# The impact of individual differences on network relations

Muñoz Herrera, Manuel

Chapter 3

# The coordination of exchange relations: Equilibrium and reciprocity in network formation

## 3.1 Introduction

Creating and sustaining social or economic relationships frequently requires that individuals solve complex coordination problems. The complexity results from the fact that, on the one hand, individuals have to make the double decision *with whom* to form relationships and *how much* resources to allocate to these relationships, while on the other hand, individuals' well-being depends on the combinations of decisions made by themselves and others. For instances, relationships of the type of productive exchanges, such as collaborations or joint ventures, are situations in which actors jointly put their resources into a common pool and use them together to achieve valuable outcomes that separately might be unattainable (Molm and Cook, 1995).

In productive exchanges, there is a requirement of mutual involvement, so that both parties need to agree for a relationship to form between them. In these cases, the coordination problem is rendered especially acute by the underlying opportunity costs of using resources in one relationship rather than another. That is, by choosing to relate to one partner individuals are leaving aside another, risking that the partner chosen may not deliver. Intuitively, in the context of productive exchange, the larger the number of ways actors can choose their partners and their involvement to the relationship, the more severe the coordination problem is. And, the more severe the coordination problem is, the less likely their collaborative relationships will be sustainable along time. For this reason, in this chapter we address the question: *Does severity of coordination reduce sustainable collaboration in the formation of productive exchange networks?*

[0]This chapter is co-authored with Jacob Dijkstra. It has been submitted and is currently under revision.

We theoretically and experimentally apply social exchange theory to address our research question (Blau, 1964; Cook and Emerson, 1978; Homans, 1958). In a social exchange, and particularly in the type of relationships denoted as productive exchanges, individuals relate between them with the intention of improving their well-being through the use and transmission of different types of resources (Foa, 1971). Friends spend time together for this makes them happier (Currarini et al., 2009; de Klepper et al., 2010; Geven et al., 2013). Firms use their money or technological assets to develop common projects (Bojanowski et al., 2012; Goyal and Moraga-González, 2001). Researchers devote time and effort to write joint papers (De Stefano et al., 2013; Jackson and Wolinsky, 1996; Muñoz Herrera et al., 2014). In all these instances individual actors have to decide with whom to connect and how much of their resources to devote to each partner, with their well-being depending on the configuration of decisions made by themselves and their potential partners. These are typically very tough decisions to make: even in cases where actors have but few potential partners, the space of possible partner choices and resource allocations quickly becomes overwhelmingly large, rendering the coordination problem very demanding and complex. Technically speaking, the severity of the coordination problem is linked with the number of strategy profiles.

Solving severe coordination problems can vary because in some situations it is more evident for those involved which relationships to form when aiming to achieve greater benefits (i.e. there are focal points), while in other situations it is very difficult to identify them. This means that the severity of the coordination problem can be attenuated by the possible ways to solve it, when some strategies are focal choices for the actors. As a result, depending on how severe the coordination problem is, the sustainability of the relationships between actors (i.e. the permanence of their choices along time) cannot always be expected to occur. Thus, by understanding the micro-process that leads to forming productive exchanges in contexts of coordination problems with different severity, we can understand the mechanisms that explain how sustainable can collaboration be between actors in exchange networks.

In essence, we define sustainable collaborations as a stable exchange relation over time. Specifically, in the sense of stable allocations of resources in productive exchanges between pairs of actors, over time. Notice, nonetheless, that sustaining collaborations does not necessarily mean that actors in a relationship are very cooperative (i.e. they allocate a lot of resources to their productive exchange). Sustainable collaboration refers to the maintenance of a certain level of investment in an exchange relationship, sometimes even when an actor has material incentives to change her involvement. That is, sustainable collaboration in our study goes along the lines of 'the power of commitment over incentives'. Explicitly, note that for collaborative relationships to be sustainable over time, it is required that the coordination problem of forming exchange relationships is solved. Actors form exchange relationships and allocate resources (i.e. solve the coordination problem they face) and interact repeatedly, so that they can choose to sustain their relationships as they are or to change them (i.e. not sustain their collaborations).

In this chapter we present a behavioral game theoretic experiment on social exchange networks, which contains three conditions that differ widely in how the coordination problem can be solved. By varying the way the coordination problems can be solved, and thus the severity of the coordination problem, we can differentiate mechanisms for the sustainability of collaborative relationships in the social network. That is, understanding the effect that different levels of severity in the coordination problem have, based on how the problem can be solved, is key to understanding the emergence and evolution of exchange networks (Buskens and van de Rijt, 2008). Moreover, it is key to understand the conditions that can lead actors in these networks to collaborate between them along time, and to exclude or include others in their relationships (Flache, 2001; Flache and Hegselmann, 1999; Komter, 1996; Molm, 1990, 1997; Skvoretz and Willer, 1993; Willer, 1999). To address this matter, the rest of the chapter is structured as follows: Section 3.2 provides our theoretical framework and presents our hypotheses. In Section 3.3 we describe the experimental design. Section 3.4 presents the results from the laboratory experiment. We conclude in Section 3.5 with a discussion.

## 3.2 Framework

The decisions actors make on how to relate between them result in a network of exchange relationships. The network of relationships represents the collective level phenomenon (i.e. outcome) that we focus on in this study. This collective outcome, the network, has the potential to evolve and change along time. Conversely, the dyadic interactions between different actors in the network can vary, new relations can be formed, and others can be severed. These changes that can take place in the network of productive relationships affect, in turn, how sustainable the collaborative relationships can be between the different actors in the social exchange network. As argued above, the severity of the coordination problem actors face when making these decisions is a determinant element on how likely is that relationships are formed and sustained. Such severity has been referred to as the difficulty actors have to identify which relationships to form and how. For instance, consider two social interactions with the same number of potential partner to choose and the same way actors can use their resources in the exchanges they form. Consider also that out of all possible ways to establish productive exchanges, one of the situations has *ten* outcomes where actors have no interest in changing their behavior and choices if they were to reach that state, while the other has just *one*. We say the first has a more severe coordination problem than the second.

Based on the example previously stated, we can argue that one major way in which the severity of the coordination problem can be solved, and in consequence in which the sustainability of collaboration in the relationships between actors can be studied, is through the notion of Nash equilibrium. A Nash equilibrium, in our framework can be intuitively understood as a state of the exchange system in which no one has an interest to change either their exchange partners or the way they exchange resources between them, given that if an actor does so she will be worse off in terms of her well being. This means that actors in equilibrium are choosing the best way to respond to the choices of those around them. Nash equilibrium is a concept that illuminates the problem of how can severity in the coordination problem reduce sustainable collaborations in productive exchange networks. In this approach subjects are assumed to behave rationally and best respond to the behavior of those around them. However, equilibrium is not the only approach in the literature on how actors form network relationships.

Another major explanation in network research of how individuals form their relationships and sustain them along time recurs on the notion of stability. In particular, it points to reciprocity motivations as a major antecedent of sustainable collaborations. Stability can be understood as a state in which actors in the network of relationships do not change their choices along time (i.e. allocate the same amount of resources to each of their productive exchanges). However, in contrast to equilibrium, stability does not necessarily imply that if an actor changes the way she relates to others, her well-being will decrease. That is, actors are not necessarily best responding to others when reaching stable outcomes that are not in equilibrium. Instead, for example, actors could be reciprocating to the behavior of those around them in the previous interactions in a way that sustains the collaborative relationship between them, although each could be better off behaving differently. Thus, reciprocity can be an important cause of stability. That is why, it is clear that all equilibrium outcomes are in theory stable but all stable outcomes are not necessarily in equilibrium.

Reciprocity is a mechanism that actors use in order to decide with whom to relate over time. Reciprocal actors respond to the behavior of their partners in a previous point in time, increasing (decreasing) their allocations to projects with partners who increase (decrease) their allocations as well. When actors condition their behavior in this way, they use reciprocity to choose the partner they want to stay with. This promotes stability in the network along time.

In order to tackle the research question of this chapter, our theoretical framework addresses the two different behavioral approaches that have been used to study sustainability in relationships: equilibrium and stability. By studying how differences in the severity of the coordination problem actors face in their exchange relationships influence their choices we can understand the conditions under which networks evolve towards an equilibrium. In addition, when equilibrium is not the outcome that results, we can assess whether actors can nonetheless use a mechanism such as reciprocity to achieve stable outcomes. Understanding the way these different approaches serve to explain behavior when coordination problems are severe is very necessary. In particular, because in the different lines of the literature on exchange relationships they have mainly been studied separately, either equilibrium or either stability. For this reason we experimentally investigate individual and aggregate choices in productive exchange networks to understand the role of equilibrium and stability as mechanisms of sustainable collaborations over time.

Importantly, this experimental study is not a direct test of the model proposed in Chapter 2. This is an experiment on the severity of coordination problems in productive exchange networks. We draw from the model in Chapter 2 a framework for our experimental game, to design a setting where collaborations between different potential partners can be form, and where the use of resources in each collaboration can be differentiated. However, we do not attempt to recreate in the lab all the features of our model from Chapter 2, because this model is not concerned with the coordination problem of how hard it is, in practice, to form productive exchange relationships. More specifically, the model in Chapter 2 is focused on equilibrium play and the properties of equilibrium.

In the following sections we present the different approaches to how the coordination problem can be solved. First we describe the general theory of action we use to study the behavior of the experimental subjects: rational choice theory. Because we are interested in productive exchange relationships which require mutual involvement and coordination of choices between exchange partners, we present how our study can be well suited to use game theory as the tool to address the strategic interdependencies of the individuals in the network of relationships. With the description of rational choice and game theory as the theoretical basis of the choices individuals make, we proceed to specify some details of how our experimental and theoretical approach differs and complements existing work on strategic interactions in networks relationships. Once the general framework of our study is presented we elaborate on equilibrium and stability and present the hypothesis we derive from the different behavioral approaches.

### 3.2.1 Exchange networks and exchange games

Theoretically, social exchange theory (Blau, 1964; Cook and Emerson, 1978; Homans, 1958) has an underlying assumption stating that individual actors are purposive and behave rationally (Wittek et al., 2013). Individuals exchange with others in order to obtain beneficial outcomes for themselves (Cook and Cheshire, 2013, reviews rational choice in social exchange). Actors benefit from the exchange interactions when both parties mutually and willingly work together and consequently form an exchange relationship. That is, actors are assumed to be purposive but their individual choices are not made in isolation of the choices of those they relate with. Individual decisions are not enough to succeed in the achievement of profitable outcomes, because the resulting benefits of an actor strategically depend on the choices of other actors (e.g. actor B cannot be friends with actor A unless actor A also chooses to be friends with actor B). In order to account for the strategic interdependencies in the exchanges, and for the sustainability of collaboration in productive exchange networks, we approach the microlevel decision problem actors face of whom to partner with and how to use one's resources, from a game theoretic angle.

The study of strategic interactions (i.e. game theory) has been widely used in sociology, among other disciplines (e.g. economics, political science), to fruitfully model and predict individual behavior when outcomes result from the interplay of decisions by different actors (Swedberg, 2001, provides a survey of the literature). That is, individual benefits strategically depend on one's and others' choices. In the game theoretic perspective, actors have strategies (i.e. action plans) and the combination of individual strategies (i.e. a strategy profile) is what brings about the behavior of the social system and the *payoffs* individuals obtain (Fudenberg and Tirole, 1999; Schelling, 1978). Therefore, rephrased in game theoretic parlance, the coordination problem we study is one in which actors have a large number of strategies to choose from, and in the exchange network (or group of actors) there is a very large number of strategy profiles.

A key characteristic of exchange problems is that actors have scarce resources to allocate between relationships, so that if choosing to exchange with a given partner, the resources cannot be used to exchange with someone else (Coleman, 1990; Cook and Emerson, 1978; Cook et al., 1983). Moreover, in the problems we study, actors make their partner and allocation choices in ignorance of what others do. This means that they do not observe first what others have chosen and react on it, but instead see the choices of others only after they have made their own choices. As a consequence, there is an underlying problem of opportunities and risk given the costs associated to not using the resources in other available options. For an illustration consider the following example:

**Example 3** *Three individuals, A, B, and C, want to use their resources to collaborate in different projects together. Everyone has 2 units of resources available, say two dollars per person. Each dollar can be spent either alone or in a joint collaborative project with another person. In this case, actors face the combined decision of whom to partner with and how to use their endowment in each relationship. If an actor chooses not to collaborate with anyone but to pursue her goals alone, she gets "a" units of benefit, for every dollar. If two actors pool resources together, each gets "$b > a$" units of benefit for every dollar they mutually invest in their venture. But, if one invests from her resources in the relationship but the other does not, this is worse than just being alone, because the collaboration is not reciprocated, so the actor who puts her money in gets "$0 < a < b$" units of benefit. Thus, collaborating with a partner gives a greater benefit than just staying alone, but choosing to stay alone is better than investing in a relationship where the other part is not involved. Some illustrative network outcomes are portrayed in Figure 3.1.*

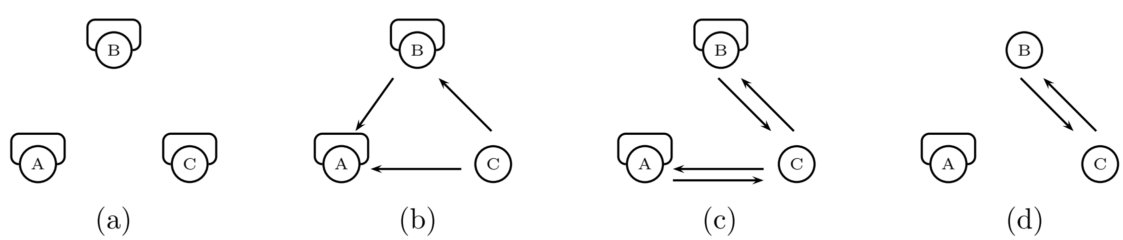


**Figure 3.1:** A loop around a node represents an actor using her resources alone. An arrow from one node to another represents an actor investing her money in a relationship with the *receiving* node. If both actors send an arrow to each other, this represents a collaborative relationship that is reciprocated mutually. If there is a single arrow coming from a node it means she uses both dollars in that relationship. If there are two arrows coming from a node it means she uses one dollar in each relationship.

Even for a simple case as that of three individuals and few units of resources to exchange together (see Example 3), there are many different strategies for the actors and there are even more combination of choices (strategy profiles) that can result. As with many other activities (e.g. friendships, co-authorships, partnerships), this example illustrates an exchange situation in which actors receive benefits only if they succeed in coordinating in the way they use their resources, either alone or together with another party. However, if out of a pair of actors only one invests resources into the relationship, this leads to a coordination failure, and the unreciprocated actor does not receive any benefit.

Figure 3.1 illustrates four cases: In case (a) all actors use their resources separately so that each stays alone instead of investing in a relationship with someone else. Case (b) illustrates the case where B wants to join forces with A, but A is not reciprocating and instead uses all her resources alone. Thus, they fail to coordinate and there is no exchange. There is also a coordination failure between C and A, and C and B. Case (c) illustrates a situation where both A and B use one dollar of their endowment alone and invest the other in a joint venture with C. Actor C splits her endowment between A and B. Finally, case (d) is one in which B and C put all their resources together, while A uses her two dollars alone.

Taking into account the example above, we can describe three essential characteristics of the experimental exchange game used for this study: (i) endogenous formation of exchange relationships, (ii) simultaneous decisions of partner selection and resource allocation, and (iii) flow of resources. The combination of these three elements builds a suitable setup where we can study how the severity of the coordination problem in the formation of productive exchange relationships can reduce sustainability in the collaborative relationships actors form over time.

The first element, *endogenous formation of relationships*, means actors actively choose their relationships instead of assuming that relationships are given to them. This addresses a main limitation that much research on exchange networks has had, by assuming networks to be *exogenously* given. In such a context, the opportunity of interacting with one partner or another is not a choice of the actors. In the tradition of exchange networks, the pattern of connections in a network structure has been conceived as a sort of a market with restrictions determining who can exchange with whom (van Assen, 2001). The limitation of this approach is, as pointed out by Jackson (2010), that one cannot investigate how networks are formed in the first place.

For this reason, we develop our study under the assumption that networks are dynamic and emerge as the result of decisions actors make on forming their exchange relationships (Buskens and van de Rijt, 2008; Corten and Buskens, 2010; Snijders, 2013). The literature on the endogenous formation of network relationships has been explored in different fields. The study of social network dynamics was pioneered by sociologists and anthropologists (Snijders, 2013; Stokman and Doreian, 1997; Weesie and Flap, 1990; Wittek, 1999, 2001). There is also a fruitful line of research on game theoretic modeling of endogenous network formation in economics (Goyal, 2007; Jackson, 2010; Vega-Redondo, 2007, survey the literature) and in sociology (Braun and Gautschi, 2006; Dogan and van Assen, 2009; Dogan et al., 2009).

The second element, *simultaneous decision of partner selection and resource allocation*, integrates in one the choices actors make. By doing so, we addresses a limitation in research on endogenous network formation, which has assumed that the choice of relationships implies in itself a certain degree of involvement of the actors in the relationships, and therefore actors need only to choose with whom to connect. For example, involvement in relationships can be operationalized as the amount of time people spend together. In this sense, the limitation is that in existing theoretical models actors would divide symmetrically their time between the relationships they form. Having a relationship determines how involved actors are, and actors cannot differentiate how they use their resources across different relationships (Jackson and Watts, 2001; Jackson and Wolinsky, 1996). Thus, to allow for a natural extension from exogenous to endogenous exchange networks, we model the choices of partner selection and resource allocation as one of *simultaneous* choice. Actors decide how much of their resources (e.g. time) they want to allocate to each of their relationships and by doing so they simultaneously choose with whom to relate and how "involved" they want to be in each relation they form.

The third element of our exchange game, *flow of resources*, addresses a very fundamental aspect of exchange networks: in exchange relationships actors exchange resources. Homans (1958)'s definition of social behavior as an exchange of goods implies pure exchange, also called direct exchange by sociologists. In pure exchange, partners are endowed with bundles of commodities that they can exchange with each other, and have different preferences over these commodities (Coleman, 1990; Edgeworth, 1881; Emerson, 1976). In contrast to choosing how to use resources to exchange, there is a line of work on exchange problems in which actors choose how to split the outcomes of the exchange (Dijkstra and van Assen, 2008).

Integrating these elements into the interactions portrayed in our exchange game and drawing from the illustration in Example 3, it is clear there are multiple possible outcomes that can result from actors' choices. That is, many different networks of relationships and levels of "involvement" in them can result. From these possible outcomes (notice there are many more possible networks, not represented in Figure 3.1), it is evident that selecting with whom to exchange and how much resources to allocate is a difficult decision. There is an implicit coordination problem when deciding what strategy to follow, given that outcomes strategically depend on the choices made by others. Individual strategies are very numerous in a case with even a small number of potential exchange partners and few resources, and the number of strategy profiles in the exchange network is huge. For this reason we address the questions of how actors choose their strategies in the exchange game and which strategy profiles emerge at the network level.

### 3.2.2 Individual rationality: Nash equilibrium

To illustrate better our theoretical framework we first briefly describe the exchange game we use in our experiment. With this in mind, we can better relate the theoretical questions on equilibrium and stability to the empirical assessment of sustainable relationships in the productive exchange network. We study an exchange game where 4 actors, each having

10 units of resources, can distribute them across four projects, one individual and three combined with the other actors (i.e. dyadic). These simultaneous choices represent the so-called *stage game*. Actors play 20 repetitions of the stage game between them. Based on this game structure, and in order to address the above mentioned questions on how actors choose their strategies, we look at Nash equilibria of the stage game.[1] Nash equilibrium is based on a requirement of *individual rationality*. That is, a Nash equilibrium is a strategy profile such that no actor individually wants to change her strategy (partner choice and resource allocation) given that others do not change their strategy either. In a Nash equilibrium no actor has individual incentives to deviate from the choice she makes. That is, if a Nash equilibrium is played over time, each individual actors has sustainable collaborations, for none has incentives to change the allocations made.[2]

From this definition of equilibrium and the requirement of individual rationality, it is clear that in Example 3, three of the networks portrayed are Nash equilibria: cases (a), (c) and (d). In all of them, no one has incentives to change her choice of who to use her endowment with and how, if the other actors do not change their choices either. For example, case (a) is a Nash equilibrium because if an actor expects a counterpart not to partner with her and invest in an exchange relationship, she is better off staying alone. In case (c) both A and B have a successful exchange with C, and both A and B also use some resources alone. None of them has incentives to change their allocation strategy unilaterally. In case (d) both B and C are successfully using all their endowment on their joint venture and have no incentives in changing their strategy. That is, they are coordinating and thus, if they each expect the other to stay involved in the relationship, neither is better off being alone or trying to collaborate with A. Also A has no incentives in changing the way she invests her endowment because that would lead to a coordination failure, given B and C are exchanging all their resources together.

Because an exchange only takes place if both parties are involved, case (b) is not a Nash equilibrium for this game. Instead of using her resources in attempting to exchange with A, B would be better off using the resources alone or reciprocating to C, because A is using everything alone. That is, if A does not change her strategy B has incentives in changing hers. The same holds symmetrically for C.

This example illustrates that even for a very simple case, such as this one, there are

[1] In finitely repeated games where the time period is fixed and known (i.e. 20 rounds), it is optimal to play a Nash strategy in the last period. From this, using backward induction, there is a sequence of equilibria corresponding to the equilibria of the stage game, if actors are assumed to be patient enough (they do not discount future payoffs). In addition, there are combinations of strategies that become equilibria even when they are not equilibrium of the stage game. Given the complexity of the game we model, and the great multiplicity of equilibria there are, we look at the set of equilibria in the repeated game that conforms to the concatenation of equilibria of the *one-shot*. This we do because we want to study the dynamics of convergence of the network game. That is, we can study how the actors converge to stable network structures in their choices of partner selection (Jackson and Watts, 2001, 2002; Jackson and Wolinsky, 1996).

[2] Notice that case (a) in Figure 3.1 is included in the set of Nash equilibria, but it is a case of sustainable non-collaboration. In our analysis, the Nash equilibrium in which everyone fully defects is excluded from our definition of sustainable collaboration.

multiple strategy combinations and from within those there are many Nash equilibria, making the coordination problem very severe. In consequence, and motivated by this complexity, we are only considering *pure strategy* Nash equilibria, so that we are focused on equilibrium that provide a complete definition of how an actor will play a game. Pure strategy Nash equilibria determine the action an actor will make for any situation she could face. This in contrast to *mixed strategy* Nash equilibria, which assigns a probability to each *pure* strategy, allowing actors to randomly select a pure strategy. However, because it is not always clear what the counterpart will choose, actors run a risk when using their resources in a relationship if they could have gained more by investing them differently. In this simple illustration it is possible to observe that notwithstanding the compelling logic of Nash equilibria, the problem in games with a large strategy space is that there will typically be very many Nash equilibria. Thus, actors and groups of actors in a network face a *coordination problem*: from among the (very) many Nash equilibria, which one should they choose?

Arguably, the coordination problem becomes less daunting if there are fewer Nash equilibria, compared to the number of strategy profiles. That is, selecting what strategy to follow becomes less problematic when the number of equilibria is smaller (Galeotti et al., 2010; Hellwig, 2002), because the potential equilibrium outcomes become focal points that can help the actors coordinate. As described by Schelling (1960), focal points are outcomes people tend to aim at in absence of communication. These outcomes are focal points "for each person's expectation of what the other expects him to expect to be expected to do" (pg. 57). Conversely, the more equilibria there are in an exchange game, the more focal points for the different actors and the harder the coordination problem becomes. Therefore, our first hypothesis refers to the likelihood of reaching equilibrium in an exchange network given the size of the equilibrium set.

**Hypothesis 1** ***Size of the Nash equilibrium set***. *The fewer Nash equilibria there are in an exchange game, the more often exchange networks will be in equilibrium*

Note that H1 is based on the assumption that actors behave rationally. Otherwise, if assumed that actors choose randomly, then there are more chances of equilibrium play the more Nash equilibria in the exchange game.

### 3.2.3 Dyadic rationality: The core

In addition to Nash equilibrium, other game theoretical solution concepts can aid actors in finding a solution to their coordination problem. In particular social exchange theory in sociology, most notably work on *the core* (Bienenstock and Bonacich, 1992, 1993), has identified an important requirement for exchange patterns to be stable. Namely, exchange patterns (i.e. strategy profiles) are in the core when *no pair of actors can mutually increase their utility through coordinated actions.* This requirement is labeled *dyadic rationality* (Dijkstra, 2009; Rapoport, 1970) and comes in addition to the Nash equilibrium requirement of individual rationality.

The work by Elisa Bienenstock and Phillip Bonacich has paid great attention to the core as a solution concept that renders clear predictions for the likelihood of reaching agreements in exchange networks (Bienenstock and Bonacich, 1992). An important result is that for exchange networks the core requirements involve only dyads, and higher order coalitions (e.g. triads, etc.) can be safely ignored (Bonacich and Bienenstock, 1995). Thus, a network of social exchange relationships is in the core when no individual actor can unilaterally improve her utility, and no pair of actors can mutually improve their utility by changing their partner choices or resource allocations. Even though the core solution was developed in the context of fixed, exogenously given, exchange networks, the principles of individual and dyadic rationality can equally well be applied to our social exchange game in which actors can endogenously choose their exchange partners.

For our example in Figure 3.1 we have illustrated some possible Nash equilibria. Consider cases (a) and (d), each satisfying the requirement of individual rationality. In neither of these cases do actors have incentives to unilaterally change their strategy if the other actors stay the same. However, we have assumed that when actors successfully form an exchange relationship they are better off than if each of them uses her resources alone. Thus, there are no coordinated actions between the actors that would move them from (d) to (a), but actors B and C would have incentives to jointly change their choice and move from (a) to (d), to improve their well-being. That is, equilibrium (d) is in the core while equilibrium (a) is not.

From our simple illustration a very important element arises: not all the Nash equilibria in a network are in the core. What is more, not all networks have equilibrium outcomes in the core. In some networks any pattern of exchange agreements will always leave at least one dissatisfied pair; a pair currently not exchanging who could do better if they were to exchange with each other, or a pair who are currently exchanging but who can profitably affect a coordinated rearrangement of their respective allocations. Those networks are classified as having an *empty core* (Bonacich, 1998), because the requirement of dyadic rationality by all pairs of actors cannot be satisfied simultaneously. Thus, in social exchange networks with empty cores every possible pattern of exchange is susceptible to a disruption by a pair of actors. In this sense, there is a clear difference between networks that have equilibria in the core and those that do not.

Arguably, the coordination problem actors face is less complex in the presence of equilibria that satisfy individual and dyadic rationality requirements than in networks with equilibria that only satisfy individual rationality. This is true because in networks with a non-empty core, equilibria in the core are less easily disrupted and thus more stable. In fact, as pointed out by Bonacich (1998), in networks with empty cores structural forces lead to instability in exchange patterns. Therefore, our second hypothesis refers to the likelihood of reaching equilibrium in an exchange network given there are equilibria in the core.

**Hypothesis 2** ***Nash equilibrium in the core.*** *When there are equilibria in the core,* *exchange networks will be in equilibrium more often than when there is an empty core, and equilibria in the core should be observed.*

Note that Hypothesis 2 (H2) is derived from the assumption that if there is equilibria in the core, actors are more likely to reach it given it becomes a focal point above all other equilibria. Furthermore, equilibria in the core are more likely to be stable along time because they are stronger to disruptions and thus, the assumption is not only that it would be easier for actors to reach them, compared to equilibria not in the core, but also that once reached, it is unlikely actors will choose different strategies. That is, if an equilibrium in the core is played over time, each individual actor and each pair of actors have sustainable collaborations, for not even pairs of actors have incentives to change their allocations of resources. Thus, more equilibria (in the core) would be played along time.

### 3.2.4 Empty cores: Reciprocity

The previous two hypotheses assume actors choose equilibrium strategies. These hypotheses are therefore inherently non-dynamic. As a consequence, there is a division between networks with equilibria in the core and those with an empty core (Bonacich and Bienenstock, 1995), given networks with an empty core are inherently unstable, from an equilibrium perspective. The separation between these networks becomes more evident when individual and dyadic rationality fail, because existing work on equilibrium and the core state that the same mechanism that predicts behavior in stable networks (i.e. rational best response) cannot be used to study unstable networks. Thus, it is not clear how to approach the coordination problem actors face in such cases. Nonetheless, there are other mechanisms that have been explored, which can be used to help explain the way people exchange, even in empty core networks and how they can use different processes to reach stable relationships even when those stable outcomes are not networks in equilibrium.

With respect to exchange networks, there is a line of work arguing that individual actors condition their behavior in terms of *reciprocity*: over the history of the interactions in the network, individuals respond to the behavior of their exchange partners in a reciprocal manner (Lawler and Yoon, 1996; Thye et al., 2002), even if their response is not a *best response*. Reciprocity is therefore a mechanism that can help us understand how actors decide with whom to relate over time. Thus, in network relationships where interactions are repeated, reciprocity can be an explanation of how actors solve the great coordination problem they face. Particularly, because it helps actors stay together and thus it becomes the underlying promoter of the stability in their relationships; and thus of sustainability of their collaborative relationships.

Work on how reciprocity can be a mechanism that helps relationships become stable along time, is based on the idea that actors respond to the behavior of their partners in a previous point in time. This can result in a dynamic effect in which actors are reciprocating to their partners behaviors which makes their interactions more likely to become stable along time. Stability due to reciprocity may even result in actors tending to stay in the relationship despite alternatives; even when these alternatives are materially superior (Lawler and Yoon, 1993). Reciprocity helps actors simplify the severity of the coordination problem they face, over time. When considering equilibrium behavior and reciprocity, it is noticeable that in situations were a stable Nash equilibrium is reached equilibrium behavior is undistinguishable from reciprocity, since no one changes their behaviors. however, when considering stable outcomes that are not in equilibrium, reciprocity can be clearly distinguishable as the force that leads to sustainable (i.e. stable) relationships. Particularly, the application of reciprocity is based on the notion of *dyadic improvements*. That is, reciprocity can lead to more stable dyadic relationships which in turn can result in more stable exchange networks. This leads to our third and final hypothesis on the allocation of resources between actors.

**Hypothesis 3** ***Reciprocity***. *The more actors reciprocate to the behavior of their exchange partners the more often stable outcomes will be reached in exchange networks*

The intuition of Hypothesis 3 (H3) is that reciprocity can be expected to be a driving force for the sustainability of exchange relationships, which in the aggregate can lead to stable networks. This hypothesis complements H1 and H2 by including how severe the coordination problem is, which can help predict the likelihood that networks are in equilibrium.

## 3.3 The experiment

In this section we discuss the design of our laboratory experiment. We first describe the experimental game we use, which is derived from the work by Muñoz Herrera et al. (2014), on the formation of collaboration networks between heterogeneous actors. The differences between types of actors in the experimental game are used as means to design the experimental treatments we test. We designed experimental treatments that systematically vary the composition of the group in terms of the types of the players. As a consequence of these variations in the composition of the group, we arrive at three treatments that vary the severity of the coordination problem in the exchange game, and these variations between treatments are used to test the three hypothesis derived from our theory.

### 3.3.1 Experimental game

The experimental game is a normal form game where four actors (A,B,C,D) interact and make simultaneous choices in a productive exchange environment. Each actor is endowed with 10 units of resources that can be allocated in two classes of projects: individual and combined. In an individual project an actor uses her resources alone. A combined project (i.e. a social exchange) requires the mutual involvement of two actors. The focal actor, say actor A, chooses an allocation vector that expresses how she uses her resources between (1) an *individual* project; (2) a *combined* project with B; (3) a *combined* project with C, and (4) a *combined* project with D. This decision integrates the choices of partner selection and resource allocation (see Figure 3.2).

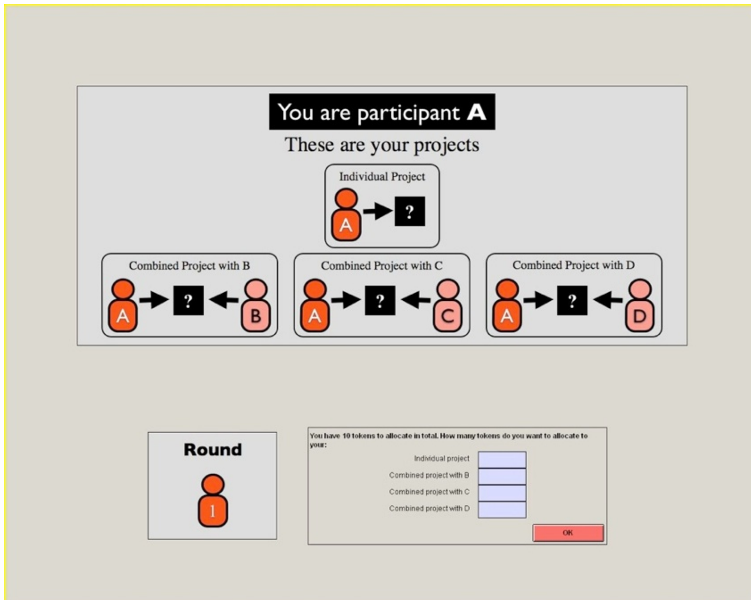


**Figure 3.2:** Decisions in the experiment. The sum of the allocations A makes into her individual project and into the combined projects with B, C and D is equal to the size of the endowment (10 units of resources).

The payoffs an actor can get are the aggregation of the total points earned in each project. This is expressed, from the point of view of actor A, below:

$$\text{Total Points} = \text{Points}_{\text{alone}} + \text{Points}_{\text{with B}} + \text{Points}_{\text{with C}} + \text{Points}_{\text{with D}}$$

The combination of the *allocation vectors* actors choose, the strategy profile, determines the *payoffs* actors receive (i.e. the value of their outcomes). In addition, actors can differ in the effect that their allocations have on the value of the outcomes, so that even if two actors allocate the same amount of resources into a project, their effect on the result need not be the same. That is, an actor, say actor A, has a type that represents her productivity, $\text{Type}_A = \{\text{Low,High}\}$. The payoff matrices depending on the type of actor A and her partner are presented in Tables 3.1, 3.2, and 3.3. Details about the payoff scheme presented in these tables will be discussed in the treatment section. Nonetheless, an important element of the interaction in a productive exchange, illustrated in the payoff matrices, is that only if both actors allocate resources to their common project a positive outcome can be achieved. This means that payoffs from the individual project depend only on the resources the actor allocates to herself (i.e. the resources not used to exchange with others), and payoffs from the combined projects depend on the mutual allocation of resources between an actor and her partner. Thus, unreciprocated relationships do not produce valuable outcomes and players get 0 points from that project.

Clearly this is a very complex coordination problem. In the game, allocations are made in integers (i.e. 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10), and actors can distribute their resources however they want between their three combined projects and the individual project. For these very small networks, each actor has 286 strategies (allocation vectors), yielding $286^4$ strategy profiles (a little under 6.7 billion). Thus, our experimental game captures the interaction of actors in a complex environment where coordination problems are overwhelmingly cumbersome.

In order to test the hypotheses derived from our theoretical framework, we vary the complexity of the coordination problem in three different experimental treatments by means of varying the *results rules* (Schelling, 1978). That is, the way in which an actor's choices can affect outcomes and payoffs in the games. To do so, we use differences in the payoffs actors can obtain by coordinating with one partner or another, given their type. Actors' payoffs depend on their type and the type of their chosen partners (low or high in productivity), as well as on the allocations made by them. Therefore, the possibilities of reaching stable outcomes at the aggregate level are not the same; given the choice of partner selection has not the same results between treatments. In other words, although actors earn payoffs jointly if they coordinate with a partner in exchanging resources in a common project, there are differences in how much they earn with one partner or the other, even if they both make the same allocation to a combined project. As a consequence, the resulting differences in the experimental treatments are expressed in terms of the size of the equilibrium set (H1), in the existence of equilibria in the core (H2), and in the use of reciprocal behavior as a mean to respond to others (H3).

### 3.3.2 Experimental treatments

We designed experimental treatments that systematically vary the composition of the group in terms of the types of the players. As a consequence of these variations in the composition of the group, we arrive at three treatments that vary the severity of the coordination problem in the exchange game. Thus, we can derive from the three experimental treatments different conditions on how sustainable collaborative relationships are. That is, on how actors choose along time to relate with the same partners and allocate the same amount of resources in their exchange relationships. Before describing the treatments we present a detailed description of the differences in payoffs given the type of the actors (i.e. result rules). To do so, we relate the different ways actors affect results to differences in actors' expertise as presented on works about the role of actors' expertise on exchange relationships (Collins, 1990; Sellinger and Crease, 2006). Intuitively, actors' expertise is a clear way to illustrate how the use of resources in an exchange can affect differently the outcomes achieved depending on who the actors are.

Research on expertise suggests that there are two main types of actors' expertise: generalist and specialist expertise (Collins and Evans, 2002, 2007). Those experts who have a general knowledge but cannot solve highly complex problems within a specific subarea of a domain hold a *generalist* expertise. This means that generalist expertise can be very effective in using their resources in simpler or more general problems, but the more specific knowledge is demanded, the less effective further investments of time and effort (i.e. resources) of a generalist will be. In our game we denote this as a *low* type. The *specialist* type of expertise, on the other hand, refers to actors who are proficient in a certain type of knowledge on a very specific subfield in their domain, so that their abilities allow them to perform a skilled practice of the task they are involved with, solving increasingly complex problems within that subfield. Thus, specialists are very effective in using their resources in a single complex problem. In our game we denote this as a *high* type.

In relation to our exchange game, payoffs for the *low* type of actors (see Table 3.1) are greater when they use their resources in such a way that they diversify and invest in multiple projects. Thus, instead of focusing on a single relationship and exchanging all their resources with only one partner, actors are better off if they invest in many projects at a time. An example of this is provided in the next section when we describe in detail Treatment 1.

| | |
|---|---|
| 0 | 0 |
| 1 | 13 |
| 2 | 17 |
| 3 | 20 |
| 4 | 23 |
| 5 | 25 |
| 6 | 27 |
| 7 | 29 |
| 8 | 30 |
| 9 | 32 |
| 10 | 33 |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 8 | 10 | 12 | 13 | 14 | 16 | 17 | 17 | 18 | 19 |
| 2 | 0 | 10 | 13 | 16 | 17 | 19 | 20 | 22 | 23 | 24 | 25 |
| 3 | 0 | 12 | 16 | 18 | 20 | 22 | 24 | 26 | 27 | 28 | 30 |
| 4 | 0 | 13 | 17 | 20 | 23 | 25 | 27 | 29 | 30 | 32 | 33 |
| 5 | 0 | 14 | 19 | 22 | 25 | 27 | 30 | 31 | 33 | 35 | 36 |
| 6 | 0 | 16 | 20 | 24 | 27 | 30 | 32 | 34 | 36 | 37 | 39 |
| 7 | 0 | 17 | 22 | 26 | 29 | 31 | 34 | 36 | 38 | 40 | 42 |
| 8 | 0 | 17 | 23 | 27 | 30 | 33 | 36 | 38 | 40 | 42 | 44 |
| 9 | 0 | 18 | 24 | 28 | 32 | 35 | 37 | 40 | 42 | 44 | 46 |
| 10 | 0 | 19 | 25 | 30 | 33 | 36 | 39 | 42 | 44 | 46 | 48 |

**Table 3.1:** Payoff tables for an exchange between low type actors. The table on the left shows payoffs for the individual project and the table on the right for the combined project. The gray column/row illustrates the resources allocated. The cells inside illustrate the payoffs earned; the same for both actors in the combined project.

Payoffs for the *high* type of actors (see Table 3.2) are greater when they use resources in such a way that they focalize into a single combined project. Thus, instead of diversifying, actors are better off relating to a single exchange partner when both use all their resources in the exchange together. An example of this is provided in the next section when we describe in more detail Treatment 3.

Finally, payoffs for an exchange between a *low* type of actor and a *high* type of actor are illustrated in Table 3.3. An example of equilibrium behavior for this case is presented in the next section when we describe in more detail Treatment 2.

| | |
|---|---|
| 0 | 0 |
| 1 | 5 |
| 2 | 11 |
| 3 | 17 |
| 4 | 23 |
| 5 | 29 |
| 6 | 36 |
| 7 | 43 |
| 8 | 49 |
| 9 | 56 |
| 10 | 63 |

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 2 | 4 | 5 | 6 | 8 | 9 | 11 | 12 | 14 |
| 2 | 0 | 2 | 5 | 8 | 11 | 14 | 17 | 20 | 23 | 26 | 29 |
| 3 | 0 | 4 | 8 | 12 | 17 | 21 | 26 | 31 | 36 | 41 | 46 |
| 4 | 0 | 5 | 11 | 17 | 23 | 29 | 36 | 43 | 49 | 56 | 63 |
| 5 | 0 | 6 | 14 | 21 | 29 | 38 | 46 | 54 | 63 | 72 | 81 |
| 6 | 0 | 8 | 17 | 26 | 36 | 46 | 56 | 66 | 77 | 88 | 98 |
| 7 | 0 | 9 | 20 | 31 | 43 | 54 | 66 | 79 | 91 | 104 | 117 |
| 8 | 0 | 11 | 23 | 36 | 49 | 63 | 77 | 91 | 106 | 120 | 135 |
| 9 | 0 | 12 | 26 | 41 | 56 | 72 | 88 | 104 | 120 | 137 | 154 |
| 10 | 0 | 14 | 29 | 46 | 63 | 81 | 98 | 117 | 135 | 154 | 173 |

**Table 3.2:** Payoff tables for an exchange between high type actors. The table on the left shows payoffs for the individual project and the table on the right for the combined project. The gray column/row illustrates the resources allocated. The cells inside illustrate the payoffs earned; the same for both actors in the combined project.

| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 3 | 4 | 4 | 5 | 5 | 6 | 6 | 7 | 7 | 7 |
| 2 | 0 | 6 | 8 | 10 | 11 | 12 | 13 | 13 | 14 | 15 | 15 |
| 3 | 0 | 10 | 13 | 15 | 17 | 18 | 20 | 21 | 22 | 23 | 24 |
| 4 | 0 | 13 | 17 | 20 | 23 | 25 | 27 | 29 | 30 | 32 | 33 |
| 5 | 0 | 17 | 22 | 26 | 29 | 32 | 35 | 37 | 39 | 41 | 42 |
| 6 | 0 | 21 | 27 | 32 | 36 | 39 | 42 | 45 | 47 | 50 | 52 |
| 7 | 0 | 24 | 32 | 38 | 43 | 47 | 50 | 53 | 56 | 59 | 61 |
| 8 | 0 | 28 | 37 | 44 | 49 | 54 | 58 | 62 | 65 | 68 | 71 |
| 9 | 0 | 32 | 43 | 50 | 56 | 61 | 66 | 70 | 74 | 78 | 81 |
| 10 | 0 | 36 | 48 | 56 | 63 | 69 | 74 | 79 | 83 | 87 | 91 |

**Table 3.3:** Payoff table for an exchange between a high type and a low type actors. The table shows the payoffs for the combined project between high and low. The gray column (row) illustrates the resources allocated by the high (low) type. The cells inside illustrate the payoffs earned; the same for both actors.

The motivation of our design is as follows. A complicating factor when it comes to solving the coordination problem implied by social exchange is that in real-life not all partners are equally attractive or productive. Hence, actors get more out of some relationships than out of others. For instance, spending time with high status or popular friends might be more rewarding than spending time with *uncool* people (Oldmeadow and Fiske, 2010). In the same vein, the compatibility with the technological assets of a certain partner can make it more profitable for a firm to form a relationship with such partner than with others (Hernández et al., 2013). Consider also the case of a scientific co-author whose expertise on a topic guarantees a better outcome for a specific research paper compared to the expertise of other co-authors (Muñoz Herrera et al., 2014). This differentiation in the way potential exchange partners influence results renders the problem of selecting partners and allocating resources (i.e. the coordination problem) particularly hard, because the potential payoffs an actor can earn depend on *who* their partners are and *how* they behave. We now describe our three experimental treatments.

To calculate the number of Nash equilibria we wrote a computer program that uses the payoff matrices presented in Tables 3.1, 3.2, and3.3, and checks for each of the strategy profiles: ($a$) whether it is a Nash equilibrium, and if so, ($b$) whether that Nash equilibrium is stable to dyadic deviations, i.e., the core. Recall that in our game, a deviation is a combination of partner selection and the use resources, represented by the allocation of resources in the exchange vector. The program is available upon request.

### Treatment 1: Large Nash set and no core

In Treatment 1 (T1) four actors of type *low* compose the group. Each is better off using her resources in creating multiple projects with others, including an individual project. As a consequence, there are 46,447 equilibrium configurations in T1.

**Example 4** ***(Nash equilibria in T1)****: A simple case of a Nash equilibrium in this treatment is illustrated by network (a) in Figure 3.3. In this Nash equilibrium all actors have 2 combined projects and an individual project. Using the payoff matrices in Table 3.1, if each actor allocates 3 units of resources to each combined project they get 18 points per project. In addition, the remaining 4 units allocated to the individual project, give them 23 points. Thus, in total each actor gets 59 points. This is a Nash equilibrium: reallocating units of resources between projects cannot improve an actor's payoffs and in some cases can make them worse off. For instance, if A moves a unit of resources from her project with B and allocates it in her project with D, while everyone stays the same, she can only gain 2 points for every unit reallocated, but her gains also decrease by 2 points in the project from which she used the resources.*

Thus, even for our simple case of 4 players with 10 units of resources to allocate, the coordination problem is cumbersome given the multiplicity of equilibria. On the other hand, even with thousands of equilibrium configurations, only a tiny fraction of the nearly 6.7

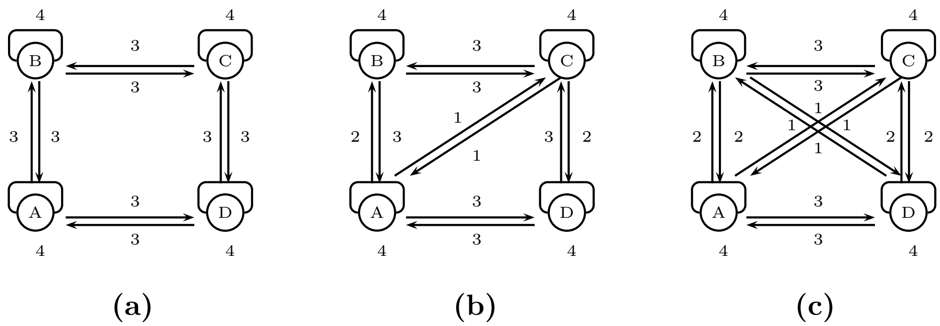


**Figure 3.3:** Nash equilibrium in T1. A loop around a node shows an actor using her resources in an individual project. An arrow from one node to another shows an actor investing her resources in a relationship with the *receiving* node. If both actors send an arrow to each other, this shows a combined project between them. The numbers next to the arrows show the resources used.

billion strategy profiles are Nash equilibria. Thus, assuming players choose their strategies *randomly*, the probability of them landing on a Nash equilibrium is close to zero. Thus, even though T1 has very many Nash equilibria in an absolute sense, these equilibria do entail a substantive prediction.

An important feature we use in the payoff scheme for T1 is that it has no *core* solution. This means that for all 46,447 Nash equilibrium configurations, there is at least one pair of dissatisfied actors who could do better by reallocating their resources together.

**Example 5** ***(Empty core Nash equilibria in T1)****: In network (a) in Figure 3.3 actors A and C, who are not exchanging, would improve if each used 1 unit of resources from any existing project to establish a relationship together, as in network (b). Using payoffs from Table 3.1 we can see that in such a case, although decreasing 1 unit of resources implies loosing 2 points, forming the new relationship together with those resources implies gaining 8 points. This is also a Nash equilibrium because no actor, not even those who are allocating 3 units to combined projects with partners who are allocating 2 units, have incentives to unilaterally deviate. However, because in T1 there are no equilibria in the core, it is easy to see that there are dyadic improvements if the other two actors not connected in network (b), actors B and D did the same and used 1 unit of resources to form a new relationship between them.*

### Treatment 2: Small Nash set and no core

In Treatment 2 (T2), two actors of type *low* (A and B) and two actors of type *high* (C and D) compose the group. There are 54 equilibrium configurations in T2.

**Example 6** ***(Nash equilibria in T2)****: A Nash equilibrium in this treatment is illustrated in network (a) in Figure 3.4. In this equilibrium each low type actor is exchanging with one high type actor, A with D and B with C. In addition, A and B each allocates resources to her individual project. Using the payoffs matrices in Table 3.3, we can see* *that if A (B) allocates 8 units to the exchange with D (C), when D (C) allocates 10 units, they each get 83 points. In addition, the 2 units A (B) allocates to her individual project give her 17 points. Thus, in total A (B) gets 100 points and C (D) 83 points. A (B) has no incentives to allocate 7 or less units to use the reallocated resources in their individual project, neither she would improve by allocating 9 or 10 and reducing her allocation to the individual project. The same holds for C (D) when considering to use 9 units or less in the combined project with B (A) and using those resources in an individual project.*

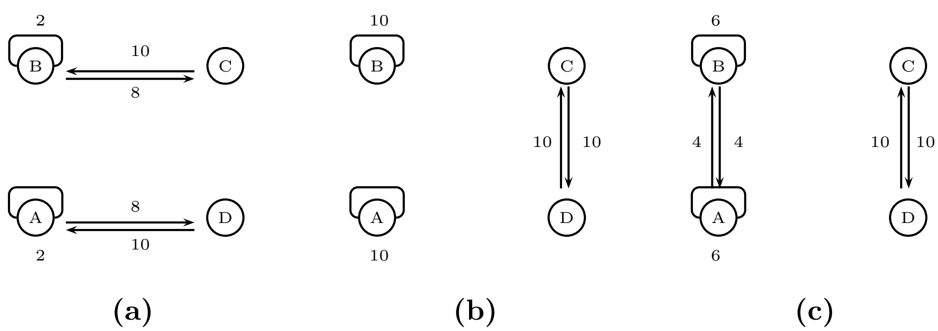


**Figure 3.4:** Nash equilibrium in T2. A loop around a node shows an actor using her resources in an individual project. An arrow from one node to another represents an actor investing her shows in a relationship with the *receiving* node. If both actors send an arrow to each other, this shows a combined project between them. The numbers next to the arrows show the resources used.

This equilibrium illustrates how actors C or D have incentives to behave as *specialists*, allocating all their resources into a single project. Actors A or B have incentives to allocate at least one unit of resources in their individual project, while forming other exchange relationships with the remainder of their resources. Due to the starkly lower number of Nash equilibria compared to T1, the coordination problem in T2 is simpler. However, as in T1, there are no equilibria in the core in T2.

**Example 7** ***(Empty core Nash equilibria in T2)****: As shown before, network (a) is a Nash equilibrium configuration for the game. However, there are pairs of actors who can improve their benefits by coordinating in bilateral deviations. Using the payoffs from Table 3.3, we can see that if C and D reallocated all of their resources into a combined project together, each would earn 173 points, which is better than the 83 points they were earning in network (a). If this is the case and they deviate, a possible equilibrium is the one portrayed in network (b). In such configuration, because neither A nor B are being reciprocated by their former partners, they use all their resources in their individual project, each earning 33 points. Network (b) is a Nash equilibrium. However, actors A and B could improve bilaterally if they jointly reallocate 4 units to a combined project together, earning 23 points each, and used the remaining 6 in their individual project, earning 27 points, for a total earning of 50 points. This is illustrated in network (c), which is a Nash equilibrium where no actor wants to unilaterally reallocate their resources.*

### Treatment 3: Small Nash set and core

In Treatment 3 (T3) four actors of type *high* compose the group. Each of them is better of using her resources in a single project than in multiple projects. There are 10 equilibrium configurations in T3 and none of them are equilibria in which players invest in more than one project at a time.

**Example 8** ***(Nash equilibria in T3)****: A Nash equilibrium in this treatment is illustrated in network (a) in Figure 3.5. Using the payoff matrices in Table 3.2, we can see that if a given actor, in this equilibrium, allocates all her 10 units of resources into their individual project, they each earn 63 points. Clearly, because no joint project is formed, neither of them has incentives to reallocate resources, unilaterally, to a relationship that will not be reciprocated.*

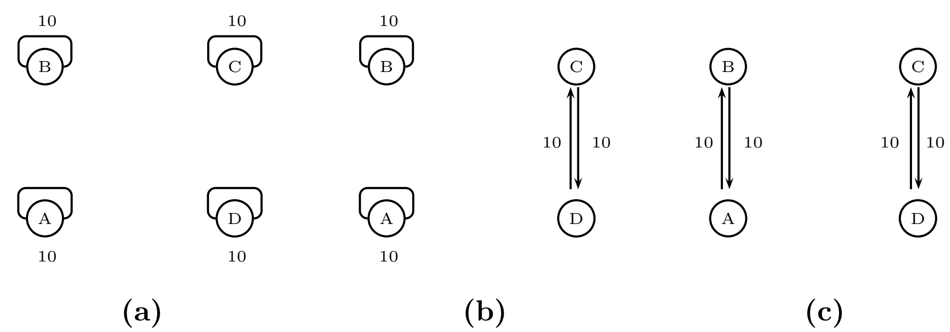


**Figure 3.5:** Nash equilibrium in T3. A loop around a node shows an actor using her resources in an individual project. An arrow from one node to another shows an actor investing her resources in a relationship with the *receiving* node. If both actors send an arrow to each other, this shows a combined project between them. The numbers next to the arrows show the resources used.

Because equilibria in T3 are such that actors allocate all of their resources into a single project, then if a combined project is more beneficial than staying alone, their incentives are to invest all their resources in that combined project maximizing their gains from it. Clearly, the coordination problem is then much simpler in T3 compared to T1 and T2, for it requires only a partner selection problem. Out of the 10 Nash equilibrium outcomes, 3 of them are in the *core*.

**Example 9** ***(Nash equilibria in the core in T3)****: Using payoffs in Table 3.2, we can see that from network (a) a pair of actors, say C and D will improve their situation by reallocation all of their resources into a combined project together, so that each would get 173 points. This is illustrated in network (b), in which A and B use their resources individually. In the same way, A and B can be better off by reallocating their resources to a combined project together, also earning 173 points. Network (c) portrays a Nash equilibrium in the core in which actors do not have incentives to reallocate unilaterally or bilaterally any of their resources. Noticeably, all core configurations are shaped by two dyads; where each actor invests all her resources to a single combined project with another* *partner.*

Notice that the number of Nash equilibria in T2 and T3 are virtually the same (out of 6.7 billion strategy profiles, 54 are equilibria in T2 and 10 are equilibria in T3), given the enormous number of strategy profiles. As a result, these treatments are practically identical with regard to the size of the Nash equilibrium set. The fundamental difference between the treatments with a "small Nash set" is that there are equilibria in the core in T3, while there are no equilibria in the core in T2.

### 3.3.3 Experimental design and procedures

The experiments reported here were conducted at the University of Groningen in May 2012. All experimental subjects were undergraduate students from the university. In each session, after their arrival to the laboratory, subjects drew a card to be randomly assigned to a computer terminal. Once everyone was seated, subjects were given the instructions for the experiment (see Appendix B). The experiment did not start until all subjects fully read the instructions. Instructions were followed by a few exercises to check the subjects' understanding of the procedures. Questions were allowed and answered privately.

Participants were randomly divided in groups of 4 and given an ID in the group: A, B, C or D. Subjects played for 20 rounds the exchange game above presented and were fixed to their group and ID for the entire experiment. That is, all subjects interacted with the same other partners along the experiment. At the beginning of each round subjects were endowed with 10 tokens and their task was to simultaneously decided how to allocate their resources (as shown in Figure 3.2). Participants interacted exclusively through computer terminals without knowing the identities of the subjects they played with, only that they were always the same for the 20 rounds.

At all times, subjects had a printed handout with their payoff matrices. Thus, they were able to calculate the points for any allocation to any potential partner. Once the allocation stage was concluded, each subject was informed about her decisions and the allocation decisions of all others in her group. The user interface displayed the formed network and a table with the allocations of each subject in their group. This screen also displayed the payoffs earned in that round (see Figure 3.6).

Once the game finished, subjects answered a debriefing questionnaire after which they were paid in cash and dismissed. On average everyone earned 10 euros, including a show-up fee of 5 euros.

In total, 48 subjects participated in four sessions, we invited 12 participants to each of them, and no one participated in more than one session. There were 3 groups in T1, 6 groups in T2, and 3 groups in T3. The experiment was programmed using z-Tree (Fischbacher, 2007) and each session lasted about 45 minutes. Subjects were recruited through online recruitment systems (ORSEE).

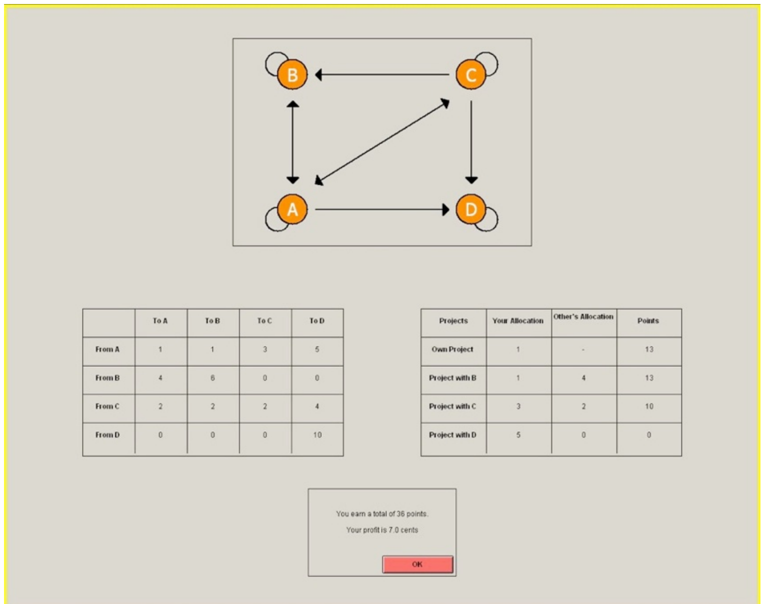


**Figure 3.6:** Output screen. A loop around a node represents that the subject formed an individual project. An arrow from one subject to another, represent that an actor made an allocation to the combined project with the corresponding partner. If the arrow has two heads it means that both actors allocated positive amounts in their combined project.

## 3.4 Results

### 3.4.1 Analytical strategy

In this section we report (i) descriptive results concerning the strategies participants used, (ii) statistical tests of H1 and H2 concerning the incidence of equilibrium play, (iii) statistical tests of H3 concerning the effect of reciprocity on allocations, and an analysis of the stability of the experimental networks. H1 and H2 pertain to the group level and are tested using non-parametric statistics. H3 pertains to the allocation decisions of subjects in each period of the experiment. We have 48 subjects allocating a total of 10 points to themselves and 3 others in sessions of 20 periods within the same groups of 4 subjects. Since for each subject in each period the sum of the four allocation decisions is always 10 we analyze only the 3 allocation decisions pertaining to the combined projects. Thus, in each period each subject makes 3 decisions, yielding 60 decisions per subject across 20 rounds and 2880 decisions for all subjects combined. Since the 2,880 observations are not statistically independent, we estimate a multivariate multilevel model (see Snijders and Bosker, 2012) accounting for the data structure to test H3. To assess the effect of reciprocity, which takes place between periods, we omit observations for period 1. Additionally, because all groups in Treatment 3 reach complete stability after period 11, we omit observations for these groups from period 12 on. We conclude with an analysis of *stability* in which we graphically and statistically analyze the extent to which allocations to combined projects are identical from one round to the next. This analysis illustrates whether subjects can reach stable outcomes, by sustaining their collaborative relationships, even if they are not in equilibrium.

### 3.4.2 Description of strategies used

Table 3.4 describes different measures of how subjects behaved in the experiment and includes variables that will be used in further analyses. The variable *Allocation* indicates the choice each subject makes of how much from her endowment to invest in a project with a given partner. Each subject has three allocation values, one for each of the three potential partners in her group, and a single allocation can range from 0 to 10. For each subject we computed the mean allocation per round (ranging from 0 to $3\frac{1}{3}$) and averaged those across all 20 periods and all subjects per treatment. *No exchange density* is a group variable that takes values between 0 and 4. For each subject that forms an individual project, allocating a non-zero amount to her individual project, *no exchange density* increases by 1 unit. We computed the mean of the variable across all periods per group and across all groups per treatment. *Exchange density* is a group variable that takes values between 0 and 6. For each pair of subjects who form an exchange relationship, both allocating non-zero amounts to their combined project, *exchange density* increases by 1 unit. We again computed the average across all groups and periods per treatment.

*Nash* is a group variable that takes value 1 if the four subjects in the group are best responding to each of their partners in that period. Otherwise it takes value 0. We average across all groups and periods per treatment. Finally, the group variable *Allocation Stability* takes values between 0 and 12. For each subject who allocates the same amount of resources to a specific partner in period $t$ and period $t-1$ the value of the variable increases by 1 unit. We focus on changes in allocations as determinant of stability for they can help understand the complexity of the coordination problem which is an aim in our study, so that we can go beyond the *binary* changes on partner selection only. Excluding the first round, we average across all 19 rounds per group and across all groups per treatment.

| | | **T1** | | **T2** | | **T3** | |
|---|---|---|---|---|---|---|---|
| | **Type** | **M** | **SD** | **M** | **SD** | **M** | **SD** |
| Allocation | *Low* | 2.5 | 1.95 | 2.5 | 2.94 | n/a | n/a |
| | *High* | n/a | n/a | 2.5 | 3.95 | 2.5 | 4.07 |
| No Exchange Density | | 3.58 | 0.62 | 1.91 | 0.96 | 0.53 | 0.93 |
| Exchange Density | | 5 | 1.34 | 2.45 | 0.90 | 2.19 | 0.60 |
| Nash | | 0 | 0 | 0.03 | 0.18 | 0.72 | 0.45 |
| Allocation Stability | | 6.83 | 3.52 | 8.40 | 3.26 | 10.51 | 2.79 |

**Table 3.4:** Descriptives of the data. Allocation is an individual level variable, the rest are group level variables.

We assess what are the most likely strategies to be chosen at the network level, evaluating the connectivity between subjects in a network (*exchange density*), and the use of resources into individual projects, instead of using them in exchanging with others (*no exchange density*).[3] There are striking differences in the strategies chosen in the three treatments. For an illustration of the most frequent network structures in each treatment see Figure 3.7. Networks in T1 tend to be highly connected (e.g. complete network), with around 5 (out of 6) relationships and 3.58 (out of 4) individual projects. Out of the 60 networks (3 groups along 20 periods) 24 (40%) were configurations as illustrated in Figure 3.7. In T2 fewer relationships are formed (2.45) and about half of the subjects form also an individual project (1.91). Out of the 120 networks 54 (45%) were as illustrated in Figure 3.7. Finally, in T3, subjects tend to form exchanges with a single other partner (2.18) and almost no individual projects are created (0.53), so that they tend to be shaped by two exchanges between separate dyads. Out of the 60 networks 43 (71.7%) were as illustrated in Figure 3.7.

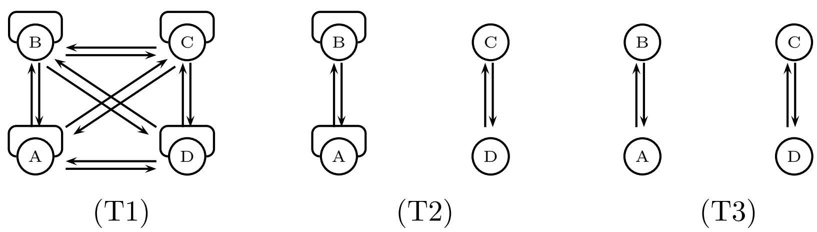


**Figure 3.7:** Most frequent configurations in each treatment. A loop around a node represents an actor using her resources in an individual project. An arrow from one node to another represents an actor allocating her resources in an exchange with the *receiving* node. If both actors send an arrow to each other, this represents an exchange relation between them.

### 3.4.3 Equilibrium: H1 and H2

Now that we know what strategies are likely to be chosen in each treatment, we want to assess whether the choices made lead to equilibrium network configurations. To test H1 and H2 we use the variable *Nash*, which counts the number of times out of 20 that the groups reach a Nash equilibrium. We test H1 by comparing T1 and T2, and H2 by comparing T2 and T3. The frequency of Nash networks per group per treatment is presented in Table 3.5.

We use non-parametric tests to assess the differences between treatments in equilibrium play. We applied the Kruskal-Wallis test to the 12 groups by (i) counting the equilibrium play per group, and (ii) comparing the frequency of equilibrium play across treatments. The test shows that on the counts in Table 3.5 there are differences between the three treatments (chi-square=8.25, df=2, p=0.016).

[3] We have run regression analysis, not reported here, to test the exchange density and no exchange density and assess how they vary between treatments and along periods. We find that differences in the choices of relating to others (exchange density) and of not relating (no exchange density) between treatments are significant.

| Treatment | T1 N=60 | | | T2 N=120 | | | | | | T3 N=60 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Group** | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| **#Equilibria** | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 2 | 0 | 9 | 17 | 17 |

**Table 3.5:** Frequency of equilibrium play per treatment. $N$ refers to the total number of periods played.

In particular, the Mann-Whitney U test shows that the null hypothesis that the equilibrium counts are drawn from the same population (i) cannot be rejected when comparing T1 and T2 (W=6, p=0.373), (ii) can be rejected with marginal significance when comparing T1 and T3 (W=0, p=0.06), and (iii) can be rejected when comparing T2 and T3 (W=0, p=0.006). This means that T1 and T2 cannot be distinguished, and thus there is not enough evidence for H1. The reduction in the number of (non-core) equilibria from 46,447 to 54 does not help in reaching Nash equilibrium outcomes. However, T2 and T3 can be distinguished, supporting H2. This suggests that having equilibria in the core helps players to coordinate on equilibrium configurations.

The hypotheses on equilibrium play (H1 and H2) go against what would be expected if choices where made randomly. Under random choice, the probability to play equilibrium would be approximately $\frac{46{,}447}{6.7\text{billion}}$ in T1, $\frac{54}{6.7\text{billion}}$ in T2, and $\frac{10}{6.7\text{billion}}$ in T3. The denominator for T2 is larger than the one for T3, but the probabilities are virtually identical given the size of the strategy space. Therefore, based on randomness we would expect no statistically discernible difference between T2 and T3; they would only be distinguished statistically with a very large number of groups. It would be expected more equilibrium play in T1 and many fewer in T2; where T2 and T3 are virtually identical. We observe the opposite pattern, no equilibria in T1, very few in T2 and many in T3. Furthermore T1 and T2 resemble each other and not T2 and T3.

Therefore, for all practical purposes related to our experiment, the treatments are indistinguishable from the point of view of random play. In summary, our results on equilibrium play suggest that it is the *dyadic rationality* implied in core solutions that matters most in our game, much more than reduction in the number of (empty core) Nash equilibria.

### 3.4.4 Reciprocity: H3

In this section we study what role reciprocity plays when subjects face the coordination problem of choosing how to allocate their resources. In the theory section we argued that reciprocity is a strong determinant of partner selection and resource allocation. In all three treatments we investigate the effect of reciprocity at the level of individual allocations to combined projects. That is, what effect did reciprocity have when subjects were interacting in joint productive exchanges between them? For our data, the concept of reciprocity answers the question *how does what a subject gives to a partner in a given period depend on what the partner gave to the subject in the previous period?* To answer this question we run models with allocation as the dependent variable. Since the 2880 allocations in our data are not statistically independent we include appropriate random variables to model the dependencies.

We estimate a multivariate multilevel model (see Table 3.6 for the results) for the allocation a player $i$ makes to her projects with the three available partners in her group. This is a four-level model with *partner* as level-one units, *period* as level-two units, *player* as level-three units and *groups* as level-four units. Thus, the allocation vector for player 1, for example, is [$\text{Allocation}_{[1\rightarrow 2]}$, $\text{Allocation}_{[1\rightarrow 3]}$, $\text{Allocation}_{[1\rightarrow 4]}$].

| | **Model A** | |
|---|---|---|
| | *Reciprocity* | |
| **Allocation** | $\beta$ | S.E. |
| *Treatment 1 (ref)* | | |
| $\text{Alloc-In}_{(t-1)}$ | 0.28 | 0.03 |
| $\text{Allocation}_{(t-1)}$ | 0.31 | 0.03 |
| $\text{Allocation}_{(t-2)}$ | 0.08 | 0.02 |
| T2 | -0.25 | 0.10 |
| T3 | -0.30 | 0.14 |
| $\text{Period}_{[2]}$ | 0.42 | 0.32 |
| $\text{Period}_{[3...4]}$ | 0.13 | 0.13 |
| $\text{Period}_{[5...10]}$ | 0.02 | 0.06 |
| $\text{T2}\times\text{Alloc-In}_{(t-1)}$ | 0.11 | 0.03 |
| $\text{T3}\times\text{Alloc-In}_{(t-1)}$ | 0.16 | 0.04 |
| $\text{Period}_{[2]}\times\text{Alloc-In}_{(t-1)}$ | -0.26 | 0.06 |
| $\text{Period}_{[3...4]}\times\text{Alloc-In}_{(t-1)}$ | -0.19 | 0.04 |
| $\text{Period}_{[5...10]}\times\text{Alloc-In}_{(t-1)}$ | -0.16 | 0.03 |
| $\text{Period}_{[2]}\times\text{Allocation}_{(t-1)}$ | 0.27 | 0.07 |
| $\text{Period}_{[3...4]}\times\text{Allocation}_{(t-1)}$ | 0.18 | 0.05 |
| $\text{Period}_{[5...10]}\times\text{Allocation}_{(t-1)}$ | 0.14 | 0.03 |
| Constant | 0.88 | 0.09 |
| *Random part* | | |
| $Var_{[\text{partner}]_{L3}}$ | 0.74 | 0.12 |
| $Cov_{[\text{partner}_i,\text{partner}_j]_{L3}}$ | -0.37 | 0.06 |
| $Var_{[\text{partner}]_{L2}}$ | -0.07 | 0.05 |
| $Cov_{[\text{partner}_i,\text{partner}_j]_{L2}}$ | 0.14 | 0.03 |
| $Var_{[\text{partner},\sqrt{\text{period}}]_{L2}}$ | 9.78 | 0.63 |
| $Cov_{[\text{partner}_i,\text{partner}_j,\sqrt{\text{period}}]_{L2}}$ | -3.28 | 0.34 |
| -2LL | 7099.720 | |
| #Observations | 2,412 | |

**Table 3.6:** Multivariate multilevel model of reciprocity. The dependent variable is Allocation.

We used Restricted Iterative Generalized Least Squares to estimate the model in MLwiN (Rasbash et al., 2005). We use dummy variables to indicate the partners (Level 1) and give these random effects ('slopes') at level 2 (period). We estimate the variance and covariances of these random effects, constraining the variances to be equal and the co-variances to be equal. Moreover, we include a random effect, $\frac{\text{dummy.partner}}{\sqrt{\text{period}}}$, for the partner dummy over the square root of period at the period level (level 2), to model the decreasing variance over periods observed in the data. Of this random effect we also estimate a single variance and a single covariance.

The constant and the time-dependent random variables at the period level associated with the dummies are assumed to be independent. This is shown in the random part of the model illustrated in Table 3.6. From this it can be inferred that the estimated variance of an allocation of player $i$ to partner $j$ in a given period is $\frac{-0.07+9.78}{\text{period}}$. Note that the negative variance estimate does not represent an actually negative variance component: estimated variance ranges from is 9.71 (=-0.07+9.78) in period 1 to 0.49 (=-0.07+9.78/20) in period 20. The estimated covariance between $i$'s allocation to $j$ and $i$'s allocation to $k$ in a given period is $\frac{0.14-3.28}{\text{period}}$, showing that within each round giving more to $j$ is associated with giving less to $k$.

At the player level (level 3) we also include random effects of the partner dummies, and estimate a single variance and covariance. Thus, the estimated between-player variance in allocations made across all periods equals 0.74, and the estimated covariance between allocations made to $j$ and $k$ across all periods is -0.37.

We also estimated a random intercept at the group level (level 4) to accommodate random group effects, but the estimated between-group variance was zero.

Fixed effect explanatory variables included are (1) dummy for treatment (T2 and T3), using Treatment 1 as the reference category, (2) the allocation received by a partner the period before, Alloc-In$_{(t-1)}$, (3) the allocation made to a partner one and two periods before, Allocation$_{(t-1)}$ and Allocation$_{(t-2)}$, (4) dummies for blocks of periods, 2, $3\ldots4$ and $5\ldots10$, and (5) interactions between the allocations received or made in previous periods with treatments or blocks of periods[4]

The interaction of the treatment dummies were significant with the allocation received in the previous period, T2×Alloc-In$_{(t-1)}$ ($\beta$=0.11, S.E.=0.03) and T3×Alloc-In$_{(t-1)}$ ($\beta$=0.16, S.E.=0.04). The model suggest that the mean allocation in T1 is significantly different from the mean allocations in T2 and T3, while there are no significant differences between T2 and T3 in this respect (We ran the same model with T2 as the reference category). The history of the interaction is particularly important to determine the allocations made. Both what player $i$ received in $t-1$, Alloc-In$_{(t-1)}$ ($\beta$=0.28, S.E.=0.03), and gave in $t-1$, Allocation$_{(t-1)}$ ($\beta$=0.31, S.E.=0.03), had a significant effect on the allocations $i$ made in period $t$.

The fact that the effect of allocation received in the previous period is still significantly

[4]We started with a maximal model which included dummies for the block of periods 11 to 20, a dummy for the type of the players, and interactions between them and the lagged allocations sent and received. We iteratively deleted parameters that were not significantly different from zero, testing model deterioration using generalized likelihood ratio tests. We tested at the significance level of 0.05.

positive after controlling for the allocation made in the previous round suggests that reciprocity plays a very important role in determining the vector of allocations chosen by a player. Furthermore, the interaction of the allocations from the previous period and the dummies for blocks of periods suggest that the effect of reciprocity is much more powerful in the first ten rounds: Period$_{[2]}\times$Alloc-In$_{(t-1)}$ ($\beta$= -0.26, S.E. = 0.06), Period$_{[3...4]}\times$Alloc-In$_{(t-1)}$ ($\beta$=-0.19, S.E.=0.04) and Period$_{[5...10]}\times$Alloc-In$_{(t-1)}$ ($\beta$=-0.16, S.E.=0.03). This shows that in our model we capture an aspect of the exchange process that we observe in the behavior of the participants in the experiment, namely, that stability increases after the first half of the experiment. This is not surprising given that we observe that after the first half of the experiment stability increases. That is, the players use the first ten or so rounds to experiment with other partners on how to allocate their resources. Given the way those partners respond, players reciprocate to them and the exchanges become more stable. In fact, this seems to be an important feature of how people solve the coordination problem they face.

Thus, regardless of whether equilibrium play is frequent (such as in T3) or not (such as in T1 and T2), reciprocity has a very strong effect on the allocation subjects make to their exchange relationships with others, corroborating H3.

### 3.4.5 Stability

We have shown that equilibrium play, although frequent in T3, hardly occurs in T1 and T2. It appears that reciprocity is the main driving force for actors to coordinate exchanges in the experiment, leading to equilibrium play only in T3, where equilibria are in the core. However, out-of-equilibrium play might well be stable over time, much like equilibrium play can be unstable when there are multiple equilibria. Therefore we report an analysis of the data to see whether subjects reach any stability in their allocations at all. To do this we create the group level variable *Allocation Stability*. In each period from period 2 onwards *Allocation Stability* is the count of the number of allocations to combined projects in the group that is identical to the allocation in the previous period. Thus, *Allocation Stability* ranges from 0 (all subjects change all their allocations to others from one period to the next) to 12 (all subjects make the same three allocations to others from one period to the next). The upper left panel in Figure 8 shows the mean *Allocation Stability* for the three treatments (6.8 for T1, 8.4 for T2, and 10.5 for T3) across the 19 periods.

The remaining three panels show the progress of *Allocation Stability* over periods 2 through 20 per treatment, with separate lines connecting the data points for separate groups. The three groups in T3 all reach perfect stability by period 13, reflecting the high incidence of equilibrium play. At that time these networks were composed of two fully exchanging dyads. What is striking is that in T1 and T2, where equilibrium play is rare or even absent, most groups reach considerable degrees of allocation stability after about 10 periods of play. In T1 two out of three groups reach high levels of stability even when they are not in equilibrium. The third group, however, shows a very erratic pattern typical of social exchange networks with empty cores. In T2 five out of six groups reach high levels of stability outside of equilibrium and the sixth group is not far behind.

For a slightly more detailed exploration we modeled the progress of *Allocation Stability* statistically with a multilevel model with the group observation per period (Level 1) nested in groups (Level 2). We included a single linear fixed effect for the period of play and a dummy indicating whether the period belonged to the first 10 periods or the last 10 periods. This yielded the kinked response curves shown as the solid lines in Figure 3.8. This kinked response curve was a much better fit to the data than a model with a single linear period effect. The response curves in Figure 3.8 show that in all treatments allocation stability increases sharply over the first 10 periods of the experiment. After that allocation stability is stationary in T1 but continues its increase in T2 and T3. The lower right panel for T3 shows that the estimated regression line is out of bounds for period 10, reflecting the fact that we did not account for the right-censoring (nor left-censoring, for that matter) of the data in our exploration. Nonetheless, the message is clear: even in the absence of equilibrium play and even in treatments with empty cores, groups of subjects reached remarkably high levels of allocation stability over the course of the periods.

## 3.5 Discussion

In this work we have studied (i) the micro-processes people use to establish and decide their involvement in collaborative relationships with others, and (ii) the conditions for relationships to last along time. We have addressed this problem in a setting of networks where subjects choose with whom to team up from a pool of potential partners, and where the complexity of choices is varied between different experimental conditions. Complexity of choices is measured by the number and type of possible outcomes, at the network level, in which individuals maximize their material gains given what others do (Nash equilibrium). Our work suggests individual choices result from an interplay of two behavioral models of action. On the one hand, a rational model of man in which individuals best respond to the choices of their partners prioritizing material gains. On the other, a committed reciprocal model of man in which individuals reinforce their involvement in a relationship due to the experience they had in previous encounters with the same partner.

The underlying mechanism is that people, regardless of how severe the coordination problem is, aim to maximize their material gains. They persistently aim for the number of relationships that give them the highest benefits (networks in equilibrium) in each of the three experimental conditions. However, the success of this aim is constrained by the severity of the coordination problem. Although the relationships formed reflect a network in equilibrium, the use of resources in them does not. People pursue their rational goals, but due to the complexity of their interactions, even in the presence of few partners, they resort to reciprocity as the mechanism to simplify their resource allocation choices. Instead of running around from one partner to another, in cases with severe coordination problems, individuals tend to form lasting relationships by means of reciprocity. Two important aspects of the underlying mechanism we found can be highlighted:

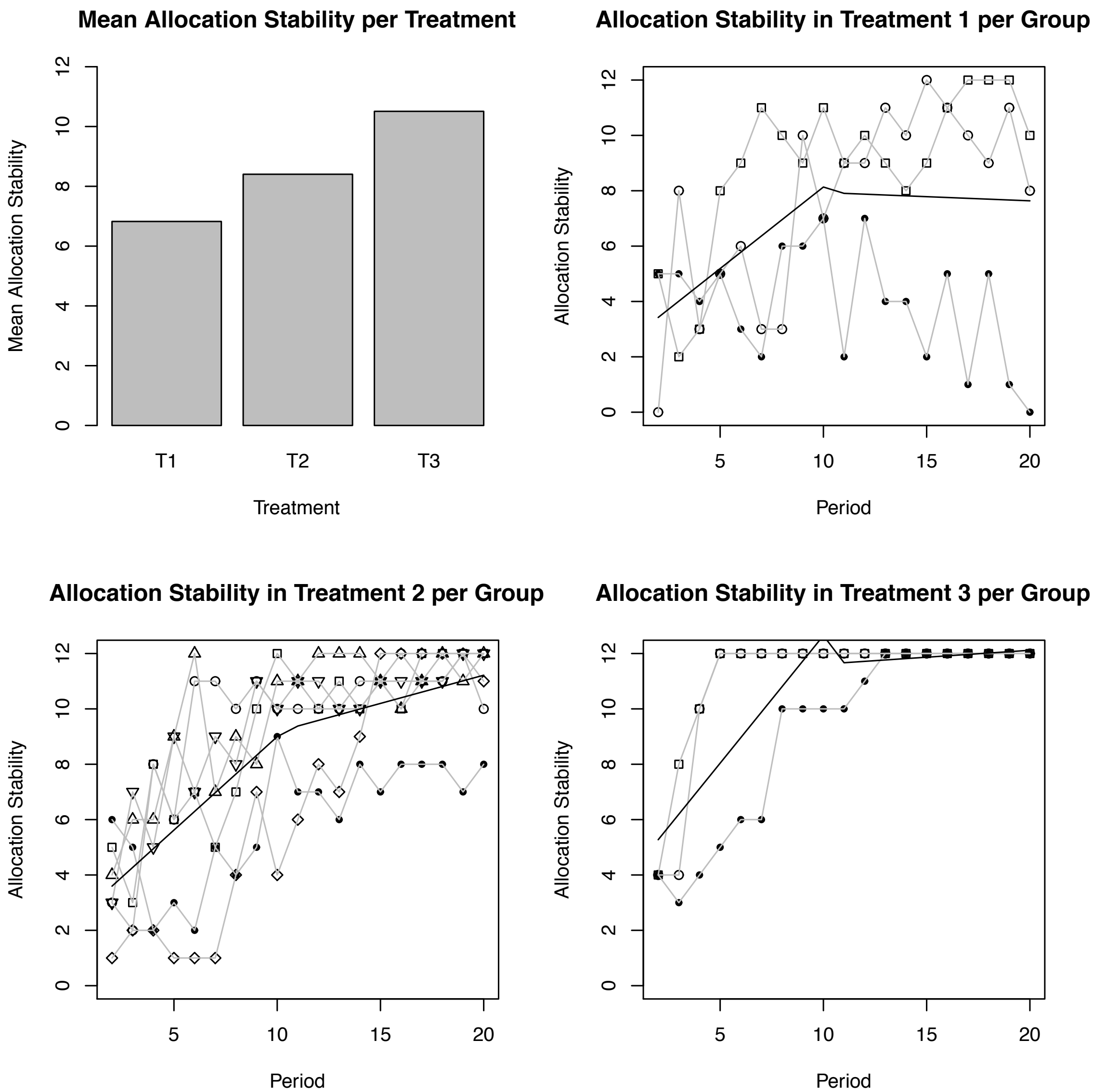


**Figure 3.8:** Allocation Stability by groups/treatments. The upper left panel portrays the means of allocation stability per treatment. The other three panels show the allocation stability score per group in each treatment for the 19 periods (2 to 20) in which it was measured. The solid lines illustrate the estimated multilevel regression lines

First, in terms of equilibrium, our main point is that if the severity of the coordination problem is expressed by the number of equilibrium outcomes in the game, this does not affect the likelihood individuals have of reaching an equilibrium outcome. However, if the severity of the coordination problem is expressed by the existence of equilibria that take into account not only individual incentives but the coordinated action of pairs of actors, then stable configurations can be ensured. This means that in exchange relationships, actors unilaterally cannot guarantee that at the collective level outcomes will be optimal. Thus, when equilibria is robust only to individual rationality (Nash equilibrium) one can expect that actors tend to find attractive partners around them and leave their existing ones. However, when people can coordinate together in their choices (Nash equilibria in the core), this results in a strong way of helping them reach equilibrium outcomes and sustain relationships of collaboration between them.

Second, in terms of stability, our main point is that reciprocity is a strong force to maintain relationships along time. As a consequence, our findings suggest that although Nash equilibrium is a very useful concept to understand behavior and sustainable cooperation in exchange networks, it is very weak to predict exchange outcomes in situations where solutions do not satisfy dyadic rationality. By disentangling the equilibrium and stable outcomes, we were able to observe that even though actors do not best respond to their partners, their choices to reciprocate to the resources exchanged in a previous interaction help them achieve lasting relationships. However, in settings of severe coordination problems the stability that is reached is not equilibrium stability. In networks with severe coordination problems (i.e. networks with empty cores) as in Treatments 1 and 2, the use of resources tends to become stable along time by means of reciprocity.

Note especially that in the case where subjects reach equilibrium behavior repeatedly (Treatment 3) rational choices cannot be distinguished from reciprocal ones. That is, best responding and reciprocating to our partners results in the same behavior. However, in contexts where equilibrium is not played, successful lasting relationships are clearly motivated by reciprocal behavior. In this direction, our choice of integrating these two theories of action in an experiment, that varies the severity of the coordination problem subjects face to establish lasting collaborative relationships, has led to a informative findings that help complement the theories by pooling their powerful explanatory advantages instead of by separating them.

Some questions that remain open for further research are related to an underlying assumption in network relationships that points to a limitation in our work: the possibility subjects have to communicate between each other. Although the repeated interactions in our experimental design allow the choices of how to use one's resources to work as signals of intentions and commitment, this is not close enough to explicit communication. On the one hand, it is possible that the effect of communication in the interactions can reinforce reciprocity strengthening the ties between existing partners and weakening the involvement in relationships that are not reciprocal. Thus, pressuring actors to select committed partners and to exclude others.

On the other hand, communication can serve as a coordination tool and instead of separating highly and weakly committed partners, it could mitigate the effect of reciprocity in simplifying the coordination problem and facilitate the achievement of equilibrium play. That is, subjects might not require strong or weak involvement as a measure of commitment, but instead could use communication as a coordination device that clarifies the focal points all want to reach. In further research we aim to model and test how the effect of pre-play communication affects equilibrium play, reciprocity, and stability. Particularly, we are interested in extending our work to understanding the effect of different types of communications, such as *cheap-talk*, where agreements have no effects on payoffs, or *binding communication*, in which the agreements made are implemented in future interactions in the game.