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Abstract

In recent work on non-cooperative network formation star-shaped networks play an important role. In a particular theoretical model of Bala and Goyal (2000) center-sponsored stars are the only strict Nash networks. In testing this theoretical model Falk and Kosfeld (2003) do not find any experimental evidence that players select the center-sponsored star. Based on a slight modification of Bala and Goyal's model we design a network formation experiment with varying link costs in which almost all groups not only reach a strict Nash network once but also switch strict Nash networks several times. The main innovation in our experiment is to use a continuous time framework which makes coordination on "stars" much easier than simultaneous strategy adaptation in discrete time.

JEL classification: C72, C78, C92

Keywords: Network formation, Nash networks, real-time network experiments

1 Introduction

Research on network formation has attracted many economists during the past decade. The theoretical approaches by Jackson and Wolinsky (1996), and by Bala and Goyal (2000) on network formation turned out to be the most influential ones. In the present paper we base our model on the non-cooperative approach by Bala and Goyal in which decision makers in a population may select their neighbors all by themselves in order to exchange valuable information. These information values are supposed to generate monetary returns. Players who initiate connections have to subtract the link costs from the information values to compute the net return they extract from a network. Typically, two different types of information flow models are distinguished in the literature. In the so-called *one-way flow model* information values flow only to the player who opened a link. In the *two-way flow model* information values flow in both directions although only one player bears communication costs.

The decisions of agents in a network to sever or open links to other agents are supposed to be strategic decisions in an appropriate non-cooperative normal form game called *network game*. Nash equilibrium in such network games turns out to be a weak concept since the number of Nash equilibrium networks even in populations of moderate size is very large. The *strict* Nash networks are an important refinement for network games since the number of strict Nash networks is significantly smaller than the number of Nash networks. Depending on the level of communication costs in the two-way flow model Bala and Goyal show that the empty network and the so-called *center-sponsored star* are the only strict Nash networks. The center-sponsored star can be represented as a directed graph where one player (the center player) opens links to all other players, while no other player opens a link to any other player. All connections are sponsored by the center player.

In contrast to the theoretical work, until recently hardly any experimental work on network formation had been published. Recent economic experiments that consider network formation are Deck and Johnson (2004), Plott and Callander (2002), and Falk and Kosfeld (2003). The experiment by Deck and Johnson is inspired by the network formation model of Johnson and Gilles (2000) which is different from the theoretical framework we want to apply in this paper. Plott and Callander (2002) carry out the first network formation experiment. They consider network formation in the one-way flow model of Bala and Goyal (2000) in which the circle network can be shown to be the only strict Nash network. In their experiment, subjects often reach a strict Nash network and stay in it for at least three periods (in 58% of the cases).[1] Furthermore, it turns out that *real-time link adjustment* facilitates coordination on the strict Nash equilibrium. In their experimental design with costly real-time adjustment of links 71% of the groups reach the strict Nash network. We will report on supporting evidence from

[1] Plott and Callander (2002) distinguish between convergence defined as staying in a network for at least three consecutive periods and reaching a Nash network, i.e playing in it at least in one period. Eleven of twelve groups in their experiment reached Nash networks.

our own experiment.

Our experiment is very much inspired by the results of Falk and Kosfeld (2003). The main intention of Falk and Kosfeld (2003) is to test the theoretical model by Bala and Goyal (2000). They consider groups of four players who play the network formation game for five periods. After that, groups are rematched twice. In both repetitions, the network formation game is played again for five periods. As one of the most remarkable results of their experiments strict Nash networks have been reached by many groups (about 50%) only in the one-way flow framework while it has never been reached in the two-way flow framework (the center-sponsored star). The authors offer some very interesting explanations for their experimental findings. To reach a center-sponsored star in the two-way flow model seems to be a *complex task* for an individual decision maker. One agent in the population has to build up as many links as possible during the course of the experiment while the remaining players, even in a model in which building a single link would generate positive net profits, have to sever all links. This is a highly asymmetrical decision situation which can be dealt with by solving a complex coordination problem. Another explanation is based on fairness considerations. In the center-sponsored star network the center player actually has significantly less equilibrium payoff than the periphery players since he subsidizes all connections in the network. Therefore, *inequity aversion* may be an issue in network formation.

In our experiment, we apply a different design which allows only limited access to the information of neighbors. More precisely, it is an essential feature in our experiment to discriminate between *active* and *passive* neighbors. If a player i opens a link to another player j he has to pay for it. We call this an active link from player i to player j. Player j is then an actively reached neighbor or, in short, an active neighbor of player i. On the other hand, player i in this case is a passively reached neighbor or passive neighbor of player j. It is essential in our experimental design that a player has access to the information values of his active and passive neighbors and, furthermore, to the active and passive neighbors of his active neighbors who are called *indirect* neighbors of i. Empirical investigations show (e.g. Granovetter 1995, Friedkin 1983) that information will not flow between all neighbors on a path of arbitrary length in the network as it is assumed in the framework of Bala and Goyal. Note that this is also one of the main differences between our experimental design and the design of Falk and Kosfeld who suppose (in accordance with the theoretical model by Bala and Goyal 2000) that a player can benefit from any other player who is reached via a finite number of links. In our particular framework, the so-called *periphery-sponsored star*[2] turns out to be the only strict Nash network for the two-way flow model.

The second main difference is that our experiment is conducted in *continuous time*. In computerized experiments, "continuity" of the evolution of time cannot be modelled in a mathematically strict sense. To be more precise, we suppose that the computer updates incoming information within very short time intervals that are smaller than

[2] In a periphery-sponsored star all periphery players subsidize the connections of the center player who benefits from the information values of all other players without having to pay for it.

players' reaction times. Thus, from an individual player's point of view the experiment seem to be conducted in continuous time. In our particular experimental design, subjects are allowed to select a strategy at any time point within a fixed interval of thirty minutes. The probability that more than one player changes his strategy at exactly the same time point is nearly equal to zero.

Typically, subjects in such an experimental environment change their decisions very often which gives good insight into the evolution of the game. In discrete time, one would certainly need a lot of repetitions in order to obtain the same amount of experimental evidence as in continuous time games. We believe that players in such a framework are able to react more adequately to the other players' strategy choices than in a framework with simultaneous strategy adaptation. Other experiments in continuous time that we know of were run, for example, by Selten and Berg (1970), Ehrhart (1997), Berninghaus, Ehrhart and Keser (1999) and by Gueth, Levati and Stiehler (2002). Continuous time experiments were also conducted in bargaining.[3] Concerning network experiments, Plott and Callander (2002) use an experimental design which is another type of continuous time experiment. In their experiment, subjects are allowed to alter their strategy choice during a time interval of two minutes. Switching strategies during this time interval is not cost free, but payoffs are realized only at the end of each of the two minutes intervals. It can be shown that even this slight modification of the standard simultaneous-choice discrete time design may help subjects to coordinate better on strict Nash networks. Our experimental results show similar features for the two-way flow model. We observe periphery-sponsored stars for large time intervals within 30 minutes in almost all groups. Moreover, in most groups center players in a periphery-sponsored star framework were substituted one after the other. Since payoffs in a periphery-sponsored star are not equally distributed between center and periphery players *inequity aversion* seems to be the guiding motive of our subjects, because by switching the center players it is possible to approach an equalization of long run payoffs. This view is supported by the results of our additional treatments by which we want to analyze the impact of increasing link costs on network formation. The cost increases are chosen so that the inequity of payoffs in the periphery-sponsored star is strengthened. As a main result we observe an even higher intensity of changing ps-stars in groups with higher communication costs.

Our paper is organized as follows. In the next section, we present the theoretical model of a network game on which our experimental design in Section 3 is based. Section 4 contains our experimental results. Section 5 concludes.

2 The network game

The network game is characterized by the set of players $I = \{1, \ldots, n\}$, the strategy sets G_i, and payoff functions Π_i. An individual strategy g_i of player i is a vector of

[3] For details, see Roth's survey on bargaining experiments (Roth (1995), Chapter D., p. 323–327).

ones and zeros $g_i \in G_i := \{0,1\}^n$ with the following interpretation. If $g_{ij} = 1$ player i establishes a link with player j, otherwise, we have $g_{ij} = 0$. By convention, a player cannot link with himself, that is $g_{ii} := 0$ for all i. A player has to pay for each link that he establishes. Note, that a bilateral connection between two players in our model is supposed to be already established if at least *one* player wants to open it, i.e. if $g_{ij} + g_{ji} \geq 1$ holds. If a bilateral connection is established both players benefit from the exchange of information even if only one player has to pay for the connection. This shows that our model belongs to the class of two-way flow models. Each strategy configuration $g = (g_1, \ldots, g_n)$ generates a directed graph[4] denoted by $\mathcal{G}_g$, where the vertices represent players and a directed edge from i to j, i.e. $g_{ij} = 1$, indicates that player i holds a link with j. According to the essential assumption of the model by Bala and Goyal we suppose that player j need not *agree* when player i wants to open a link with him. This distinguishes our model from any other type of network formation models in which selection of neighbors is not modeled as a non-cooperative game.[5]

In a network generated by the strategy configuration g each player i may have a number of agents with whom he is connected. We call these agents *neighbors* of i. It is essential for our model to distinguish three types of neighbors. *Actively reached neighbors* are all players i holds links with:

$$N_i^a(g_i) := \{j \in I \mid g_{ij} = 1\}.$$

Slightly abusing language, we call players in $N_i^a(g_i)$ *active neighbors*. Links of i with players in $N_i^a(g_i)$ are called i's *active links* or simply i's links. We call *passive neighbors* of i all players who hold a link with i:

$$N_i^p(\mathcal{G}_g) := \{j \in I \mid g_{ji} = 1\}.$$

A link of j to i is called a *passive link* of i. We call *indirect neighbors* of i all active or passive neighbors of all active neighbors of i, i.e.

$$N_i^{ind}(\mathcal{G}_g) := \{k \in I \mid \exists j \neq i \neq k : \; g_{ij} = 1 \text{ and } \max\{g_{jk}, g_{kj}\} = 1\}.$$

Thus, the set of *all neighbors* of player i is given by

$$N_i(\mathcal{G}_g) := N_i^a(g_i) \cup N_i^p(\mathcal{G}_g) \cup N_i^{ind}(\mathcal{G}_g).$$

Let $n_i(\mathcal{G}_g)$ denote the number of elements in $N_i(\mathcal{G}_g)$ and $n_i^a(g_i)$ the number of elements in $N_i^a(g_i)$. Note that both active and passive neighbors are direct neighbors (in contrast to indirect neighbors). That is, they are connected in the associated directed graph by

[4] Bala and Goyal (2000) introduce a network in the two-way flow model as a non-directed graph. This makes sense when an edge between two players denotes the two-way flow. In the present paper, we emphasize the aspect of opening connections. We are interested in finding out which players initiate links with other players. For example, when both players i and j open a link with each other they are connected in the corresponding directed graph via two adversely oriented edges.

[5] This type of model was introduced by Jackson and Wolinsky (1996).

an oriented edge. Since direct neighbors in our model are treated differently depending on how the links with them are financed it makes sense to subdivide the class of direct neighbors into active and passive ones.

Costs for opening a link are supposed to be the same for each player and are denoted by c (> 0). The benefit or return which player i can extract from being connected (either actively, passively or indirectly) with player j is the same for all players and supposed to be equal to a (> 0). Given strategy configuration $g = (g_1, \ldots, g_n)$, player i's payoff or net return is given by

$$\Pi_i(g) := a\, n_i(\mathcal{G}_g) - c\, n_i^a(g_i). \tag{1}$$

We see from this definition that player i may benefit from a connection to j although he does not have to pay for it[6] which is an implication of our two-way flow model. We also find that player i's payoff is equal to zero if i is an isolated player in the network, that is, if $N_i(\mathcal{G}_g)$ is an empty set.[7]

Our framework contrasts with the neighborhood concept applied by Falk and Kosfeld. They assume (according to the theoretical model by Bala and Goyal 2000) that the set of neighbors of player i consists of all players connected with i by a path in the non-directed graph associated with $\mathcal{G}_g$. We limit access of i, first, to return of those players j to whom i has an active link (active neighbors) plus the return of all direct neighbors of j. For these active links i has to pay link costs. Second, i has access to the return of those players k who have an active link to him (passive neighbors) but not with the neighbors of k. That is, if i pays for a link with a direct neighbor j, he also has access to the return of j's direct neighbors. However, if i does not pay for a link with a direct neighbor k, he does not have access to the return of k's neighbors. A player can only benefit once from every other player in the network, i.e. if he is, for example, actively and indirectly connected with the same player he will not get his return twice.

We believe that our neighborhood concept is certainly more realistic for real-world networks than the assumption that players have access to the information of arbitrarily distant players (in the network) provided they can somehow be connected with each other. In labor markets, for example, social networks play a significant role in getting a job. The empirical investigation of Granovetter (1995) concentrates on jobs found via social contacts. It reveals that the main part of the people, who got their job via social contacts, had heard about it from their friends, relatives or acquaintances (39.1% of the cases), or from acquaintances of those (45.3 %). That is, from a network point of view the person who is looking for a job has access to the information of his "neighbors" who are at the most two "steps" away. Furthermore, 48% of those who had heard about their job from their friends were looking for a job, 52% had heard of their current job through friends but were not looking for a new job. Finally, 72% of those employees who had received the information about their job from friends of friends were looking for

[6] For example, if $g_{ij} = 0$, but $g_{ji} = 1$ holds.

[7] This assumption contrasts with the framework of Bala and Goyal in which a player receives a payoff of a even if he is isolated in the network.

jobs. This supports our interpretation of indirect connections that are only accessible via active links.

For network games $\Gamma = \{G_1, \dots, G_n;\ \Pi_1(\cdot), \dots, \Pi_n(\cdot);\ I\}$ a *Nash network* is defined to be a vector of individual link proposals $g^* = (g_1^*, \dots, g_n^*)$ so that no single player i has an incentive to open additional links different from g_i^* or to sever links prescribed by g_i^*.

Definition 1 *A strategy configuration g^* in Γ is a Nash equilibrium if*

$$\forall i : \quad \Pi_i(g_{-i}^*, g_i^*) \geq \Pi_i(g_{-i}^*, g_i) \text{ for all } g_i \in G_i, \tag{2}$$

where $g_{-i}^* = (g_1^*, \dots, g_{i-1}^*, g_{i+1}^*, \dots, g_n^*)$. $\mathcal{G}_{g^*}$ is the Nash network generated by g^*.

Moreover, if in (2) the strict inequality holds for all i and g_i, the strategy configuration g^* is called a strict Nash equilibrium.

By altering Bala's and Goyal's original model their theoretical results do no longer hold. For example, one can easily show that a center-sponsored star, a strict Nash network in Bala and Goyal's two-way flow model, is not even a Nash network in our modified framework.[8] To get an overview of all possible Nash networks in our experimental design we explicitly calculated all Nash networks for the parameter values of our experiment. The results of our analysis for low costs of $c = 2$ are summarized in Berninghaus, Ehrhart, Ott and Vogt (2004). Because of the large number of Nash networks in this case, strict Nash networks are a reasonable refinement. In the treatment with link costs c higher than 2, no non-strict Nash networks exist. Depending on the particular parameter constellation in our experiment strict Nash networks can be characterized as *periphery-sponsored stars* and/or the *empty network*, i.e. a network without any link. In the following we give conditions for a periphery-sponsored star and the empty network being a strict Nash network in our framework.

Proposition 1 *If $n > 3$ strict Nash architectures*[9] *are:*

(a) for $c \leq a$ the periphery-sponsored star (ps-star),

(b) for $a < c < (n-1)a$ the ps-star and the empty network,

(c) for $(n-1)a \leq c$ the empty network.

[8] A center-sponsored star in the Bala/Goyal model is the unique strict Nash network iff $a > c$ (Bala and Goyal (2000), Proposition 4.2). In our model, a periphery player is only passively connected with the center player in a center-sponsored star. Therefore, each periphery player can strictly improve his payoff by opening a link with the center player which gives him access to $n-2$ additional information values.

[9] Two networks have the same architecture if one network can be obtained from the other by permuting the labels of agents. For example for $n = 6$ players the ps-star architecture has 6 configurations, i.e. the ps-stars are 6 of $(2^5)^6 = 1.073.741.824$ possible networks or 1 of 1.540.944 possible architectures.

Proof Ps-stars as strict Nash equilibria: It is sufficient to show that unilateral deviation from a ps-star results in payoff reductions. A periphery player in a ps-star obtains payoff equal to $a(n-1)-c$. Opening new links does not add additional information value but increases link costs and, therefore, reduces his payoff. Moreover, by dropping his only link to the center player a periphery player reduces his payoff to zero. Combining both deviations, that is, dropping the link to the center player and opening m new links to other periphery players results in a payoff equal to $(a-c)m+a$ which is for $m \leq (n-2)$ and $n > 3$ strictly smaller than the status quo payoff. The payoff of the center player in a ps-star is equal to $a(n-1)$. By opening new links he cannot increase his information values obtained from the other players but has to pay link costs. Therefore, the payoff of the center player is reduced.

The empty network as strict Nash equilibrium: It is a strict Nash equilibrium for $a < c$, as opening one or more links strictly reduces a player's payoff if no other player has a link. Only if indirect connections are accessible it may pay to build a link.

q.e.d.

We call a network *efficient* when the sum of individual payoffs is maximized. Note, if $c \leq na$ a ps-star is also an efficient network[10], while the empty network is efficient for $c \geq na$.

Both star-shaped networks, the periphery-sponsored and the center- sponsored star, are illustrated graphically for an example with 6 players by the drawings in Figure 1 below.

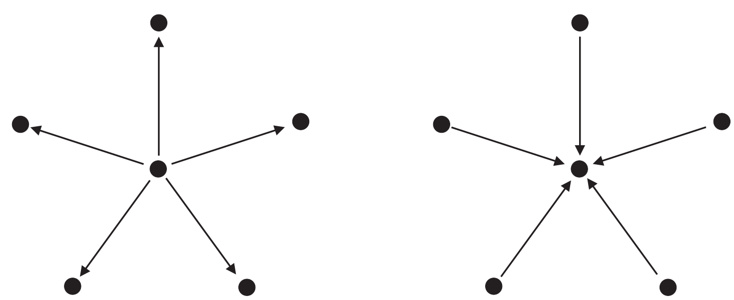

Figure 1: a) center-sponsored star b) periphery-sponsored star

3 Experimental design

The computerized experiment was performed in the experimental laboratory at the University of Karlsruhe. Subjects were selected from a pool of students of various faculties.

[10]In a ps-star each player extracts the maximum returns from all players in the population with a minimum of total link costs.

	treatment I	treatment II	treatment III	treatment IV
Strict Nash equilibrium	ps-star	ps-star and empty network	ps-star and empty network	empty network
Efficient network	ps-star	ps-star	ps-star	ps-star

Table 1: Benchmark solutions of the base game

The experiment was organized in 14 sessions with two groups of six subjects participating in each. The software for the experiment was developed in our laboratory to conduct experiments in continuous time.

In our setting, the network game, as described in Section 2, is repeated in continuous time. Each game lasts 30 minutes. The game starts when all subjects have made their first decision, i.e. each subject has to decide for every possible active link if this link is built or is not. Thereafter, subjects can change their strategies i.e. either open or sever links at any time. Information is updated by the computer five times per second. Particularly, the current payoff flow is computed every fifth of a second and accumulated payoff is "integrated" up to the given moment. Some information is presented on the subjects' computer screens throughout the game. This includes the player's current payoff flow and her current accumulated payoffs. A subject's own and the other subjects' active links are illustrated on the screen by arrows. Moreover, the subjects to whom a player is connected have a different color on the computer screen than the remaining ones. The elapsed time is indicated on each screen during the entire course of the experiment (for more details see the experimental instructions in the Appendix).

The return per connected player is set equal to $a = 3$ ExCU (experimental currency units) per minute and the costs per link differ with respect to the *treatment* we consider (see Table 2). In *treatment I* we set $c = 2$ ExCU per minute which still guarantees a positive net return for each individual connection. In *treatment II* we assume $c = 7$, in *treatment III* we assume $c = 13$, and in *treatment IV* we set $c = 16$. In treatments II–IV opening a new link with another player without any active or passive links is no longer profitable. Nevertheless, in treatments II and III ps-stars and empty networks both are strict Nash (see Proposition 1), while in treatment IV only the empty network is a strict Nash network. An overview of the benchmark solutions of the base game is given in Table 1.

Eight groups participated in each of the treatments I–III. Therefore, we have eight independent observations for these treatments. Only four groups participated in treatment IV. We restricted the number of participating groups in this treatment since the experimental results of these four groups were unambiguous.[11]

The payoffs for each subject were accumulated over 30 minutes and paid out in cash after the experiment was finished. For example, suppose a player extracts a payoff of

[11]It is easy to see that the strategic problem for a single player in treatment IV is rather simple. The empty network is the only strict Nash network, no other network has the Nash property.

	Treatment			
	I	II	III	IV
Link costs c [ExCU per minute]	2	7	13	16
Groups per treatment	8	8	8	4

Table 2: Treatment variable of our experiment: costs per link

four ExCU per minute from the network for ten seconds and then switches strategies so that she obtains two ExCU per minute for 50 seconds her accumulated payoff for this minute is equal to 4 ExCU/60*10 + 2 ExCU/60*50 = 2.33 ExCU. The maximum payoff (resp. minimum payoff) earned in the experiment was equal to 17.89 € (12.20 €). The average payoff was 14.83 €. Since subjects in treatments II, III, and IV have a lower expected payoff than subjects in treatment I we endowed the participants in treatments II–IV with 125 ExCU as show-up fee and additionally compensated the communication costs increase by varying the conversion rate of ExCU into Euro.[12]

Before the experiment started, subjects had to solve some selected problems on making connections in their group and calculating the resulting payoff. Particular emphasis was laid on the subjects not becoming familiar with the concept of star-shaped networks and its relevance for network formation.

Underlying our method of experimentation is a general and a specific reasoning: generally, we believe that continuous time experimentation is important in the Social Sciences. In natural social systems, there is rarely something like a global clock which causes all members of the system to simultaneously update their strategies. We know from the theory of dynamical systems (see, for example, Huberman and Glance 1993) that the dynamics of strategy selection processes in an asynchronous world are completely different from the dynamics in a synchronous world. Their results show that it may be misleading to attempt to draw valid conclusions about real-world systems from models of synchronous strategy adaptation. Specifically, we believe that forming ps-stars in a population of players is a coordination problem which is hard to solve. In our experimental design, five players have to behave differently from the remaining (center) player. In a non-cooperative framework it is certainly easier to designate a potential center player when decisions are made sequentially rather than simultaneously.

[12]The conversion rate is 1 € per 24 ExCU in treatments I and II, it changes to 1 € per 15 ExCU in treatment III, resp. 10.5 ExCU in treatment IV. The show-up fee is the same in treatments II, III, and IV (125 ExCU) and differs between those treatments and treatment I. In treatment I there is no show-up fee. The conversion rates are determined such that the sum of payoffs (measured in Euro) is the same in all treatments provided that the ps-star is played the whole time.

4 Experimental results

It is one of the main features of our results that almost all groups (except for groups in treatment IV) reach several strict Nash networks, i.e. ps-stars, during the course of the experiment and, moreover, keep these networks for a considerable amount of time. However, there are still significant differences in the results between the treatments which will be demonstrated in more detail below.

4.1 Results of treatment I

In treatment I, the net return from being connected with another player is strictly positive irrespective of this player being connected with other players. Therefore, the empty network is not a Nash network in the network base game. The ps-star is the only strict Nash network and, furthermore, it is efficient. As it is shown in Table 3 seven (out of eight) groups reach the ps-star. Moreover, six groups leave the strict Nash network in order to form other ps-stars with a different center player. In continuous time

Group number	1	2	3	4	5	6	7	8	Average
# strategy changes	385	263	100	557	283	278	606	346	352.25
# ps-stars	10	19	9	6	10	6	21	0	10.13
# different ps-stars	2	3	1	2	4	3	6	0	2.63
Time spent in ps-stars:									
Minutes	6.26	9.20	19.52	2.98	10.92	7.05	5.20	0	7.64
Percentage of total time [%]	20.86	30.66	65.08	9.94	36.40	23.52	17.34	0	25.48
Average time spent in a ps-star [seconds]:	38	29	130	30	65	71	15	0	45
Time until first ps-star reached:									
Minutes	7.80	12.59	3.38	21.02	10.04	18.26	10.77	–	11.98
Percentage of total time [%]	26.00	41.96	11.27	70.08	33.47	60.85	35.90	–	39.93
# strategy changes until first ps-star reached	88	63	24	421	82	188	176	–	148.86
# different networks formed	354	199	61	500	250	239	522	319	305.50
Average payoff [€]	14.54	15.15	15.88	14.14	14.95	15.00	14.13	14.81	14.82

Table 3: Group performance (treatment I)

experiments, subjects typically change strategies very often. The maximum number of changes (606) is reached by group 7, while in group 3 we find only 100 changes which still corresponds to an average strategy change of approximately 3 per minute. As further variables characterizing the group performance we present in Table 3 the number of ps-stars reached, the number of different ps-stars, i.e. ps-stars with different center players, the total time spent in ps-stars, the average time spent in a ps-star, the time until the first ps-star is reached, the number of strategy changes until the first ps-star is reached, the total number of different networks formed, and the average payoff per player (in Euro).

The average payoff does not vary much across the groups, however, group behavior is not homogenous with respect to other aspects. For example, consider group 7 which is extremely active in forming new ps-stars while group 3 is successful in visiting only one ps-star several times. Similar variations can be found in the time the groups need to reach a ps-star for the first time. Group 4 needs 70% of the total time while group 3 needs only 11% of the total time to reach the first ps-star. In contrast to group 7, group 8 does not even reach one ps-star during the course of the experiment. In treatment I no group ever played an empty network.

All these results are illustrated graphically, separately for each group in Figure 2. On the ordinate the player labels (from 1 to 6) are written. The abscissa is the time axis (30 minutes). The rectangle in a group's drawing in Figure 2 has no geometric meaning. The width of a rectangle shows how long a player was center player of a ps-star without any interruption. The height of a rectangle indicates the label of the center player in question.[13]

We see from Figure 2 that most groups leave the ps-star after some minutes but return to it again after some time or switch to another ps-star with another center player. Let us consider group 3 again. Subjects in this group leave the same ps-star (with center player 5) for eight times during 30 minutes, but do not switch to another ps-star. Group 7, on the other hand, "visits" *all* six ps-star networks within 30 minutes.[14] The time spent in *non-strict* Nash networks is negligible. Group 1 spends two seconds and group 4 spends 18 seconds in a non-strict Nash network.

In Figure 2 it is shown that group 8 is the only one which does not succeed in forming any ps-star. However, this group shows another remarkable kind of behavior which will be discussed more thoroughly in Section 4.5 below.

[13]Note, that each player has a different label (from 1-6) which is kept fixed during the experiment. However, in the experimental instructions each player is told to be "player 1".

[14]In a population of $n = 6$ players we find 6 essentially different ps-stars that are obtained by interchanging the center players.

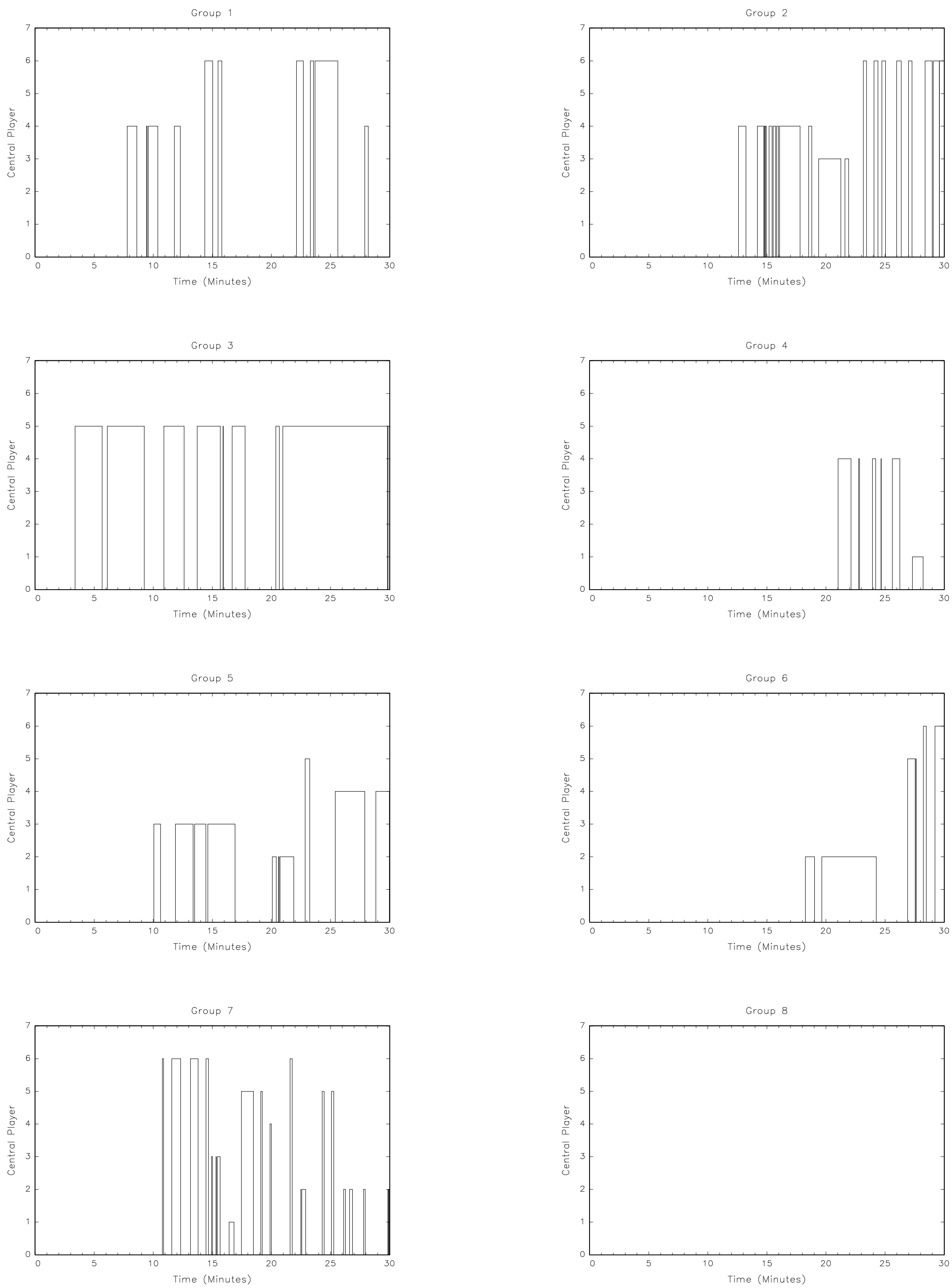

Figure 2: Observed ps-stars in groups 1–8 (treatment I)

4.2 Results of treatment II

In treatment II, the net return of a single active link is strictly negative. There exist only two Nash networks, which are both strict: the ps-star and the empty network. Note, the ps-star is efficient, while the empty network is not. As it is shown in Table 4 half of all groups reach all ps-stars in this environment. The minimum number of different ps-stars reached by a group was equal to three (group 6) while half of all groups reach all different ps-stars within the 30-minute period. Particular attention should be given to group 2 that switches three times from one ps-star to the next by interchanging the respective center player.

Group number	1	2	3	4	5	6	7	8	Average
# strategy changes	645	281	113	495	85	532	530	869	443.75
# ps-stars	25	26	15	11	6	14	19	9	15.63
# different ps-stars	6	6	6	5	5	3	6	4	5.13
Time spent in ps-stars:									
Minutes	6.85	21.74	23.72	2.43	18.05	2.10	7.96	1.62	10.56
Percentage of total time [%]	22.82	72.47	79.07	8.11	60.18	7.01	26.54	5.40	35.20
Average time spent in a ps-star [seconds]:	16	50	95	13	181	9	25	11	41
Time until first ps-star reached:									
Minutes	2.34	1.63	0.83	6.91	0.92	7.20	0.44	1.54	2.73
Percentage of total time [%]	7.79	5.42	2.78	23.04	3.07	24.01	1.46	5.14	9.09
# strategy changes until first ps-star reached	38	27	21	57	11	44	6	27	28.88
# empty networks	0	1	0	0	0	0	3	0	0.50
Time spent in empty network:									
Minutes	0	0.03	0	0	0	0	0.16	0	0.02
Percentage of total time [%]	0	0.11	0	0	0	0	0.53	0	0.08
Average time spent in a empty network [seconds]:	0	2	0	0	0	0	3	0	2
# different networks formed	565	215	90	440	75	484	444	796	388
Average payoff [€]	11.85	14.90	13.45	9.25	14.64	10.65	10.97	10.29	12.00

Table 4: Group performance (treatment II)

As further variables characterizing the group performance we present in Table 4 the number of empty networks as well as the total and average time spent in the empty network.

Compared with the results in treatment I, the average number of strategy changes and the average percentage of the total time spent in ps-stars increases. But the average payoff decreases. This is easy to understand since redundant links are punished more seriously in treatment II than in treatment I.

In comparison to Table 3, in Table 4 we additionally consider the time spent in the empty network. The respective row in Table 4 shows that only 2 groups reach the empty network but stay in it only for a negligible portion of the total time. Subjects seem to prefer efficient Nash networks. Another explanation for this behavior may be that there is a “natural” resistance of subjects to remain passive in an experimental environment, i.e. to opening no links at all.

How can we explain the difference of the results between treatment I and II? In treatment II there seems to be greater pressure on the players to change the respective center player, i.e. to switch from one ps-star to the next than in treatment I. The payoff difference between center and periphery player in a ps-star is much larger in treatment II than in treatment I. The inequity aversion motive seems to put strong pressure on the players to change ps-stars so that each group member at least for some minutes has the chance to be in the advantageous position of a center player. Otherwise, it would be difficult to reach an equalization of payoffs between all players in the long run.

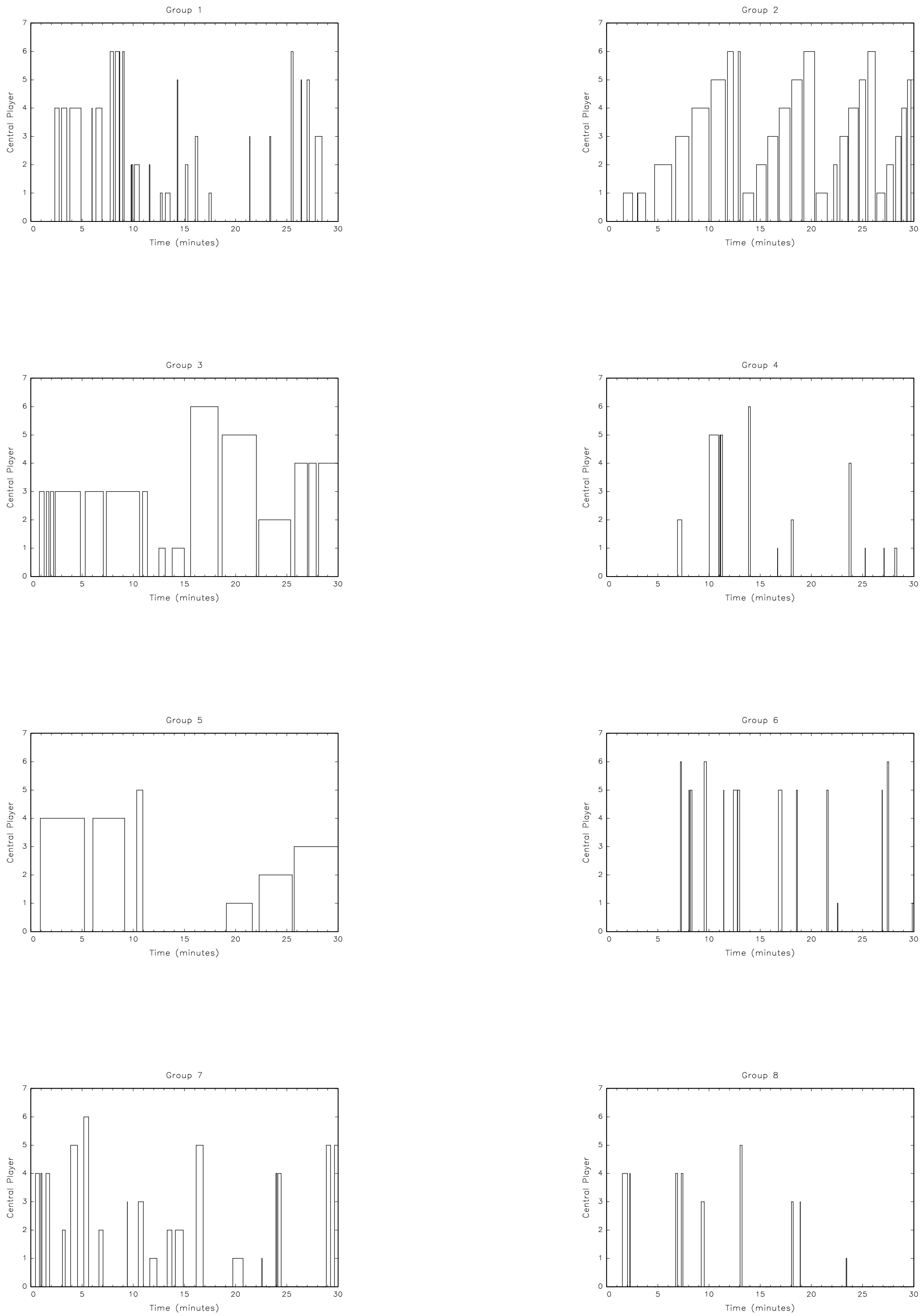

Figure 3: Observed ps-stars in groups 1–8 (treatment II)

4.3 Results of treatment III

In treatment III, the net return of a single active link like in treatment II is strictly negative. Compared with treatment II, it is more than twice as negative. Therefore, an individual player has to be careful when opening new links with members of his group. With each link, he should rather catch as many indirect neighbors as possible. There is no non-strict Nash network. There are only two strict Nash networks, the ps-star and the empty network. The former is also efficient while the latter is not. The experimental results are shown in Table 5. Compared with treatment II, we observe that on average less ps-stars are reached during the experiment but the number of different ps-stars reached during the experiment is still larger than in treatment I. The same conclusion holds for the average time spent in ps-stars. Redundant links are punished more severely in treatment III than in treatment II which may favor subjects who rather stay in empty networks than open non-profitable links.

Group number	1	2	3	4	5	6	7	8	Average
# strategy changes	461	374	316	93	301	468	266	580	357.38
# ps-stars	13	22	2	1	22	20	18	14	14.00
# different ps-stars	6	6	2	1	6	6	6	4	4.63
Time spent in ps-stars:									
Minutes	0.91	13.71	0.32	1.18	19.97	8.64	15.17	2.06	7.75
Percentage of total time [%]	3.02	45.71	1.06	3.92	66.58	28.81	50.57	6.86	25.82
Average time spent in a ps-star [seconds]:	4	37	10	71	55	26	50	9	33
Time until first ps-star reached:									
Minutes	3.17	5.72	18.93	9.47	5.09	0.83	0.14	4.91	6.04
Percentage of total time [%]	10.58	19.07	63.12	31.57	16.98	2.78	0.48	16.36	20.12
# strategy changes until first ps-star reached	59	52	179	40	69	25	3	87	64.25
# empty networks	44	39	16	19	24	56	29	28	31.88
Time spent in empty network:									
Minutes	4.76	3.42	3.23	21.80	1.27	6.44	5.85	3.97	6.34
Percentage of total time [%]	15.88	11.40	10.78	72.68	4.24	21.46	19.51	13.22	21.15
Average time spent in a empty network [seconds]:	7	5	12	69	3	7	12	8	12
# different networks formed	256	173	229	57	179	259	120	430	212.88
Average payoff [€]	9.33	11.51	4.64	7.77	13.51	9.69	12.33	6.23	9.38

Table 5: Group performance (treatment III)

In fact, a few subjects finish the experiment with pecuniary losses. Moreover, we see that the average percentage of the total time spent in empty networks increases considerably compared with treatment II. As in treatment I, subjects change strategies very often. However, the average number of changes is not as high as in treatment II. The average group payoff is declining from treatment I to treatment III. The difference in the average group payoff is largest between treatment I and III. Since the number of individual network links in treatment III that generate payoff losses is higher than in treatment I, this result is not surprising. The drawings in Figure 4 show the temporal evolution of ps-stars for each group. We see from these drawings that two groups (group 2 and 5) reach all different ps-stars by interchanging the center player three times in the same order. Group 7 shows similar behavior. According to our interpretation of this behavior in treatment II, we could say that the "pressure" to interchange center players in order to equalize profits in the long run is much stronger in treatment III since the payoff difference between center player and periphery players is significantly larger than in treatment II.

In contrast to treatment II, subjects in treatment III spend a significantly longer time period in the empty network. Group 3 and 4 prove to be extreme examples of this behavior. Subjects in these groups keep ps-stars for a very short time. The average time of all groups spent in the empty network is about 20% of the total time. We could say that the pressure on the groups to switch as many ps-stars as possible is dampened by the tendency to play empty networks. Both types of behavior are observed for different groups in treatment III.

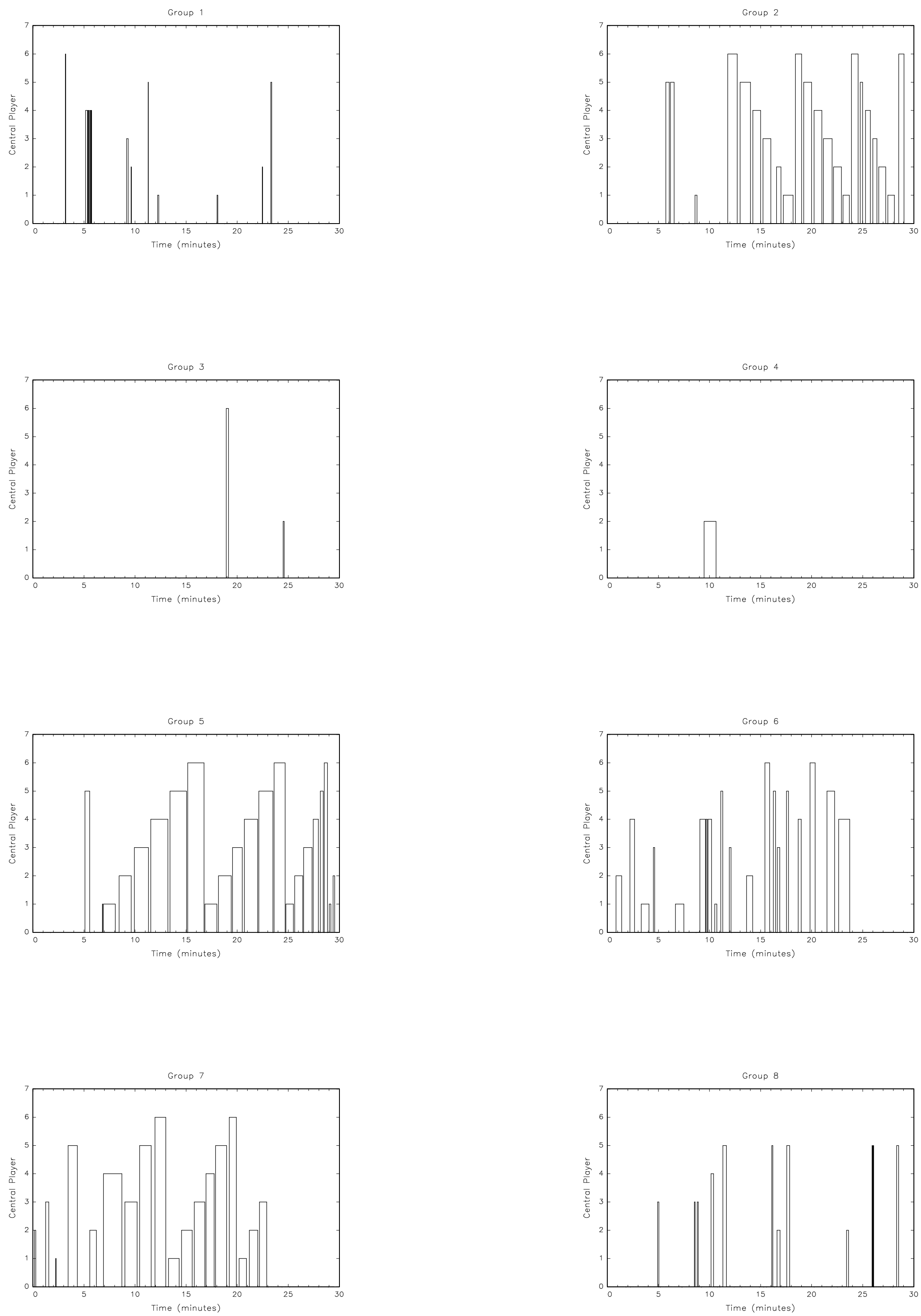

Figure 4: Observed ps-stars in groups 1–8 (treatment III)

4.4 Results of treatment IV

Like in treatments II and III the net return of a single active link in treatment IV is strictly negative. However, in contrast to these treatments the ps-star is no longer strictly Nash. The only strict Nash network in treatment IV is the empty network. However, the ps-star is still efficient. Because of the assumed extremely high link costs we do not expect ps-stars to be formed at all during the course of the experiment. Indeed, the experimental results in Table 6 show that the groups spend most of the time in the empty network whereas no ps-star was reached at all. The strategic situation in treatment IV proves to be much more transparent than in the remaining treatments. Interacting in this treatment is certainly boring for most subjects in the groups. Therefore, only four groups are involved in this treatment and we base the statistical analysis in the following sections on the first three treatments only. The results in Table 6 treatment IV are convincing. In forming another network than the empty one there is a great chance for the group members to end in negative payoffs. Although a ps-star is still efficient, the net return of a periphery player is strictly negative which induces these players to sever connections. Subjects seem to have been quite clear about this particular strategic situation. They remain passive in opening links for a significant amount of time. As an extreme example consider group 4 whose participants remain inactive for 95% of the total time.

Group number	1	2	3	4	Average
# strategy changes	37	281	319	27	166.00
# of ps-stars	0	0	0	0	0
# empty networks	10	44	50	8	28.00
Time spent in empty network:					
Minutes	25.78	17.04	9.58	28.53	20.23
Percentage of total time [%]	85.92	56.79	31.93	95.11	67.44
Average time spent in a empty network [seconds]:	155	23	11	214	43
# different networks formed	18	154	111	17	75
Average payoff [€]	11.11	7.96	4.69	11.60	8.84

Table 6: Group performance (treatment IV)

4.5 The phenomenon of "fair stars"

We remember the results of group 8 in treatment I, which was the only group in this treatment which does not reach a ps-star. What did the participants of this group do during the 30 minutes? A closer look at this group's results shows that the subjects for almost half of the total time get stuck in a network which could be called a "nearly ps-star". This network is characterized as a ps-star in which the center player wipes away his payoff advantage by opening exactly one active link to another group member.

This results in instantaneous payoff equalization among the group members. We call these type of network a "fair star" in order to indicate that the subjects in these groups seem to be motivated by establishing equal distribution of payoffs. The results in Table 7 show that fair star networks are not only formed in group 8. Also for groups 5, 6, and 7 such networks prove to be quite attractive.

Group number	1	2	3	4	5	6	7	8	Average
# fair stars reached	1	2	1	1	2	1	4	1	1.63
Time spent in fair stars:									
Minutes	0.04	0.73	0.05	0.31	4.02	5.79	2.99	12.94	3.36
Percentage of total time [%]	0.15	2.43	0.16	1.03	13.40	19.30	9.96	43.13	11.20
Time until first fair star reached:									
Minutes	15.43	11.95	3.33	21.00	4.45	10.74	4.13	17.00	11.00
Percentage of total time [%]	51.44	39.82	11.11	69.99	14.84	35.79	13.75	56.65	36.67
# strategy changes until first fair star reached	169	60	23	420	51	143	105	342	164.13

Table 7: Group performance with respect to fair stars (treatment I)

From Table 7 we see that half of the groups stay in fair star networks for less than one minute, however half of the groups stay in fair star networks for several minutes. Extreme behavior is shown by group 8 who stays in the fair star network about 43% of the whole time. Note, that for this high stability of the fair star not only the behavior of the center player is important but also the periphery players' behavior. In this group every periphery player accepts a payoff of $(n-1)a-c$ for a long period. No ps-star (with a higher payoff for the center player but the same payoff for the periphery players) in any other group is as stable as this fair star. On average, groups in treatment I spend about 11% of the total time in fair stars. Note, that fair star networks are neither Nash nor efficient.

The situation changes in the remaining treatments. In treatment IV, no fair stars are reached at all. In treatments II and III fair stars do not play as important a role as in treatment I. The average percentage of time spent in fair stars is equal to 2% in treatment II and equal to 3% in treatment III. The maximum time spent in fair stars per group is equal to 7% in treatment II and equal to 8% in treatment III. A center player in treatment III (treatment II) has to dispense with 7 ExCU (13 ExCU) when forming a fair star instead of a ps-star. This may explain why fair stars play a more important role in treatment I than in the remaining treatments.

We regard fair stars as one of several possible expressions of inequity aversion. In order to deepen this aspect of our experiment we analyze the *transition behavior* of groups *to* and *from* a fair star. Looking at the strategy configuration one step before resp. one step after a fair star. When a center player in a ps-star opens an additional link we call this a *positive transition* from a ps-star to a fair star. On the other hand, when a center player in a fair star severs the only link he holds with a periphery player we call this a *negative transition* from a fair star to a ps-star. By counting for each group the negative and positive transitions from and to a fair star separately we find that:

- All transitions in treatment I were negative.
- In treatment II, only two groups showed positive transitions. For these groups the percentage of ps-stars which pass into fair stars via a positive transition is given as follows:

	Group 4	Group 6
% positive transitions	30	16

- In treatment III, four groups show positive transitions, whose percentage is given in the table below:

	Group 1	Group 2	Group 5	Group 8
% positive transitions	26	16	33	8

If all transitions were positive the phenomenon of fair stars would clearly indicate that center players prefer fair stars rather than ps-stars. However, our results show that fair stars are very often the last step on the way to a ps-star. Positive transitions occur only in treatments II and III. This is not easy to understand since building positive transitions to fair stars is much more "expensive" than in treatment I. However, one should not overemphasize these results since the total time spent in fair stars in treatments II and III is still very low so that positive and negative transitions can be interpreted as the result of individual random choices.

5 Analysis of experimental results

5.1 Correlations

In this section, we analyze correlations between some selected variables which has been described in Tables 3–5: number of strategy changes, number of different ps-stars reached, percentage of time spent in ps-stars, number of networks formed during the duration of the experiment, and the average per capita payoff.

Note, that in Table 8 significant correlations based on a 5% significance level are presented by boldface numbers. We summarize the interrelationships between the variables characterizing groups' performance in treatment I–III as follows.

1. We find *positive correlations* in each of the treatments I–III between
   - the number of strategy changes and the number of formed networks,
   - the time spent in ps-stars and the average payoff.

	Variable 1	Variable 2	Treatment I r_s	(*p*-value	Treatment II) r_s	(*p*-value)	Treatment III r_s	(*p*-value)
1)	# strategy changes	Time spent in ps-stars	**-0.762**	**(0.021)**	**-0.810**	**(0.010)**	-0.190	(0.619)
2)	# strategy changes	Average payoff	**-1.000**	**(0.000)**	-0.619	(0.086)	-0.286	(0.460)
3)	# strategy changes	# networks	**1.000**	**(0.000)**	**1.000**	**(0.000)**	**0.929**	**(0.000)**
4)	# different center players	Average payoff	-0.241	(0.537)	0.575	(0.120)	**0.791**	**(0.015)**
5)	Time spent in ps-stars	Average payoff	**0.762**	**(0.021)**	**0.833**	**(0.005)**	**0.905**	**(0.000)**

Table 8: Spearman rank correlation coefficients r_s

These correlations are not surprising. When a group is characterized by a large number of strategy changes, i.e. if it is active in changing links it may have a better chance of forming new networks than an inactive group with a small number of strategy changes. This is reflected in relationship 3). Relationship 5) easily follows from the fact that ps-stars are efficient states. Groups which stay in ps-stars for a long time will achieve a larger average payoff per player than other groups.

2. We find two *negative correlations* in each of the treatments I–III between

   - the number of strategy changes and the time spent in ps-stars,
   - the number of strategy changes and the average payoff.

   The first relationship is plausible since more active groups have to diminish the time spent in ps-stars. Therefore, we expect that groups with a larger number of strategy changes show a tendency to spend less time in ps-stars. This is reflected in relationship 1). Relationship 2) is more difficult to understand. It expresses a fact which meanwhile has been observed in other experiments of quite different types. High activity levels of the subjects in those experiments are often connected with low payoffs (see, for example Berninghaus et al. 1999, Selten, Schreckenberg, Pitz, Chmura and Kube 2002). According to these results, to be successful in earning monetary payoffs one should not be "too active." At first glance, this seems to be surprising. Concerning our experiment on network formation it may be explained by the fact that players have to solve a difficult coordination problem. A high intensity of individual strategy changes or a high degree of experimenting with links seems to make it more difficult for the players to agree on the same center player and, therefore, may prolong the time until players reach efficient networks. This relationship is significant at a 5%-level for treatment I only. For treatment II it is most significant at a 10%-level. And for treatment III, this interrelationship is not significant any more.

3. We find a correlation between the number of different ps-stars reached and the average payoff which is *partly negative* and *partly positive*.

   The positive part of this interrelationship is easier to explain since ps-stars are the only efficient networks. For treatment I, the direction of this correlation is adverse and no longer significant. A brief glance at the results of treatment I shows (see Table 3) that the number of different ps-stars reached by a group in this treatment is not always a good indicator for the time a group spent in a ps-star.[15]

5.2 Differences between treatments

In this section we apply some standard non-parametric tests to our data. In Table 9 we consider some selected performance variables. It is checked whether there are significant differences between the treatments I, II, and III. The results of non-parametric tests (Kruskal/Wallis and Mann/Whitney rank sum test) are given in Table 9. Below the test statistics the respective p-values are presented in brackets. The Kruskal/Wallis

Performance variables	Kruskal/Wallis: test statistic (p-value) Treatment I,II,III	Mann/Whitney: test statistic (p-value) Treat I,II	Treat I,III	Treat II,III
# strategy changes	0.74 (0.691)	62 (0.547)	66 (0.878)	76 (0.442)
# different center players in ps-stars	**6.59 (0.037)**	**44.5 (0.010)**	51.5 (0.083)	68.5 (0.959)
% total time in ps-stars	0.74 (0.692)	65 (0.798)	69 (0.959)	78 (0.328)
% total time until first ps-star reached	**9.324 (0.009)**	**82 (0.001)**	73 (0.054)	58.5 (0.328)
Average payoff [€]	**13.90 (0.000)**	**93 (0.007)**	**100 (0.000)**	83 (0.130)
	Treatment II,III,IV	Treat II,III	Treat II,IV	Treat III,IV
% time in empty network	**17.01 (0.000)**	**36 (0.000)**	**55 (0.002)**	**52 (0.011)**

Table 9: Significant treatment differences in performance variables

test shows that there exist significant differences between treatments in the *number of different stars reached*, in the *time before a ps-star is reached for the first time*, and the *average payoffs*. The Mann/Whitney tests give more information by pairwise comparison of treatments. Considering the number of different ps-stars reached, we see that the

[15]As a drastic example see group 3 which reaches only one ps-star but visits this ps-star several times and spends most of the time in this ps-star, which results in high individual payoff levels. Group 8 does not reach a ps-star at all but spends most of the time in a fair star.

differences between treatments II and III are not significant at all but that there exists a significant difference between treatment I and the remaining treatments.

Although we compensate the difference in potential earnings in the different treatments (for details see Section 3) we observe significant differences between the treatments. Again we conclude from the bilateral rank sum tests that this difference is caused by the differences between treatment I and the remaining treatments. Indeed, this reflects the difference between treatment I and treatments II and III which are similar with respect to the earnings. In experimental investigations it is often rather difficult to restore comparability of groups between different treatments after varying one parameter. We vary the link costs which clearly implies a decline in the total average payoff. To compensate for this we choose a mix of fixed additional payment and adapting the transfer rate.[16] In contrast to treatment I we have the *empty network* as an additional strict Nash network in treatments II and III. We observed that the subjects in these treatments actually choose the empty network much more often than the subjects in treatment I where the empty network does not play any role at all. This is certainly an additional determinant that creates the average payoff differences between the treatments. We design our experiment so that the fixed-payment part of the maximum possible earnings grows with increasing link costs and we observe that the resulting average payoff decreases, which indicates that the groups become less efficient from one treatment to the next.

5.3 Explaining our results: Inequity aversion as a plausible motive

Summarizing the most important observations of our experimental investigation we conclude:

1. Contrary to the previous experiments conducted by Falk and Kosfeld, we observe that almost all groups not only reach strict Nash networks but also visit such networks several times. Moreover, some groups even visit all possible ps-stars during the course of the experiment.

   Compared with the Falk/Kosfeld experiments in *discrete time* we think that in our *continuous time* design subjects can coordinate better on star-shaped networks. Building stars is not an easy task because a center player has to be determined by the remaining group members. That is, five subjects have to agree on the same person to act as center player while the designated center player has to behave differently from the designated periphery players. We believe that this coordination task is easier to solve in a continuous time environment with sequential decision making in which subjects always can react to the other participants' responses.

[16]Note, that increasing the fixed-payment part of the payoffs would have created a serious incentive problem for the subjects.

In fact, in treatment III we observe that subjects show a considerable amount of inertia. Most subjects in these groups open a link to a potential center player after a "sufficient" number of the participants selected one of the participants as a potential center player.

In our particular experimental design the ps-star is the only strict Nash network. Falk and Kosfeld use the theoretical model of Bala and Goyal (2000) in which the center-sponsored star is the only strict Nash network. In a center-sponsored star the only active player by severing one link to a periphery player reduces his own payoff by $a-c$. In our design, an active periphery player by severing a link reduces his payoff from $(n-1)a-c$ to zero. Thus, in our design the costs of deviation are higher.

In our design, the best an isolated player can do is to link with the center player. If he prefers to remain inactive at least five players (in treatment I), three players (in treatment II), and one player (in treatment III) have to open links with the isolated player in order to give him at least the same payoff as he receives as periphery player in a ps-star.

The distribution of payoffs in a center-sponsored star is less or equal than the payoff distribution in a ps-star. In both types of strict Nash networks, the active players have to bear more link costs than the inactive ones. But the center player in a center-sponsored star has to bear all link costs while a periphery player in a ps-star pays for exactly one link. Falk and Kosfeld (2003) conjecture that *inequity aversion* might have prevented the subjects from forming a center-sponsored star, i.e. the only type of strict Nash networks.

2. Groups exchange the center players in a ps-star. They leave a strict Nash network in order to form a new one with a different center player. Finding a new center player is not an easy task. Therefore, some groups do not succeed in forming new ps-stars but return to a center player on whom all have agreed before. This is observed very often in treatment I. In treatments II and III, we observe an additional phenomenon. Groups exchange the center player several times in the same order. One group in treatment II and three groups in treatment III show exactly this behavior while many of the remaining groups also visit all different ps-stars several times (but not in the same order).

   Why do we observe such behavior? In our design, center players are subsidized by the periphery players. Even if the instantaneous payoff difference between center and periphery player in a ps-star is not that large, accumulated payoff differences after 30 minutes show a considerable difference. In order to establish payoff equalization in the long run, groups have to exchange the center player. This generates payoff distributions in the long run, which show only a low degree of inequity. Therefore, we think that the principle of inequity aversion is an important motive that drives our experimental results.

6 Concluding remarks

By appropriately modifying the original model of network formation we observe that groups prefer to stay in strict Nash networks for some time and, moreover substitute the respective center player to reach ps-stars with different center players. Similar systems of rotation have been observed by anthropologists in societies in New-Guinea (Rubel and Rosman 1978, Rappaport 1968). In the Maring society, for example, each clan serves as a host for a big feast to neighbor clans. At the feast, many pigs and other food are eaten. People use this opportunity to exchange information and goods.[17] The whole feast is very costly to the host who can be regarded as the center player in a center-sponsored star network whereas the guests are the periphery players. The clans have the obligation to reciprocate, which results in the rotation of center players in the stars. Each clan has to become host at one time. Although our model does not perfectly match the anthropologists' stories, since we have ps-stars, it is easy to transfer the main aspects of these observations to our framework. Rotation of center players in center-sponsored stars compensates the center players for bearing all link costs. The rotation of center players in ps-stars pushes each group member into the same privileged situation in which her connections are subsidized by the other group members. Both phenomena can be explained by inequality aversion.

Our results of experiment in continuous time are encouraging. Therefore, we plan to extend our experiments as follows. Beside choosing their neighbors in a network, the subjects additionally can select particular strategies in a given two-person game which they play pairwise against all other subjects with whom they are connected in a network. This is a very complex compound strategic decision problem which has recently been dealt with in some theoretical papers (see, for example, Goyal and Vega-Redondo 2005, Berninghaus and Vogt 2003). We know only of one experimental approach to this problem by Corbae and Duffy (2003) which, however, is rather preliminary work. Corbae and Duffy let the subjects choose strategies in a pure 2×2 coordination game. We plan to conduct strategy and network formation experiments where the subjects pairwise play an arbitrary 2×2 game against each of their neighbors. We are particularly interested in analyzing how the type of the underlying 2×2 game will determine network formation. Moreover, are there similar observations concerning inequality aversion as have been made in pure network formation experiments? By conducting these experiments we hope to gain a better understanding of network formation.

[17] This is a nice example of a two-way flow model.

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Appendix

Translation of Experimental Instructions

In the following, we present the experimental instructions for treatment I. Note, that the instructions for the remaining treatments only differs with respect to connections costs c and the conversion rate.

Instructions

You are participating in an experiment on interactive decision making. In this experiment, you can earn cash. How much you earn, depends on your own decisions and the decisions of the other participants. In the experiment, payoffs earned are measured in so-called **experimental currency units** [**ExCU**]. The sum of currency units you earn in total will be transformed into Euro at the end of the experiment and paid out in cash. Each participant makes his decisions separate from the remaining participants sitting at his computer-terminal. Communication between participants is not allowed.

At the beginning of the experiment, you will be randomly matched with five other participants to form a **group of six**. The participants of a group are not necessarily sitting side by side. The composition of a group persists during the course of the experiment. There is no interaction with other groups. The six members of your group will be randomly assigned internal labels from one to six. **However, each participant is denoted on his screen as player *T1***. In the following, the term participant will be used only to denote participants of your group. Any other participant in your group obtains exactly the same instructions as you do.

The experiment runs for **30 minutes**. During this time you can open or sever links with the other participants of your group. You obtain a continuous payoff stream whose size depends on the connections built by all participants in the group.

Connections

There are three ways to be connected to other participants in your group.

You can decide to open connections to other participants by yourself. These connections will be called your **active connections**. Your active connections will be displayed as

arrows pointing from you to other participants.
You can build active connections to as many participants as you want. However, to each participant you can only open one active connection. You can change your connections at any point in time.
The participants to whom you have opened an active connection will be called your **actively reached participants**.

In addition to your actively reached connections, your so-called **passive connections** and your **indirect connections** are also relevant for you.

A passive connection for you is a connection, that another participant opened to you. That is, it is a participant's active connection to you.
Your indirect connections are the **passive and active connections of your actively reached participants**. In other words, these are the passive and active connections of those participants, to whom you have an active connection. Through your passive connections you do not have access to indirect connections.

A participant cannot open connections with himself.

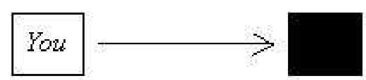
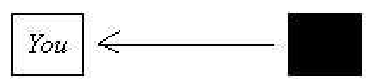
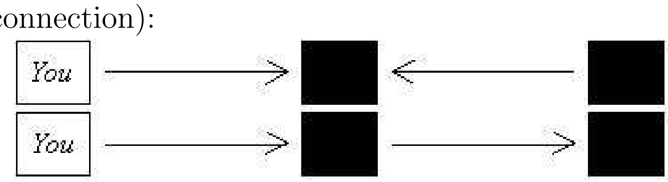
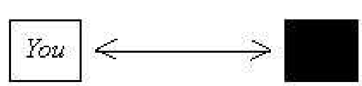
Type of connection	Meaning
1. active	Your connection to another participant. Graphical illustration: 
2. passive	Other participant's connection to you. Graphical illustration: 
3. indirect	Active and passive connections of a participant, who is actively reached by you. Graphical illustration (two possibilities of indirect connection): 

Table 1: Types of connection

If you have an active and a passive connection to a participant at the same time, it will be displayed as a double arrow.



The following Figure 1 illustrates the meaning of the denotations **active, passive** and **indirect** connection. This figure only helps the illustration. In the experiment, the arrows will neither be labeled nor broken.

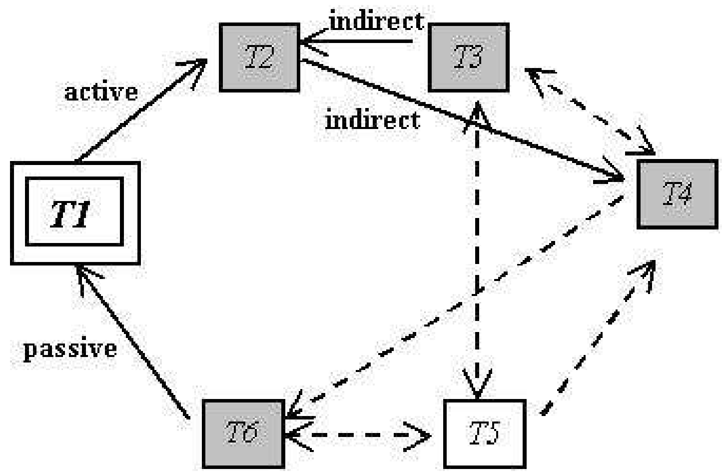


Figure 1: Types of connection from *T1*'s point of view

The arrowheads in Figure 1 point away from the participant, who has opened the connection. The dashed arrows have no consequences for *T1*. *T1* is connected with the participants *T2*, *T3*, *T4* and *T6* marked in grey (in the experiment: blue marking). *T2* is actively reached by *T1*, since *T1* has an active connection to *T2*. *T1* is indirectly connected to *T3* and *T4*, because *T2*, who is actively reached by him, is passively resp. actively connected with them. *T1* is passively connected to *T6*. *T1* is not connected with *T5*.

Establishing connections: As participant *T1* you are marked in red on the screen. You can choose active connections to other participants by writing the participant's number (2, 3, 4, 5, or 6) into the upper line labeled with "participant's number" in the green input window at the lower right corner of the screen. Then switch to the lower line of the window labeled with "activation of the connection" by clicking on the enter button. In this line you write "1" and confirm by clicking on the enter button again. You can dissolve an existing connection by writing the number of the respective participant on the upper line of the input window and entering a "0" on the lower line.

As soon as you have chosen an active connection all participants in your group see this link on their screen. Likewise you can see all active connections which currently exist in your group. When you are connected with another participant (actively or a passively or an indirectly) this participant will be **marked blue** on your screen.

At the beginning of the experiment you have to decide for each possible connection (connection with *T2*, *T3*, *T4*, *T5*, *T6*) whether you want to open it (enter "1") or not (enter "0"). All inputs have to be confirmed by pushing the enter button. The clock is activated only after all participants made their decisions on their possible connections.

Costs and earnings

Now you are informed about all three types of connection. In this section you learn how your earnings are determined.

You obtain a continuous profit stream which is calculated in currency units per minute. The size of your profit stream depends on the active connections currently chosen by you and the other five participants. It is calculated as follows.

Costs: Each **active connection** that you have chosen at a point in time **costs you 2 ExCU per minute**. So if you keep a connection for a whole minute you pay 2 ExCU. If you dissolve this connection for example after 15 seconds you have to pay 0.5 ExCU. Your costs are subtracted continuously depending on the number of your current active connections. You can see your cost flow per minute on the lower right corner of your screen. The costs are directly included in the payoff flow.
Your passive and indirect connections do not cause costs for you. That is, each connection is paid by the player that the arrow points away from. In the case of double arrows ($\longleftrightarrow$) this means, that both players concerned have to pay.

Earnings: Your earnings are determined by the number of participants you are connected with.
For each participant you are connected with (actively, passively, or indirectly), you obtain an **earnings flow of 3 ExCU per minute**. The participants you are connected with (actively, passively, or indirectly) are **marked in blue** as mentioned before.
Multiple connections with a participant (e.g. simultaneously active and passive connections to the same participant) generate single earning only. Example: *T5* in Figure 1 earns only 3 ExCU per minute through his connection with *T3*, although he has an active, a passive, and an indirect connection with *T3*.
Your **earnings of one minute** are calculated as follows: Count the number of participants you are connected with (maximum 5) and multiply it by 3 ExCU per minute. Your earnings are then between 0 ExCU and $5 \cdot 3 = 15$ ExCU per minute. At building or deleting connections the earnings are calculated with respect to the duration of the respective situation.

Profit flow: Your **profit flow** is the difference of your earnings flow and your cost flow from active connections:

Profit flow= (Earnings flow) - (Cost flow from active connections)

Accumulated profits: Your actual **accumulated profits** are determined by continuously adding your profit flow. The accumulated profits are shown at the lower right corner of the screen. They are continuously updated according to the actual earning and cost flows.

Example:
Suppose you are confronted with an earnings flow of 3 ExCU per minute and a cost flow of 2 ExCU per minute. Then your accumulated profits grow in one minute by 1 ExCU. Your accumulated profits are continuously updated in this minute. When you or another participant of your group changes a connection, for example, after 10 seconds, such that you now have a profit flow of 4 ExCU per minute then your accumulated profits will grow by 1 ExCU$/60 \cdot 10 = 0.17$ ExCU during the first 10 seconds and afterwards with a rate equal to 4 ExCU per minute. Therefore, your accumulated profits would have grown in one minute by 0.17 ExCU +4 ExCU$/60 \cdot 50 = 0.17$ ExCU +3.33 ExCU= 3.5 ExCU.

Information

At any point in time the actual values of the following variables will be displayed on the screen.

- your present earning flow (in ExCU per minute)
- your present cost flow (in ExCU per minute)
- your present profit flow (in ExCU per minute)
- your accumulated profits (in ExCU)
- your active connections (as arrows in the graphical illustration on the screen and as "0" or "1" in a table)
- all active connections in your group (as arrows in the graphical illustration)
- the participants whom you are connected with (by an active, passive or indirect connection) are displayed as blue colored squares in the graphical illustration
- the participants whom you are not connected with are displayed as grey colored squares in the graphical illustration
- the amount of time the experiment is already running

Payment

The total amount of ExCU which is flowing to you during the experiment will be accumulated as your profits. It will be converted into Euro and will be paid out in cash immediately after the experiment is finished. The conversion rate is 24 ExCU to 1 Euro. The payment will be made individually and anonymous.

Before the experiment starts, you will be asked some questions about the rules of this game. If there is anything you do not understand, let us know. Your questions will be answered directly at your seat. After having answered all questions the experiment starts.

Please, look only at your own screen and do not talk to other participants.

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