a* G_j^{S} (G_j^{B}).

Moreover, a given node always belongs to the same type of subgraph for any such decomposition. We will write $G = G_1^{\mathrm{S}} \cup \cdots \cup G_{nS}^{\mathrm{S}} \cup G_1^{\mathrm{B}} \cup \cdots \cup G_{nB}^{\mathrm{B}} \cup G_1^{\mathrm{E}} \cup \cdots \cup G_{nE}^{\mathrm{E}}$, *with the union being disjoint.*

Proof. See Corominas-Bosch [18]. □

We can adapt the theory to the particular networks used in our design: applying Theorem 1 to the networks used in the experiment, we get the following decompositions as shown in Figs. 23–29.

Appendix B. Propositions and proofs

For simplicity, in the propositions and theorems below, we denote by Π_t the amount that can be split among any two agents at round t. That is, $\Pi_t = 2500 - (t-1) * 100$, for $1 \leqslant t \leqslant 6$. Whenever we speak about a proposal $(p, 1-p)$, we mean that the proposer suggests a share of p for himself and $1-p$ for the responder.

Proposition 1. *Suppose that the initial network is given by Fig.* 30. *Then there is a unique PEP equilibrium payoff, which gives a payoff of* 200 *to each of agents* s_1 *and* s_2, *and* 2300 *to agent* b.

Proof. First note that if two agents reach agreement the game is immediately finished, since there is no possibility of a second agreement among another pair of agents. Suppose now that we are in the sixth round, when agent b has to propose a division of Π_6. If s_1 or s_2 reject, they do not reach an agreement and so they receive a payoff of 200. Therefore the game reduces to an ultimatum game, and the only equilibrium is the one in which b proposes $(\Pi_6 - 200, 200)$ and the proposal is accepted.

Now, suppose that we are in the fifth round. Interestingly, whether this is the last round of the bargaining session or not, the only equilibrium is the one in which both s_1 and s_2 propose

[44] The task of checking whether a graph is of one of this three types is simplified by using Hall's Theorem [31], a well-known result in graph theory that relates the existence of a matching to the property of a subset of nodes being collectively linked to a set of at least the same number of members.

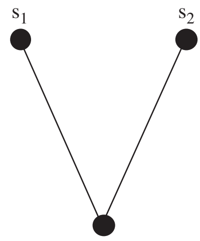

Fig. 30.

Fig. 31.

$(200, \Pi_5 - 200)$ and b accepts. To see why, suppose w.l.o.g that agent s_1 proposes a share of $(p, \Pi_5 - p)$ with $p > 200$ and b accepts. Then, either s_2 also proposed $(p, \Pi_5 - p)$, in which case s_1 and s_2 both get a payoff of $p/2$, or s_2 proposed a different share, in which case s_2 gets 200 and s_1 gets p. But then, s_2 could undercut and instead propose (in round 5) the division $(200 + \varepsilon, \Pi_5 - 200 - \varepsilon)$ which b should accept, since $\Pi_5 - 200 - \varepsilon > \Pi_5 - p$ and since the most b can get in the next round is $\Pi_6 - 200$, which is smaller than $\Pi_5 - 200 - \varepsilon$. With similar arguments we can determine the strategies for the other rounds.

We now specify the set of strategies leading to the PEP equilibrium.

- At round t, with $t \in \{1, 3, 5\}$: Agents s_1 and s_2 both propose $(200, \Pi_t - 200)$. Agent b accepts a proposal iff the share offered is greater than or equal than $\Pi_t - 200$. If both proposals are greater or equal than $\Pi_t - 200$, the buyer accepts the proposal that gives a higher share for himself. Otherwise, b rejects.
- At round t, with $t \in \{2, 4, 6\}$: Agent b proposes $(\Pi_t - 200, 200)$. Agents s_1 and s_2 both accept iff the share offered is greater than 200. Otherwise, they reject. □

Lemma 1. *Suppose that the initial network is given by Fig.* 31. *Then, there is a unique PEP equilibrium payoff, which gives a payoff* 1300 *to the seller and* 1200 *to the buyer.*

Proof. Suppose that we are in the sixth round. The equilibrium will then be agent b proposing $(\Pi_6 - 200, 200)$ and agent s accepting, following the structure of an ultimatum game. Now, suppose that we are in the fifth round and we know that a sixth round has to be played. Then, from standard bargaining results (see Rubinstein [44]) we know that proposals will always leave

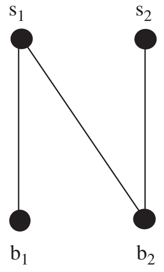

Fig. 32.

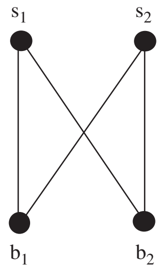

Fig. 33.

the responder indifferent between accepting or rejecting, and therefore s will leave the responder indifferent between accepting or rejecting, and will therefore propose $(\Pi_5-(\Pi_6-200), \Pi_6-200)$. If we are in the fifth round and this is the last one, the only equilibrium tells s to propose $(\Pi_5 - 200, 200)$. Since there exists a sixth round with probability 1/2, after finishing round 4, in expected terms the seller expects to get a payoff of $1/2(\Pi_5 - (\Pi_6 - 200)) + 1/2(\Pi_5 - 200) = \Pi_5 - (\Pi_6/2)$ and the buyer expects to get $\Pi_6/2$. In this manner, we can calculate all the proposals in equilibrium.

We now specify the set of strategies leading to the PEP equilibrium.

- At round t, with $t \in \{1, 3\}$, and with $t = 5$ if 5 is not the last period: Agent s proposes $(\Pi_t - (50(5-t)+\Pi_6/2), (50(5-t)+\Pi_6/2))$. Agent b accepts a proposal iff the share offered is greater than or equal than $(50(5-t)+\Pi_6/2)$. Otherwise, b rejects.
- At round t, with $t \in \{2, 4\}$: Agent b proposes $((50(6-t)+\Pi_6/2), \Pi_t - (50(6-t)+\Pi_6/2))$. Agent s accepts a proposal iff the share offered is greater than or equal than $\Pi_t - (50(6-t) + \Pi_6/2)$. Otherwise, s rejects.
- At round t, with $t = 5$, if 5 is the last period: Agent s proposes $(\Pi_5 - 200, 200)$. Agent b accepts a proposal iff the share is equal or greater than 200, otherwise b rejects.
- At round t, with $t = 6$: Agent b proposes $(\Pi_6 - 200, 200)$. Agent s accepts a proposal iff the share is equal or greater than 200, otherwise s rejects. □

Proposition 2. *Suppose that the initial network is given by one of the two networks* (*see Figs.* 32 *and* 33). *Then, there exists a unique PEP equilibrium payoff, in which sellers* s_1 *and* s_2 *get a payoff of* 1300 *and* b_1 *and* b_2 *get a payoff of* 1200.

Proof. Suppose that we are in the sixth round. If there is only a pair left, we know the equilibrium by Lemma 1 and we are done. Alternatively, suppose that all four agents are still in the market.

Now, suppose that we are in the sixth round. Note that responders will never reject in equilibrium (not even reject with some probability). The finite nature of the game implies that after a rejection, agents will always get 200. Then, the fact that a responder rejects with some probability, implies that accepting was no better than rejecting. This implies in turn that both proposers proposed to keep all the pie for themselves and leave 200 for the responder. Then, at most one proposer was able to receive all the pie minus 200. Then, the other proposer would be willing to deviate and propose to give $200 + \varepsilon$ to the responder, and this is an offer that would clearly be accepted by at least one responder (as the alternative is accepting 200 or rejecting).

Now, suppose that both agents accept a price p_1 from the same proposer, with the other proposers having proposed p_2. Clearly the other proposer would not be matched and would receive 200. Thus, this proposer would be willing to deviate and propose to get $200 + \varepsilon$ for himself, an offer that would clearly be accepted by at least one responder. Therefore, it must be the case that responders accept from different proposers or that both proposers proposed the same price. Thus, we conclude that in equilibrium responders accept from different proposers with probability one or accept the same price proposal p, p being the proposal of both proposers. Given that after rejection, proposers will get only 200, one can conclude that the proposals in equilibrium will give everything to the proposers and leave only 200 to respondents.

Once we deduce the payoffs for round 6, we can proceed as before by using induction, since proposals will always leave the responder indifferent between accepting or rejecting.

We now specify the set of strategies leading to the PEP equilibrium.

If all players are in the game:

- At round t, with $t \in \{1, 3\}$, and for $t = 5$ if 5 is not the last period: Both sellers propose $(\Pi_t - (50(5 - t) + \Pi_6/2), (50(5 - t) + \Pi_6/2))$. Buyers accept the highest proposal for themselves iff the share offered is greater than or equal than $(50(5-t)+\Pi_6/2)$, and otherwise they reject.
- At round t, with $t \in \{2, 4\}$: Both buyers propose $((50(6-t)+\Pi_6/2), \Pi_t-(50(6-t)+\Pi_6/2))$. Sellers accept the highest proposal for themselves iff the share offered is greater than or equal than $\Pi_t - (50(6 - t) + \Pi_6/2)$, and otherwise they reject.
- At round t, with $t = 5$, and 5 being the last period: Both sellers propose $(\Pi_5 - 200, 200)$. Buyers accept the highest proposal for themselves iff the share offered is greater or equal than 200, and otherwise they reject.
- At round t, with $t = 6$: Both buyers propose $(\Pi_6-200, 200)$. Sellers accept the highest proposal for themselves iff the share offered is greater or equal than 200, and otherwise they reject.

If not all players are in the game, then it must be the case that we are in the network described in Lemma 1. Proceed according to the set of strategies defined in Lemma 1. □

The PEP described above can be generalized in a PEP that exists for any given network, as shown by Theorem 2.

Theorem 2. *Take any graph G and decompose it as a union of G^S, G^E and G^B according to Theorem* 1. *Then, there exists a PEP in which*:

Sellers in G^S receive 200, *buyers in G^S receive* 2300.
Sellers in G^B receive 2300, *buyers in G^B receive* 200.
Sellers in G^E receive 1300, *buyers in G^E receive* 1200.

Proof. We will show the result using induction.

Step 0: ($n \leqslant 2, m \leqslant 2$) We first show the result for a number of sellers $\leqslant 2$, and a number of buyers $\leqslant 2$. Only four different graphs are possible with at most two sellers and two buyers. These are the graphs analyzed in the previous results (Lemma 1, Propositions 1 and 2), in which the above statement is true.

Step 1: ($n \leqslant k, m \leqslant k$) Suppose that the result is true for graphs of sizes $n \leqslant k-1, m \leqslant k-1$. We now have to show that the result is true for graphs of sizes $n \leqslant k, m \leqslant k$.

Given that in our game a pair of connected agents may reach a agreement at any point in time, while unmatched agents keep playing, to describe the subgame-perfect equilibria of the game we need to know the equilibrium in any possible network that results as a consequence of the deletion of some of the links in the initial network.

We now write the strategies that would support the PEP for a graph of size $n \leqslant k, m \leqslant k$.

- Strategies whenever the current graph is G_i, a strict subgraph of G (somebody has traded). By the induction step we know of the existence of an PEP in this subgame. This is the PEP strategies will prescribe agents to follow.
- Strategies whenever the graph is G (nobody has traded). Call the current round t, with $1 \leqslant t \leqslant 6$. Call this set of proposals, price proposal P.

Proposal P:

- At round t, with $t\,(1, 3, 5)$ with 5 not being the last period: Sellers in G^{S} propose $(200, \Pi_t - 200)$. Sellers in G^{B} propose $(\Pi_t - 200, 200)$. Sellers in G^{E} propose: $(\Pi_t - (50(5-t) + \Pi_6/2), (50(5-t) + \Pi_6/2))$.
- At round t, with $t\,(2, 4)$: Buyers in G^S propose $(\Pi_t - 200, 200)$. Buyers in G^{B} propose $(200, \Pi_t - 200)$. Buyers in G^{E} propose: $((50(6-t) + \Pi_6/2), \Pi_t - (50(6-t) + \Pi_6/2))$.
- At round t, with $t = 5$, with 5 being the last period: Sellers in G^{S} propose $(200, \Pi_5 - 200)$. Sellers in G^{B} propose $(\Pi_5 - 200, 200)$. Sellers in G^{E} propose $(\Pi_5 - 200, 200)$.
- At round t, with $t = 6$: Buyers in G^{S} propose $(\Pi_6 - 200, 200)$. Buyers in G^{B} propose $(200, \Pi_6 - 200)$. Buyers in G^{E} propose $(\Pi_6 - 200, 200)$.

Acceptances: If the price proposal has been equal to P, then all responders in G^{S} accept the proposal made by proposers in G^{S}, responders in G^{B} accept the proposal made by proposers in G^{B}, and responders in G^{E} accept the proposal made by proposers in G^{E}.

We now write what agents do facing some of the possible unilateral deviations:

Members of G^{S} (odd round, sellers proposing): If the distribution differs from P in one price only, then call s_i the seller that deviated in its proposal. Buyers in G^{S} will continue to accept the share of $\Pi_t - 200$ for themselves. By the definition of a G^{S} subgraph, there exists a way to match all buyers in G^{S} with a set of sellers in G^{S} which excludes s_i. Therefore, all buyers can get $\Pi_t - 200$, and the seller that deviated is isolated and gets 200. The rest of buyers all accept the proposal made by sellers in their respective subgraph. Similarly for Members of G^{B} in an even round, with buyers proposing.

Members of G^{E} (odd round, sellers proposing): Suppose that seller s_i tries to propose a better share for himself. Relabel agents so that s_i and b_i are linked in a matching involving all agents in G^{E} (the existence of this matching is guaranteed by the definition of G^{E}). Then, all buyers excepting b_i accept the proposal stated by all sellers excepting s_i, and b_i rejects. The rest of buyers all accept the proposal made by sellers in their respective subgraph. This means that in the following period agents s_i and b_i will remain isolated and play as in Lemma 1. Similarly for members of G^{E} in an even round, with buyers proposing.

Now it is easy to check that what we have above is indeed a Nash Equilibrium, as no agent can unilaterally deviate asking for a larger share and be accepted, and no responder can do better by rejecting.

To define a subgame-perfect equilibrium, we must also state what strategies specify off the equilibrium path. We now explain how strategies can be constructed so that the strategies above conform to a subgame perfect equilibrium. For any distribution of prices, agents have a finite set of actions that consist of either accepting one of the proposals or rejecting all. If less than the maximum possible number of pairs form, then by the induction step we know that there exists a PEP in the resulting subgraph (since this will be a subgraph that has a number of agents strictly smaller than k). We define strategies so that if less than the maximum possible number of pairs form, then strategies follow the PEP of the resulting subgraph (which we know exists by the induction step). If all agents reject, then the strategies will prescribe for proposers to propose price distribution P and for responders to accept. Therefore we can conclude that given an action for all responders, the payoffs are immediately determined. This must have at least one NE. We will define the strategies as follows: for any distribution of prices, strategies will tell responders to play according to this NE. However, note though that there may be multiple NE. If this is the case, strategies must specify which of the several NE will be played. Any specification would suffice. □

Proposition 4. *Suppose that the initial network is given by one of the two networks* (*see Figs.* 34 *and* 35). *Then*, *the unique PEP equilibrium payoff will give*:

- *a payoff of* 200 *to agents* s_1 *and* s_2;
- *a payoff of* 2300 *to agent* b_1;
- *a payoff of* 1300 *to sellers* s_3 *and* s_4; *and*
- *a payoff of* 1200 *to buyers* b_2 *and* b_3.

Proof. Existence is immediate by Theorem 1, as the above networks decompose as a subgraph of type G^{S} (formed by agents s_1, s_2 and b_1) and a subgraph of type G^{E} (formed by agents s_3, s_4, b_2, b_3) (see Appendix A).

To show uniqueness, as a first step, we will show that in either case sellers s_1 and s_2 receive a payoff of 200 in equilibrium, while buyer b_1 receives 2300. Suppose to the contrary (w.l.o.g.) that s_1 receives a payoff higher than 200. This cannot happen in an odd round, through s_1 proposing a partition that b_1 accepts, since s_2 would have undercut by proposing $(200 + \varepsilon, \Pi_t - 200 - \varepsilon)$, a proposal that b_1 cannot reject, as it is strictly better than anything b_1 can get in the next period. Then, it should be the case that s_1 accepted from b_1 in an even round. But if this is the case, s_2 would also accept, therefore both sellers s_1 and s_2 would be accepting from b_1 in an even round, each reaching agreement with the same probability, and otherwise receiving 200. But this cannot be an equilibrium either, as b_1 could propose a higher share for himself (and would still be accepted, since sellers in the following round would get 200). We can conclude then that s_1 and s_2 get 200 in equilibrium and b_1 gets the rest of the pie, starting in any subgame.

Now it is intuitive to see that agents s_3, s_4, b_2, and b_3 will play as in Proposition 2, as if the link connecting b_1 and s_3 would not exist. Indeed, if all four agents are still in the market in the last round, we know that in equilibrium buyer b_1 will propose $(\Pi_6 - 200, 200)$ and that this would be accepted by sellers s_1 and s_2. Clearly, if s_3 or s_4 rejects, he receives a payoff of 200, so should accept any proposal that is greater than or equal to it. Thus, we can apply the arguments of Proposition 2 here as well. □

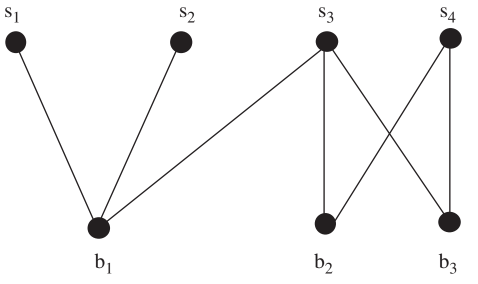

Fig. 34.

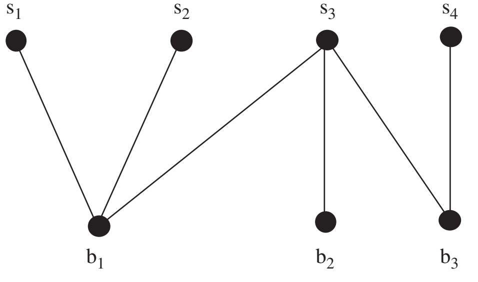

Fig. 35.

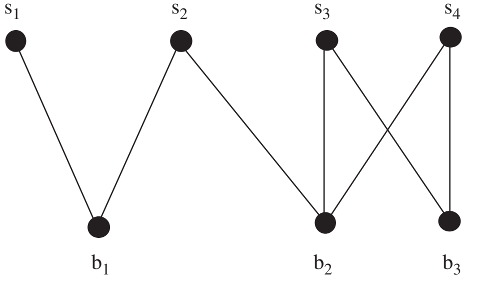

Fig. 36.

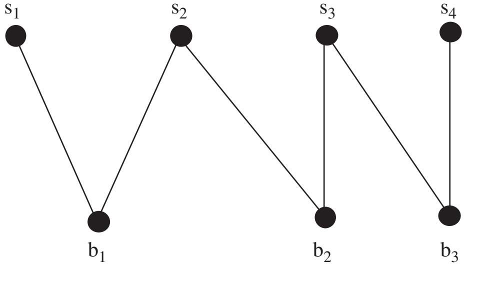

Fig. 37.

Proposition 5. *Suppose that the initial network is given by one of the two networks* (*see Figs.* 36 *and* 37). *Then*, *the unique PEP will give*:

- *a payoff of* 200 *to all sellers*;
- *a payoff of* 2300 *to all buyers*.

Proof. Existence is immediate by Theorem 1, as the above networks decompose as a unique subgraph of type G^S (see Appendix A).

To show uniqueness, note first that as four pairs will never form, at least one of the sellers must receive a payoff of 200 in equilibrium. Let us call this seller s_i. This seller must be linked to at least one buyer, call him b_i. Now, since s_i received 200 in equilibrium, this implies that he could not deviate in the first round and propose $200 + \varepsilon$ for himself. This implies in turn that b_i could accept a share of 2300 from somebody else (since note that in the network we are analyzing any buyer b_i is linked to at least two sellers), call him s_j. That is, this implies that seller s_j was proposing 200 for himself and was accepted. But again, if he could not deviate, this implies that all the linked buyers accept 2300 from other sellers. That is, the fact that a seller s_i received the reservation value in equilibrium implies that the sellers linked to b_i, with b_i being a buyer linked to s_i, also receiving the reservation value. Given the structure of the networks, in this case this implies that all sellers proposed the reservation value for themselves and were accepted. □

Appendix C. Instructions

Thank you for participating in this experiment. You will receive 500 pesetas for attending the session and appearing on time. In addition, you will make decisions for which you will receive an amount of money; the amount depends on the choices made in the experiment. You will receive a subject number that we will use to identify you during the experiment. Please hold on to this number, as we will need it in order to pay you.

In this experiment, you will be in a group of seven persons who will engage in anonymous bargaining sessions. As explained below, people will make proposals to divide a sum of money between them. In each session, every person will be *connected* to one or more other persons. You can only bargain with those people with whom you are connected. An individual can only reach an agreement with at most one other person in a bargaining session.

An example of a diagram of a *network* (the overall set of possible connections between people) is shown on the board. A network has two *sides*, a top and a bottom.

Your connection(s) will be constant throughout a bargaining session; however, there will be multiple bargaining sessions and your location on the network may change from one session to the next. The network itself will remain constant for some number of bargaining sessions, but the network will change at some point in the experiment. You will be informed when this occurs and a diagram of the new network will be displayed on the board.

Each bargaining session will consist of up to five or six *rounds*, each of which consists of two parts. In the first part of the first round, each member of the top side of the network will make a *proposal* for dividing a sum of money with anyone on the bottom side of the network with whom he or she is connected. A proposal is a suggestion of how much money you would receive and how much money a person accepting the proposal would receive. In the second part of the first round, individuals on the bottom side of the network respond to the proposals made by those individuals with whom they are connected. One may choose to accept one of these proposals or choose to reject all available proposals. If a proposal is accepted, there is a *match* and both parties to the match are removed from the network for the remainder of that bargaining session. If there are no more possible matches that can be made, the bargaining session has been completed.

If there are still possible matches, we continue to a second round. In the first part of the second round, all persons on the bottom side of the network who have not become matched will make proposals to divide a (smaller) sum of money with connected persons on the top side of the network. In the second part of the second round, each unmatched individual on the top side of the network will choose either to accept one of the proposals made by people with whom he or she is connected or to reject all available proposals. Matches are determined and displayed. Once again, if there are no more possible matches to be made, the bargaining session is over. If there are still potential further matches, the bargaining session will continue to a third round, in which the top side of the network will make proposals to divide a (still smaller) sum of money. A fourth round, where the bottom side of the network would make proposals, would follow if necessary.

If we reach a fifth round of a bargaining session, we will flip a coin to see if a sixth round will be permitted (if necessary) or if the bargaining session ends after the fifth round.

The amount of money to be divided will diminish over the course of a bargaining session, in the following manner:

A proposal made in the first round suggests a division of 2500 pesetas.
A proposal made in the second round suggests a division of 2400 pesetas.
A proposal made in the third round suggests a division of 2300 pesetas.
A proposal made in the fourth round suggests a division of 2200 pesetas.
A proposal made in the fifth round suggests a division of 2100 pesetas.
A proposal made in the sixth round suggests a division of 2000 pesetas.

Any individual who remains unmatched at the end of a bargaining session would receive a payoff of 200 pesetas for that session.

Mechanics: A diagram of the network in use will be shown on the board at all times. We designate positions on the network with the letters A–G. When proposals are made, we will indicate all of the proposals on this diagram. The choice of each responder to either accept or reject proposals will subsequently be displayed. If a match has been made, the connection between the two matched parties will be circled.

At the beginning of each bargaining session, you will receive a sheet of paper with a drawing of the network; your location on the network will be circled. You have been given a stack of small pieces of paper with your subject number on them. When you are making a proposal or when you are rejecting or accepting proposals, please do so on one of the small pieces of paper and also fill in your assigned letter in the space provided.

As it may be possible that a responder could respond to more than one proposal, if you choose to accept a proposal you must indicate the letter of the person making this proposal.

In the event of more than one person accepting the same proposal, we will randomly determine which responder becomes matched. If you have accepted a proposal but do not become matched, you must proceed to the next round.

We wish to preserve anonymity throughout the experiment. We therefore ask that you turn in one of the small pieces of paper in each part of each round played, even if you are already matched or if it is not your turn to propose or respond. If this procedure were not followed, other participants might be able to deduce the identity of the person at a location on the network. If it is your turn to propose or respond, please do so. If it is not your turn, we ask that you write “Not my turn” on one of the small pieces of paper.

Payment: Although there will be a number of bargaining sessions, at the end of the experiment we will randomly select (using a die) the results from one of these bargaining sessions for actual payment.

If you have any questions, please ask them now or by raising your hand during the course of the experiment. Communication between participants is strictly forbidden. Are there any questions?

Appendix D. Average payoffs[45]

The average payoffs for all four treatments i.e. 1–4 are shown in Tables D1–D4.

Table D1
Average payoffs in treatment 1

Period	Network position						
	s_1	s_2	b_1	s_3	s_4	b_2	b_3
1	533	783	1350	1033	1217	1117	867
2	567	533	1567	1183	1233	1233	1183
3	533	467	1667	1317	1217	1183	1217
4	650	200	1717	1267	1217	1233	1217
Avg. 1–4	546	496	1575	1200	1221	1192	1121
5	683	200	1783	1183	1250	1217	1250
6	658	200	1842	1250	1250	1083	1217
7	267	500	1933	1283	933	1217	867
8	200	507	1993	1267	1283	1233	1183
9	450	200	2050	1217	1250	1233	1233
10	233	233	2133	1217	1233	1183	1200
Avg. 5–10	415	307	1956	1236	1208	1194	1158

Table D2
Average payoffs in treatment 2

Period	Network position						
	s_1	s_2	b_1	s_3	s_4	b_2	b_3
1	725	650	1325	1225	1225	1250	1225
2	200	1100	1375	1250	1212	1250	1238
3	425	838	1438	1225	1238	1225	1238
4	800	425	1475	988	1138	988	1162
Avg. 1–4	538	753	1403	1172	1203	1178	1216
5	1012	675	1488	1225	675	1325	1250
6	788	1112	1512	688	700	1338	1038
7	819	600	1481	875	1056	1400	1294
8	1062	875	1438	875	675	1362	1362
9	1012	775	1488	612	912	1438	1388
10	806	569	1494	875	1088	1394	1375
Avg. 5–10	916	768	1484	858	851	1376	1284

[45] These are actual payoffs for all bargaining rounds.

Table D3
Average payoffs in treatment 3

Period	Network position						
	s_1	s_2	b_1	s_3	s_4	b_2	b_3
1	450	913	1338	1212	1238	1212	1212
2	912	425	1362	1312	900	1188	1575
3	1012	200	1488	1300	1200	1175	1275
4	900	200	1600	1350	675	662	1188
Avg. 1–4	818	434	1447	1294	1003	1059	1312
5	400	581	1719	1250	1188	1200	1288
6	275	669	1756	1250	1162	1175	1312
7	619	200	1881	1238	1238	1162	1262
8	494	200	2006	1025	1262	950	1238
9	325	350	2025	1012	1288	962	1212
10	288	319	2094	1375	1262	1125	1212
Avg. 5–10	400	386	1914	1192	1233	1096	1254

Table D4
Average payoffs in treatment 4

Period	Network position						
	s_1	s_2	b_1	s_3	s_4	b_2	b_3
1	825	450	1425	1212	900	950	1288
2	200	938	1588	1300	1181	1200	1218
3	375	525	1725	1225	1200	1250	1300
4	300	688	1712	1138	1238	1188	1188
Avg. 1–4	425	650	1612	1219	1130	1147	1248
5	812	575	1688	538	875	1562	1075
6	925	762	1500	862	425	1512	1612
7	762	600	1738	512	850	1650	1338
8	875	862	1600	525	625	1588	1525
9	525	725	1750	650	825	1675	1450
10*	833	883	1667	567	233	1583	1700
Avg. 5–10	789	734	1657	609	639	1595	1450

*One of the four sessions did not have a period 10.

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