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Essays in Economic Networks

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por

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Abstract

Essays in Economic Networks

by

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This thesis analyzes two economic problems using *network theory*. In the first paper, we analyze the hold-up problem in outsourcing industries. Typically, in automobiles, semiconductors and software, companies and suppliers of inputs jointly invest in specific assets before making transactions. We investigate how the structure of these relationships generates a large number of trading oportunities, equates the bargaining power of firms and reduces oportunistic behaviour. The second paper analyzes the influence of the structure of interactions in self-organized teams (academics, law, accounting, sports) on individual levels of effort. Because these teams do not have a principal, we study the way in which the agents organize tasks and roles to achieve higher levels of production.

Rodrigo Harrison
Chair

Resumen

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Esta disertación analiza dos problemas económicos utilizando teoría de redes. En el primer paper, analizamos el problema de hold-up en industrias que trabajan mediante outsourcing. Típicamente, en automóviles, semiconductores y software, las companías y los proveedores deben invertir conjuntamente en activos específicos antes de realizar transacciones. Investigamos de qué manera la estructura de relaciones de outsourcing puede igualar el poder de negociación de las firmas y reducir comportamientos oportunistas en inversiones en activos específicos. El segundo paper analiza la influencia de la estructura de interacciones en equipos con auto-organización de tareas (academicos, abogados, contadores, deportistas) en los niveles de esfuerzo individual. Dado que estos equipos no tienen un principal, estudiamos el modo en que los agentes organizan las tareas y roles para alcanzar niveles más altos de producción.

Rodrigo Harrison
Profesor Guía

To my family

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Chapter 1

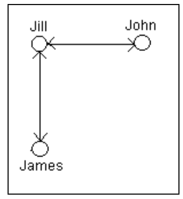
Introduction

Network structures are important in the organization of some significant economic relationships in which *the transactions are not anonymous*, e.g. agents are related by specific comercial, technological, financial and social relationships. For example, personal contacts can play critical roles in obtaining information about job, business and finance opportunities (Bala and Goyal, 2000).

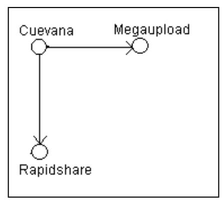
Several models of network formation have been studied in economic applications. For example, collaborative agreements in R&D (Goyal and Moraga, 2001) and market-sharing (Belleflamme and Bloch, 2004), information gathering and public goods provision (Bramoullé and Kranton, 2005), network structure in labor markets (Calvo-Armengol and Jackson, 2004), crime (Ballester, Calvo-Armengol and Zenou, 2006), gas (Galizzi, 2009), airline rutes (Hendricks, 1999) and free trade (Furusawa and Konishi, 2002).

The theoretical framework underlying these models is Graph Theory. A network is modelled as a set of links connecting several nodes, where the links represent specific relationships between the nodes, the economic agents. For mathematical simplicity, models of networks usually specify the presence or absence of a relationship and not its closeness.

Links can represent either individual or mutual relationships between agents. A network is *non-directed* when any two players are either connected or not. For example a network where links represent direct family relationships, partnerships, friendships, alliances or acquaintances:



A network is *directed* when one player may be connected to a second without the second being connected to the first. For example a network in which the nodes are websites and the links are references to other websites:



Models of network formation are divided in two categories. On one hand, there is a physics-based modeling, in which agents do not make decisions. These models describe *stochastic* processes of network formation using tools of the random graph literature. Examples can be found in sociology, computer science and statistical physics. On the other hand, we have models of *strategic* networks, which arise from the interaction of self-interested agents, for example in economics and political science.

The first model of economic networks dates back to Myerson (1977) in the context of cooperative games. He analyzes situations in which economic agents *cooperate*, and model such cooperation as links between players. The value function of the game depends on the structure of the network. Myerson produced a prediction of how this value should be split among the members of a society: the Myerson Value.

Jackson and Wolinsky (1996) were the first to analyze models of network formation in which economic agents act *strategically* in the formation of links. The idea is that multiple links enhance an agent's competitive position in a network. For example, when suppliers of inputs have connections with more companies, they are insulated from the difficulties facing by one particular buyer. And viceversa, a company secures better terms of trade with access to more sources of supply.

An important property of strategic networks is *stability*, the extent to which an agent or group of agents wish to form or cut links. The notion of stability is different depending if the network is direct or non-direct. In the first case, agents can unilaterally form new relationships, but in the second a consent of two players is needed to form links (Bala and Goyal, 2000). A pairwise-stable network involves checking stability for any pair of agents, and more stronger notions require checking incentives for any coalition of players (Dutta and Mutuswami, 1997; Jackson and van den Nouweland, 2002).

Beginning with the pioneering work of Jackson and Wolinksy, several *models of economic networks* have been developed in the literature. Some of them are described here:

1) The co-author model (Jackson and Wolinsky, 1996): each node is a researcher who spends time working on research projects. A link between two researchers represents that they are working on a project together. The sinergy between two co-authors is inversely related to the number of projects they are involved in.

2) The free-trade model (Furusawa and Konishi, 2002): the authors model free-trade agreements as a network in which countries are linked only if both have no tariffs. Two linked countries trade their goods at a lower price, but there are also indirect effects through their links with third countries. The prices of tradable goods depend on the structure of the network.

3) The market-sharing agreements model (Belleflamme and Bloch, 2004): a set of firms that sell the same good in markets segmented by geographical characteristics. A link between two firms represent a commitment not to enter into the same geographical market. The price in one market depends on the number of firms presented in this market.

4) The labor-market network model (Calvo-Armengol and Jackson, 2001): each node represents a person in the labor force and each link represents social ties such as friendship. In each period, there is an exogenous probability that some workers end up losing their jobs. When a job offer arrives to a worker, he can keep his current job and pass the information of the vacancy to their linked partners, or he can accept the new offer and quit his actual job. When a job offer arrives to an unemployed, he can refuse it and pass the information to his friends, or he can accept it and become employed. The probability that a person will get a job depends on the structure of the network.

5) The crime model (Ballester, Calvo-Armengol and Zenou, 2006): the benefit from criminal activities depends on the level to which individual's friends and neighbors engage in it (because there are complementarities in learning and cooperating about criminal pursuits). Benefits also depend on the presence of different networks, because there might be tigher enforcement as overall criminal activity grows.

6) The buyer-seller network model (Kranton and Minehart, 2001): there is a competitive advantage steaming from fined tuning coordination between buyers and sellers of specialized inputs that cannot be purchased in the stock market. From microelectronics to rock music, firms devote considerable time, effort and financial resources to choose and bread business parties. The set of physical and intangible relations between two firms is

an specific asset which is represented by a link. Vertical networks are increasingly important for innovation: companies decide on whether to adopt innovative products without full knowledge of its usefulness. Companies innovate through patents or manufactured equipment from vertically disintegrated suppliers rather than produce it in in-house R&D labs (Cottica and Ponzi, 2002).

7) The associations model (Wang and Watts, 2002): the authors model a vertical network in which companies and suppliers form horizontal associations to negotiate prices and sales. The advantage of an association is that their members get more bargaining power, but the disadvantage is that sales are rationated (Wang and Watts, 2002).

In this thesis, we analyze two economic problems using economic networks. The *second chapter* is concerned about the hold-up problem in outsourcing industries. It is traditionally accepted that firms rely on in-house production when specific investments are involved. Nevertheless, when business environment is uncertain, such as in automobiles, semiconductors or software, companies outsource the production of inputs in several suppliers. We think that the success of these industries in terms of production, sales and rates of technological innovation is related to the structure of outsourcing relations because it reduces the incentives to behave oportunistically. To analyze this hypothesis, we develop a two-stage model of network formation in which companies and external suppliers of inputs first invest in specific assets (links), and then bargain over the formed network.

We show that the structure of outsourcing relations (the network) is important because it generates trading oportunities for firms, equates the bargaining power of different groups and reduces the possibility of hold-up. The results show that the hold-up problem is more or less severe depending on: i) the relative number of companies and suppliers; ii) how firms model uncertainty; iii) how the investments in specific assets are shared between companies and suppliers; iv) external asymmetries in the bargaining process.

The ideas for the *third chapter* emerged from interesting conversations with my tutors about the problem of optimal structure of self-organized teams, that is, teams in which their members usually organize the different tasks and roles together. For example in sports, screenwriting, academics, law and accounting. Much of the literature is concerned about the problem of a principal who wants to induce an agent to exert the right amount of effort under moral hazard and adverse selection (Alchion and Dempsetz, 1972; Holmstrom, 1982). There is also an increasing literature of optimal structure of teams, which is concerned about team formation by self-interested agents (Lazear and Rosen, 1981; Farrell and Scotchmer, 1988).

The third chapter is more related to the second stream of literature. We are interested in the way in which agents organize tasks and roles in self-organized teams (academics, law, accounting, sports). Because these teams do not have a principal, the structure of interactions is very important to achieve higher levels of production. Several factors influence these interactions: the productivities of the agents, the disutility of the effort, the sinergy between the agents and the value of team production.

To analyze this hypothesis, we develop a two-stage game of network formation. In the first stage agents organize tasks, which results in a pattern of mutual interactions (network). In the second stage, given the network, agents decide non cooperatively the level of effort. We study the equilibrium networks and optimal levels of effort for two cases: i) the case in which individual production is not observable and agents use a partnership rule; and ii) the case in which individual production is observable and agents use a pay-per-production rule.

The results show that relative abilities (productivities) of agents are very important for the structure of networks and levels of production in equilibrium. In particular, *in the case in which individual production is not observable (partnership rule), agents tend to work more in teams than the case in which individual production is observable (pay-per-production rule).* The reason is that under partnership the more productive members are interested in increasing the production of the less productive members.

On the other hand, suppose two teams with the same number of members, one with high dispersion in productivities and the other in which all agents are equally talented. Assume that the average productivity of both teams is the same. *In the case in which individual production is not observable (partnership rule), agents with similar productivities tend to work less in teams than agents with high dispersion in productivities.* The intuition is that under partnership it is less valuable a collaboration for agents with similar talents. This result is reversed when individual production is observable and agents work under a pay-per-production rule: in this case agents with high dispersion in productivities are more reluctant to work in teams.

CHAPTER 2

Outsourcing, network formation and the hold-up problem

2.1 Introduction

The make-or-buy decision has been extensively discussed in the literature of *theory of the firm*, in particular the problem of specific investments. The specificity of an asset is "the extent in which the investments made to support a particular transaction have a higher value than they would have if they were redeployed for any other purpose" (Mc Guiness, 1994). Examples of specific assets are "the specialized tools that can only be used to produce the products of one manufacturer, the training that increases worker productivity exclusively in using those tools or the supplier facilities that have been located in close geographic proximity to purchasers" (Lafontaine and Slade, 2007).

The problem with asset specificity is that parties in the relationship may be locked in after signing the contract. This is known as the *hold-up problem*, a situation in "which firms may be able to work most efficiently by cooperating, but refrained from doing so due to concerns that they may give one party increased bargaining power ex-post" (Tirole, 1988; Schmitz, 2001). Sometimes firms are unable to sign long term contracts because they cannot foresee some contingencies in the relationship. In these cases, the parties have incentives to behave oportunistically ex-post, increasing the costs of writing, administering and negotiating the contract.

Consider for example the construction of a pipeline between a natural gas producer and a distributor. Suppose that after the start of the project, there is an unanticipated increase in maintenance costs. Because asset specificity generates bargaining power, the producer may pressure for a higher transfer price. In anticipation, the distributor could become cautious with his own investments, risking the success of the project.

A large body of empirical research has found support for the notion that specific investments are economically and statistically important when it comes to the decision of organizing the production of inputs. Given the possibility of hold-up, the literature predicts that suppliers and companies should vertically integrate. There are two fundamental theories about the incentives to invest in specific assets generated by integration:

1) *Transaction Costs Approach* (Williamson, 1975; Klein, 1980): vertical integration reduces average costs of production when the scale of operations is important. It avoids transaction costs related to physical transfer of goods and contract supervision.

2) *Property Rights Approach* (Grossman y Hart, 1986; Hart y Moore, 1990): vertical integration provides exclusive rights of use of specific assets to the integrated firm. Transfering the property of the asset to one party avoids oportunistic behaviour ex-post. In the example of the pipeline, if the producer and the distributor form an integrated firm, the incentives of this firm to invest are aligned with the social optimum.

On the other hand, firms usually organize the production of inputs through *outsourcing*. It is a contractual relation in which an external supplier provides an input or service to a firm. Both parts invest in specific assets such us plants, product design, collaborative agreements, exchange of personnel. The contract is not detailed but provides mechanisms to solve unexpected contingencies (Klein, 1980; Williamson, 1985). Tipically, the duration of the contract is short but it is renegotiated and renewed based on confidence relations and reputation (Weigelt and Camerer, 1988; Dore, 1998; Sako, 2006).

The advantage of outsourcing over vertical integration is that a firm chooses among several suppliers. This is important in automobiles, semiconductors and software because consumer preferences change rapidly about volumen, design and other characteristics of the final good. In these industries, the scale of operations is reduced and average fixed costs associated with in-house production become prohibitive. Outsourcing also allow firms to diversify business risk because it eases the flow of transactions and technical knowledge necessary for the production of inputs (Tirole, 1988; Klein, 1988; Crocker y Masten, 1991).

A well-known example of outsourcing is the japanese automobile industry. In the 80's, companies like Toyota, Nissan and Honda signed *black-box* collaborative agreements with autoparts like Nippon Denso, Calsonic, Bridgestone and Mitshubishi Belting for the provision of automatic transmission, catalytic converter, radiator, seats and windows, among other components. Companies and suppliers invested in specific assets such as *localization* (closeness of autoparts to the companies' plants), *physical capital* (equipment, machinery, buildings) and *human capital* (engineers specialized in part design). The aim was to "reduce production costs, improve quality standards and accelerate the development of new models" (Dyer, 1996).

These are some performance indicators of the automobile industry in Japan (Dyer, 1998):

Specific assets	"Arms-length" relation	"Partner" relation
% outsourcing of components	18,90%	60,00%
Distance between plants (miles)	125	41
Number of invited engineers	2,3	7,2
Level of assistance from suppliers in cost reduction (scale 1-7)	2,6	4,2
Source: Dyer (1998)		

Companies with *arms-length* relationships are characterized by "minimizing dependence on suppliers, maximizing bargaining power and avoiding any form of commitment" (Porter, 1980). In contrast, companies based on *partner* relationships "(i) share more information and are better at coordinating interdependent tasks, and (ii) invest in relation-specific assets which lower costs, improve quality, and speed product development" (Dyer, 1996). Observe in the table that the physical distance between plants is 80 miles less in partner firms, companies receive double attendance in cost reduction and exchange more engineers. Japanese companies outsource 60% of the value of its components compared to 18,9% of integrated companies (Dyer, 1998, Holmstrom and Roberts, 1998; Kimura, 2002; Schaede, 2009).

Examples such as japanese automobiles or Silicon Valley electronics suggest that the structure of outsourcing relationships is important in reducing the hold-up problem. But to our knowledge, there is no theoretical analysis of this issue in the literature. The authors are more concerned about the differencies between vertical integration and outsourcing (Thomas and Worrall, 1994; Baker, Gibbons and Murphy, 2001; Calzolari and Spagnolo, 2009). For instance, Baker, Gibbons and Murphy analyze how a relational contract affects the incentives of a company to vertically integrate with a supplier. In their model, the supplier prefers outsourcing because he retains the ownership of the input. However, it also encouraged the supplier to increase its alternative value (*outside option*), which is not convenient for the company. Given a low discount factor, the first effect dominates the second and firms choose to work under outsoutcing.

Nevertheless, these models are focused on the make-or-buy decision, and not on the effect of the buy decision (outsourcing) on the hold-up problem. Also, the interactions typically refer to a company and a suplier, while in practice we have several firms in an industry. Third, models do not consider that firms interact in a context of uncertainty. Finally, the value of outside-options (used to negotiate transactions) are exogenously generated by the supplier investing in alternative uses of the input. On the contrary, in our framework we *endogenize the value of outside-options* to the structure of outsourcing relationships. Both suppliers and companies invest strategically to improve their bargaining position.

For example, consider an hypothetical case in which Toyota (company) works with Denso (autopartist). Suppose that Toyota unexpectedly needs a new engine for a particular model. Given no written contract, Denso may pressure Toyota for a higher price. In response, Toyota could invest in an outsourcing relation with Aisin Seiki (autopartist). Because Toyota negotiates simultaneously with both suppliers, it seems reasonable that Denso has more incentives to maintain a fair agreement with Toyota.

In this chapter, we analyze the relation between the structure of outsourcing relations and the incentives of firms to invest in specific assets. We model joint investments in specific assets as links between companies and suppliers, and the set of links between firms as networks (Kranton and Minehart, 2001; Elliott, 2010). First, firms invest in links, and then they negotiate prices and transactions over the forming network. Using a cooperative framework to solve the stage of bargaining, we find that there is a unique pairwise-stable matching associated with any network. It is characterized by a Nash-Bargaining process in which all firms receive at least their outside-option value in a transaction. With the results of the bargaining stage, we calculate the equilibrium networks and compared them with the social optimum networks to study the hold-up problem.

The results show that the hold-up problem is less severe when companies and suppliers share more evenly the cost of investments and there are no exogenous asymmetries in the bargaining power of both groups. Other important factors are the relative number of companies vs. suppliers and how firms model uncertainty. There is a strategic motivation of firms to invest in links: improve their bargaining position in the network. The case of japanese automobiles is a network structure with many links, in which the bargaining power of different groups is equalized, reducing the possibility of oportunistic behaviour.

The rest of this chapter is organized as follows. The second section describes the general model. The third analyzes the case of three suppliers and two companies. The fourth compares the equilibrium network structures with the social optimum. The fifth analyzes the case of the asymmetric Nash bargaining and compare the efficiency of a networked industry vs. a vertically integrated industry. Finally, the sixth section discusses the results and concludes. The proofs are relegated to the appendix.

2.2 The model

2.2.1 Preliminaries

Consider a set $C = \{1, 2, 3, ..., n_C\}$ of companies, each of whom demands one indivisible unit of an input, and a set of $S = \{a, b, c, .., n_s\}$ suppliers who each have the capacity to produce one indivisible unit of an input at zero cost ($n_S < n_C$). We assume that firms cannot write state-contingent, long term binding contracts to set links, future prices or side payments. A company can obtain a good from a supplier only if both invest in a *link*, e.g. if both invest in an specific asset. With this asset, the company $i \in C$ has a value $v_i > 0$ for the supplier's input. This value is uncertain at the time of investments, but it is known for all that it is independently and identically distributed on $[0, 1]$ with continuous density function $f(v_i)$.[1]

After investments are made, the structure of the network and the set of input valuations become common knowledge. Then, given the network, companies and suppliers negotiate bilateral transactions according to a sequential process: 1) suppliers offer different (or perhaps the same) prices to their linked companies; 2) companies choose one offer from their linked suppliers (or reject all); 3) suppliers accept one offer from their linked companies (or reject all); 4) the remaining suppliers offer new prices to the remaining linked companies; 5) and so on, until no firms have incentives to search for a transaction. This process results

[1] "This setting captures the characteristics of at least the following industries particularly well: clothing, electronic components, and engineering services. They share the following features: uncertain demand for inputs because of frequently changing styles and technology, supply-side investment in quality-enhancing assets, specific investments in buyer-seller relationships, and small batches of output made to buyers' specifications. In short, sellers in these industries could be described as "flexible specialists", to use Michael J. Piore and Charles F. Sabel's (1984) term. Edward H. Lorenz (1989), Scott (1993), and Nishiguchi (1994) study the engineering and electronics industries in southern California, Japan and Britain, and France, respectively" (Kranton y Minehart, 2001).

in a set of transactions and prices called *matching*.

The utilities of company i and supplier j in a bilateral transaction are:

$$\begin{aligned} \text{Company } i &: \quad v_i - p_j - (1-\gamma)\, cn_i \\ \text{Supplier } j &: \quad p_j - \gamma c n_j \end{aligned}$$

where $\gamma \in [0,1]$ is the share of the supplier in the total cost of a link $c \in [0,1]$, p_j is the price charged by supplier j, and n_i and n_j are the number of investments in links for i and j (the input have no existence value for the suppliers).[2]

Because input valuations are random, firms choose their investments to maximize the *expected* value of their utilities.

Formally, define t_{ij} as a dummy variable which takes a value of 1 if company i invest in a link with supplier j, and zero otherwise (similarly, define t_{ji}). Analogously, define m_{ij} as a dummy variable which takes the value of 1 if there is a bilateral transaction between i and j (similarly, define m_{ji}).

The problem of company $i \in B$ and supplier $j \in S$ in the stage of investment in links is:

$$\begin{aligned} \pi_i\left(t_i^*, t_{-i}^*, t^{S*}\right) &= \underset{t_i^*}{Max}\ E_{\varpi}\left(u_i\left(m\left(t_i, t_{-i}^*, t^{S*}\right)\right)\right) - n_i\left(t_i\right)(1-\gamma)\, c \\ \pi_j\left(t_j^*, t_{-j}^*, t^{C*}\right) &= \underset{t_j^*}{Max} E_{\varpi}\left(u_j\left(m\left(t_j, t_{-j}^*, t^{C*}\right)\right)\right) - n_j\left(t_j\right)\gamma c \end{aligned}$$

where t_{-i} is the set of investments in links from companies other than i, t_{-j}

[2] This assumption is standard in network theory because it allows to separate the pure effect of network formation on prices and matching (see Kranton y Minehart, 2001).

the investments from suppliers other than j, t^S the investments of all suppliers, t^C the investments of all companies, m is the set of bilateral transactions, and π_i and π_j are the expected utilities of i and j (which depend on the joint probability density function $\omega = [f(v_i)]^{n_C}$).

With these elements, define a simultaneous game of link formation:

$$G = \{B, S, T_B, T_S, \Pi_B, \Pi_S\}$$

where the capital letters indicate the set of firms, investments in links and expected utilities.

A set of strategies $\{t_B^*, t_S^*\} \in \{T_B, T_S\}$ is a *pure nash equilibrium (NE)* of G if no unilateral deviation is profitable for any firm:

$$\begin{aligned} \forall_i &\in B, t_i \in T_i, t_i \neq t_i^* : \pi_i\left(t_i^*, t_{-i}^*, t^{S^*}\right) \geq \pi_i\left(t_i, t_{-i}^*, t^{S^*}\right) \\ \forall_j &\in S, t_j \in T_j, t_j \neq t_j^* : \pi_j\left(t_j^*, t_{-j}^*, t^{C^*}\right) \geq \pi_j\left(t_j, t_{-j}^*, t^{C^*}\right) \end{aligned}$$

We will solve for the NE of G with the property of pairwise-stability in links. A **Nash Pairwise-Stable equilibrium of G (NPS)** is an NE of G in which: 1° two firms cannot increase their expected utility by forming a link; and 2° no firm can increase his expected utility by dropping unilaterally a link (Jackson and Wolinsky, 1996).[3]

2.2.2 Applying the model to analyze the hold-up problem

To analyze the hold-up problem using this framework, we will proceed as follows.

[3]Note that pairwise-stability in links is a weak requirement for network stability. A stronger notion of stability involves checking incentives to form/drop link for coalitions of more than two players. In the model of this paper, both requirements give the same predictions because firms cannot trade with more than one partner (Jackson and van Nouweland, 2005).

First, we will show that for any network and realization of valuations, there is a unique pairwise-stable matching characterized by a Nash-Bargaining process. That is, the process of bilateral negotiations is such that firms receive at least their outside-option value and no pair company-supplier would have reciprocal incentives to deviate and trade together.

Second, we will use the solution of the bargaining stage to solve the NPS's of G for the particular case of three companies, two suppliers and uniform distribution of valuations $f(v_i) = U[0,1]$. We will analyze how the equilibrium networks change for different values of parameters γ (share of supplier in the cost of link) and c.(total cost of link).

Finally, we will compare the equilibrium networks with the socially optimal networks to see if the incentives of firms to invest in links are aligned with the social optimum. In the case in which firms privately invest in less links than the social optimum network, we will say that there is a hold-up problem.

2.2.3 Optimal transactions and prices

Given the network and the realization of valuations, firms negotiate bilateral transactions.

An equilibrium of the sequential bargaining process is a set of transactions and prices in which no pair company-supplier have reciprocal incentives to deviate and trade together. We call it a *pairwise-stable matching.*

To find the set of pairwise-stable matchings we will use a cooperative game framework. We will model bargaining in networks as an assignment game (Roth and Sotomayor, 1990).

An *assignment game* is a market where each seller owns one indivisible object and each buyer, who wants to buy at most one object, has valuations over all objects. An assignment is a description of deliveries of objects from sellers to buyers and a vector of prices, one for each object.

A *core* of a game of assignment is a set of transactions in which no coalition of firms has a profitable deviation. Shapley and Shubik (1972) prove that any assignment game has a non-empty *core*.

The bargaining problem in networks is an assignment game in which buyers value the same each object sold by their linked sellers, and value zero each object sold by their non-linked sellers. Elliott (2010) proves that the core and the set of pairwise-stable matchings is the same when there can be only bilateral transactions in the network. Moreover, there is generically a unique pairwise-stable matching because any pair of firms must be satisfied with the transaction.

We state the principal proposition of this chapter.

Proposition 2.1 *For any network structure and distribution of valuations, there is generically a unique stable matching characterized by a Nash-Bargaining process in which firms receive at least their outside-option value. The rest of the value of the transaction is divided according to an exogenous parameter of asymmetry in negotiation.*

Proof. See appendix, subsection A ■

Technically, the proposition says that the utilities of firms in the core, partially ordered by companies' utilities, have a lattice structure with a company optimal point and a supplier optimal point (Shapley and Shubik, 1972). At the company optimal point of the core, all companies receive the highest payoff they can at any point in the core while all suppliers receive the lower payoff they can. And vicecersa: at the supplier optimal point of the core, all suppliers receive the highest payoff while all companies receive the lower payoff. Both cases imply that any firm must receive at least their outside-option value in a pairwise-stable matching.[4]

Demange, Gale and Sotomayor (1990) identify an algorithm to find the company's optimal and the supplier's optimal points of the core. Elliott (2010) apply a variation of this algorithm to find the pairwise-stable matching in an exogenous network. Understanding the outside-option of a firm as the minimum payment that a firm could receive from his partner in the pairwise-stable matching without having a profitable pairwise deviation with some other firm, it turns out from the algorithm that these outside options depend entirely on the structure of the network and the value of transactions.[5]

It is important to emphasize that I do not actually intend the algorithm to be used as a reduced form for a sequential bargaining game of negotiations between companies and suppliers. The idea is to focus on the result of this process, which is a set of pairwise-stable transactions, and then use it to solve the stage of network formation. This is the important part in modelling the hold-up problem, the decision of investments in links by firms.

Returning to proposition 2.1, the lattice structure of the core is characterized by the prices that maximize the product of Nash $\left(u_j - \underline{u_j}\right)^{\beta} \left(u_i - \underline{u_i}\right)^{1-\beta}$, where $\underline{u_i}$ is the

[4]The outside-options in a network can be seen as the outside-options in a model with alternate offers (Rubinstein, 1982). In a network, a company and a supplier can be interested in reaching an agreement as soon as possible because a third party could interfere and risk the transaction. Similarly, in the model of Rubinstein there is an exogenous probability in each period that the parties never reach an agreement, in which case they receive their outside options. Binmore, Rubinstein and Wolinsky (1996) prove that if the time between two negotiations tends to zero, the solution converges to the static bargaining model of Nash (1953).

[5]See the description of the algorithm in page 12 of Elliott (2010).

outside-option value of the company i, $\underline{u_j}$ is the outside-option of the supplier j, $\beta \in [0,1]$ is the exogenous asymmetry in bargaining power and $u_i = v_i - p_j$ and $u_j = p_j$ are the utilities of company i and supplier j in a transaction.

If we solve for the optimal price, we have:

$$p_{ji} = \beta\left(v_i - \underline{u_i}\right) + (1-\beta)\,\underline{u_j} \tag{2.1}$$

When $\beta = 0$, companies have all the bargaining power and suppliers receive their outside-option ($p_{ji} = \underline{u_j}$). When $\beta = 1$, suppliers have all the bargaining power and companies receive their outside-option ($p_j = v_i - \underline{u_i}$).

As an example, consider two typical automobile companies in Japan, Toyota and Nissan, and a typical supplier of autoparts, Aisin Seiki. Each company demands one unit of input, and the supplier offers one unit. Suppose that firms invest in links and form the following network:

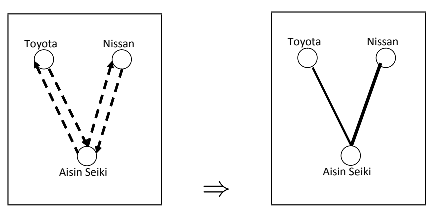


Fig. 2.1: Network Formation

After the network is formed, the uncertainty about input valuations dissapear and companies receive valuations $v_{TOYOTA} = 1/3$ and $v_{NISSAN} = 1/2$. What is the pairwise-stable matching for $\beta = 1/2$?

Using the algorithm of Elliott (2010), we obtain $\underline{u_{NISSAN}} = 0$ and $\underline{u_{AISIN}} = 1/3$. The intuition is that Nissan have no alternative but to trade with Aisin, while Aisin could also trade with Toyota.

Replacing the outside-options in expression (2.1), we get the Nash-price charged by Aisin Seiki to Nissan, $p_{AISIN} = 5/12$. Because $5/12 > 1/3 = v_{TOYOTA}$, the pairwise-stable matching is Aisin Seiki-Nissan at price 5/12.

Note that the company with the highest valuation gets the input. The *efficiency* of the matching is the consequence of pairwise-stability and the assumption of bilateral transactions: if no coalition of two firms (company-supplier) have incentives to deviate, then neither a large coalition arranged itself into pairs.

Also, observe that having more links relative to a partner *improve his bargaining position.* If we cut the link Aisin Seiki-Toyota, the price charged to Nissan would be reduced to $1/4 < 5/12$.

In summary, for any network and distribution of valuations we have a unique profile of pairwise-stable transactions and prices. We will show how firms take into account this information to decide their investments in links.

2.2.4 Optimal investments in links

For example, consider the following network with three companies $\{1, 2, 3\}$, two suppliers $\{a, b\}$ and $\beta = 1/2$:

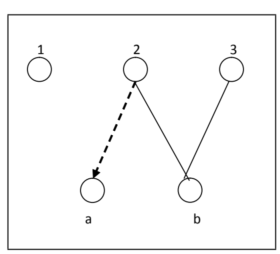


Fig. 2.2: Connection proposal

What is the best response of supplier a to the proposal of link by company 2?

If supplier a accept the proposal, there are two possibilities:

i) $v_2 \geq v_3$: to calculate the optimal price according to (2.1), we need $\underline{u_2}$ and $\underline{u_a}$. Using the algorithm of Elliott, we have $\underline{u_a} = 0$.

It is instructive to calculate $\underline{u_2}$ in a different way. Demange (1982) shows that the maximum value that a could negotiate in a transaction is the Vickrey-utility: the maximum social utility in the network with the presence of a less the maximum social utility in the network without the presence of a:

$$\overline{u_a} = (v_2 + v_3) - (v_2) = v_3$$

Also, Shapley y Shubik (1972) find that a transaction in which a gives 2 the value of his outside-option and receives the difference is in the core of the assignment game. Then:

$$\underline{u_2} = v_2 - \overline{u_a} = v_2 - v_3$$

Using (2.1), the Nash-price is:

$$\begin{aligned} p_a &= \beta \left(v_2 - \underline{u_2}\right) + (1-\beta)\, \underline{u_a} \\ p_a &= \left(v_2 - v_2 + v_3\right)/2 \\ p_a &= v_3/2 \end{aligned}$$

Because v_2 and v_3 are unknown at the time of investments in links, the *expected* price conditional on $v_2 \geq v_3$ is $E\left(v^{2:2}\right)/2$, half the expected value for the second-order statistic from a distribution of two valuations.

ii) $v_2 < v_3$: with a similar procedure, we have $\underline{u_2} = \underline{u_a} = 0$. The Nash-price is :

$$\begin{aligned} v_2 - p_a &= p_a \\ p_a &= v_2/2 \end{aligned}$$

Conditional on $v_2 < v_3$, the expected price is $E\left(v^{2:2}\right)/2$.

The *unconditional* expected price is the weighted average of cases i-ii, where the weights are given by the probabilities of the cases. Assuming $f(v_i) = U[0,1]$, we have:

$$\begin{aligned} p_a^e &= 1/2 * E\left(v^{2:2}\right) + 1/2 * E\left(v^{2:2}\right) \\ &= 1/2 * 1/6 + 1/2 * 1/6 = 1/6 \end{aligned}$$

Then, the expected utility of a if he accepts the proposal of 2 is:

$$\pi_a = 1/6 - \gamma c$$

If this expression is positive, the best response for a is to accept the proposal of 2 and form the link; otherwise, he will refuse the proposal.

2.3 Three companies and two suppliers

To analyze the hold-up problem in the simplest way, we will solve the Nash Pairwise-Stable networks (NPS) for the case of three companies, two sellers, symmetry in negotiation and $f(v_i) = U[0,1]$, taking into account the pairwise-stable matching of the bargaining stage.

The possible types of networks for this case are:

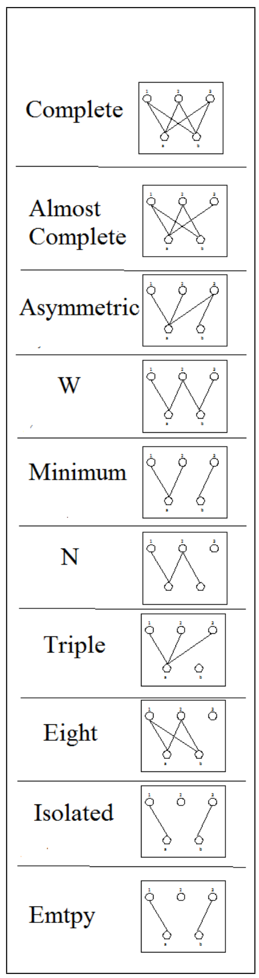


Fig.2.3: Possible types of networks

Because firms are simmetric in the formation of the network ex-ante, we calculate the expected utilities of suppliers in the networks of fig. 2.3:

Table 2.1: expected utilities of suppliers, case $\beta = 1/2$

Network	π_a	π_b
C	$\frac{E(v^{1:3})+E(v^{2:3})}{2} - 3\gamma c$	$\frac{E(v^{1:3})+E(v^{2:3})}{2} - 3\gamma c$
AC	$\frac{1}{2}E(v^{1:3}) + \frac{1}{3}E(v^{2:3}) + \frac{1}{6}E(v^{3:3}) - 3\gamma c$	$\frac{E(v^{1:3})+E(v^{2:3})}{2} - 2\gamma c$
Asim	$\frac{1}{3}(E(v^{1:3}) + E(v^{2:3}) + E(v^{3:3})) - 3\gamma c$	$\frac{1}{3}\left(\frac{1}{2}E(v^{1:3}) + E(v^{2:3})\right) - \gamma c$
W	$\frac{1}{2}E(v^{1:3}) + \frac{1}{3}E(v^{2:3}) + \frac{1}{6}E(v^{3:3}) - 2\gamma c$	$\frac{1}{2}E(v^{1:3}) + \frac{1}{3}E(v^{2:3}) + \frac{1}{6}E(v^{3:3}) - 2\gamma c$
Min	$\frac{1}{2}(E(v^{1:2}) + E(v^{2:2})) - 2\gamma c$	$\frac{1}{2}E(v^{1:1}) - \gamma c$
N	$\frac{1}{4}(E(v^{1:2}) + E(v^{2:2})) - 2\gamma c$	$\frac{1}{2}E(v^{1:2}) - \gamma c$
Triple	$\frac{1}{2}(E(v^{2:3}) + E(v^{3:3})) - 3\gamma c$	0
Eight	$\frac{1}{2}E(v^{1:2}) - 2\gamma c$	$\frac{1}{2}E(v^{1:2}) - 2\gamma c$
Isolated	$\frac{1}{2}E(v^{1:1}) - \gamma c$	$\frac{1}{2}E(v^{1:1}) - \gamma c$
Empty	0	0

And the expected utilities of the companies:

Table 2.2: Expected utilities of companies, case $\beta = 1/2$

Network	π_1	π_2	π_3
C	$\frac{1}{3}E(v^{3:3}) - \frac{1}{3}E(v^{1:3}) - 2(1-\gamma)c$	$\frac{1}{3}E(v^{3:3}) - \frac{1}{3}E(v^{1:3}) - 2(1-\gamma)c$	$\frac{1}{3}E(v^{3:3}) - \frac{1}{3}E(v^{1:3}) - 2(1-\gamma)c$
AC	$\frac{1}{3}E(v^{3:3}) - \frac{1}{3}E(v^{1:3}) - 2(1-\gamma)c$	$\frac{1}{3}E(v^{3:3}) - \frac{1}{3}E(v^{1:3}) - 2(1-\gamma)c$	$\frac{1}{6}E(v^{3:3}) + \frac{1}{6}E(v^{2:3}) - \frac{1}{3}E(v^{1:3}) - (1-\gamma)c$
Asim	$\frac{1}{6}E(v^{3:3}) - \frac{1}{6}E(v^{1:3}) - (1-\gamma)c$	$\frac{1}{6}E(v^{3:3}) - \frac{1}{6}E(v^{1:3}) - (1-\gamma)c$	$\frac{1}{3}E(v^{3:3}) - \frac{1}{3}E(v^{1:3}) - 2(1-\gamma)c$
W	$\frac{1}{6}E(v^{3:3}) + \frac{1}{6}E(v^{2:3}) - \frac{1}{3}E(v^{1:3}) - (1-\gamma)c$	$\frac{1}{3}E(v^{3:3}) - \frac{1}{3}E(v^{1:3}) - 2(1-\gamma)c$	$\frac{1}{6}E(v^{3:3}) + \frac{1}{6}E(v^{2:3}) - \frac{1}{3}E(v^{1:3}) - (1-\gamma)c$
Min	$\frac{1}{4}E(v^{2:2}) - \frac{1}{4}E(v^{1:2}) - (1-\gamma)c$	$\frac{1}{4}E(v^{2:2}) - \frac{1}{4}E(v^{1:2}) - (1-\gamma)c$	$\frac{1}{2}E(v^{1:1}) - (1-\gamma)c$
N	$\frac{1}{4}E(v^{2:2}) + \frac{1}{4}E(v^{1:2}) - (1-\gamma)c$	$\frac{1}{2}E(v^{2:2}) - 2(1-\gamma)c$	0
Triple	$\frac{1}{6}E(v^{3:3}) - \frac{1}{6}E(v^{2:3}) - (1-\gamma)c$	$\frac{1}{6}E(v^{3:3}) - \frac{1}{6}E(v^{2:3}) - (1-\gamma)c$	$\frac{1}{6}E(v^{3:3}) - \frac{1}{6}E(v^{2:3}) - (1-\gamma)c$
Eight	$\frac{1}{2}E(v^{2:2}) - 2(1-\gamma)c$	$\frac{1}{2}E(v^{2:2}) - 2(1-\gamma)c$	0
Isolated	$\frac{1}{2}E(v^{1:1}) - (1-\gamma)c$	0	$\frac{1}{2}E(v^{1:1}) - (1-\gamma)c$
Empty	0	0	0

Note that the expected prices are higher if the suppliers have more links vs. the companies. The intuition is the same as in the analysis of fig.2.1: investing in one additional link tend to increase the value of the outside option and the optimal price, but it requires an additional cost. Companies face a similar trade-off.

For any $f(v_i)$, we eliminate networks that are not pairwise-stable because a supplier have incentives to drop one link:[6]

Network	Not pairwise-stable because
C	A supplier have incentives to break a link
CC	b have incentives to break the link with 1
Eight	A supplier have incentives to break a link
Asym	a have incentives to break a link with 3
N	a have incentives to break a link with 2

The rest of the networks can be pairwise-stable depending on the particular probability density function. Using $f(v_i) = U[0,1]$, the expected utilities of firms in the rest of the networks are:

Network	π_a	π_b	π_1	π_2	π_3
W	$\frac{5}{12} - 2\gamma c$	$\frac{5}{12} - 2\gamma c$	$\frac{1}{8} - (1-\gamma)c$	$\frac{1}{6} - 2(1-\gamma)c$	$\frac{1}{8} - (1-\gamma)c$
Min	$\frac{1}{2} - 2\gamma c$	$\frac{1}{4} - \gamma c$	$\frac{1}{12} - (1-\gamma)c$	$\frac{1}{12} - (1-\gamma)c$	$\frac{1}{4} - (1-\gamma)c$
Triple	$\frac{5}{8} - 3\gamma c$	0	$\frac{1}{24} - (1-\gamma)c$	$\frac{1}{24} - (1-\gamma)c$	$\frac{1}{24} - (1-\gamma)c$
Isolated	$\frac{1}{4} - \gamma c$	$\frac{1}{4} - \gamma c$	$\frac{1}{4} - (1-\gamma)c$	0	$\frac{1}{4} - (1-\gamma)c$
Empty	0	0	0	0	0

Working algebraically with these expressions, we plot in a two-dimentional graph the pairwise-stable networks for different values of the suppliers's share cost parameter γ

[6]See the proof in the appendix, subsection B

(abscissa) and total cost c (ordinate):

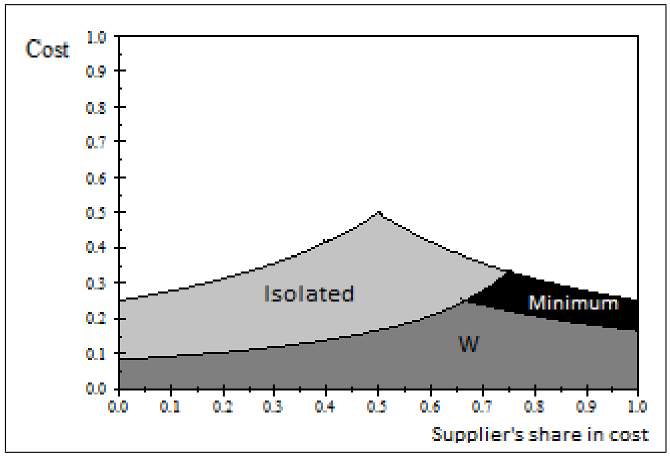


Fig. 2.4: NPS Networks for $n_C = 3, n_S = 2, U\,[0,1]$

It is not difficult to see that these networks are Nash Pairwise-Stable (NPS). The intuition is simple. For a network to be pairwise-stable but not Nash, either i) a firm wants to cut two or three links; or ii) a firm wants to accept two or three proposals for links. But these decisions imply a higher trade-off than cutting or adding one link.[7]

Analysis of equilibrium networks

In fig. 2.4, we observe that the incentives of firms to invest in links depend not only on the total cost of link but also on how it is financed between companies and suppliers:

- If the cost of a link is low, the W network is an equilibrium no matter how the cost is shared between companies and suppliers.
- When the cost of a link rises:
  - If γ is high, the minimum network is an equilibrium. The benefit of investing

[7] See the appendix, subsection B

in one additional link for a supplier and forming the W network -given by an expected increase in his outside option and the price- is lower than the additional cost γc

- If γ is low, the isolated network is an equilibrium. In this case, the benefit of investing in an additional link for a company and forming the minimum network -given by an expected increase in his outside option and a drop in the price- is lower that the extra cost $(1-\gamma)\,c$

• If the cost of a link is high, the equilibrium is the isolated or the empty network. Note that company and supplier have to finance a *similar* portion of the cost as it rises.

The results reflect a trade-off between the benefits and costs of investing in one additional link. On one hand, it rises bargaining power (in expected value); on the other hand, it requires an additional cost (which depends on parameters γ and c).

2.4 Social optimum networks and the hold-up problem

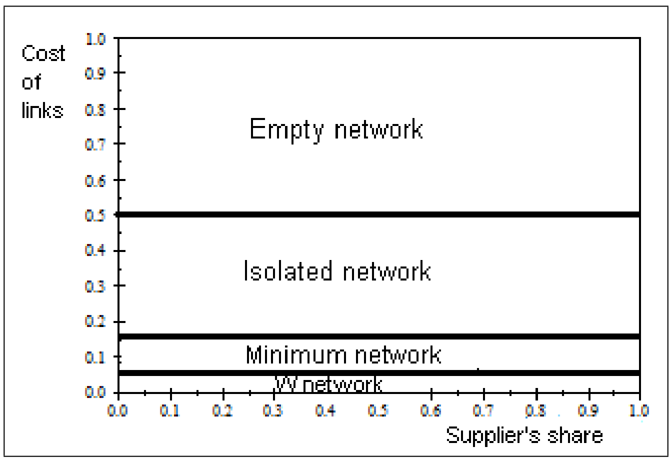
We define an *efficient* network as the network that maximizes the total expected value of transactions less the total cost of links.

In this section, we compare the NPS networks with the the socially efficient networks for different values of the parameters.

The social utilities for the case of three companies and two suppliers are:

Network	Social utility
W	$E(v^{2:3}) + E(v^{3:3}) - 5c$
Minimum	$E(v^{3:3}) + \frac{2}{3}E(v^{2:3}) + \frac{1}{3}E(v^{1:3}) - 3c$
Isolated	$2(E(v^{1:1}) - c)$
Empty	0

We graph the efficient networks for the case of three companies, two suppliers, $f(v_i) = U[0,1]$ and $\beta = 1/2$:



Note that the only relevant parameter for social efficiency is the total cost of the link, not how it is shared between companies and suppliers.

We compare the NPS networks with the efficient networks together (the NPS networks are drawn without their names):

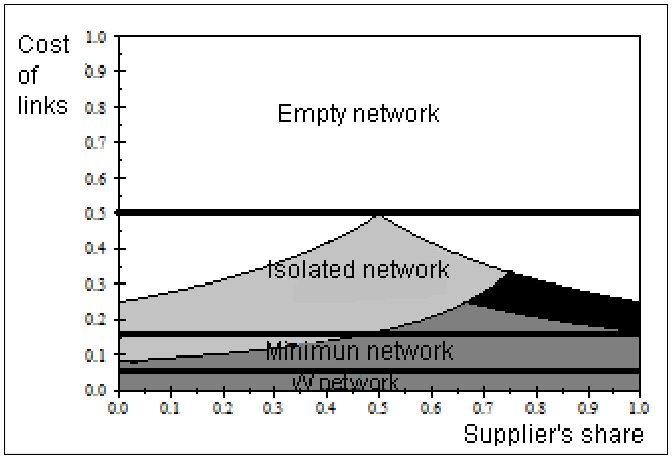


Fig. 2.5: Equilibrium vs. Efficient Networks

where the dark grey area is W, the dark is the minimum, the grey is the isolated and the white is the empty network.

Observe that *firms may have incentives to overinvest or underinvest with respect to the social optimum network:*

- When W is socially optimal, private incentives of firms coincide with the social optimum. Since many firms are investing and the cost of link is low, it is not important how it is financed between companies and suppliers.

- When the minimum network is socially optimum, firms may underinvest (isolated) or overinvest (W).

  In the underinvestment equilibrium, companies have to fund the most part of the investment. They are not willing to invest in one additional link because suppliers would increase their bargaining power (expected prices would be higher in the minimum than in the isolated network).

In the overinvestment equilibrium, suppliers have to fund the most part of the investment. Nevertheless, they are willing to invest in one additional link with the companies because it would increase their bargaining power (in the W network one supplier gains in expected price and the other loses, compared to the minimum network. But as a group suppliers are better).

- When the isolated network is socially efficient, firms have incentives to underinvest (empty), invest the same (isolated) or overinvest (minimum and W). The intuition is analogous.

In summary, if the cost of investments is high or a large share of the cost is supported by either companies or suppliers, the firms become too cautious and invest less than the social optimum network. This is the *hold-up* problem.

Note that the hold-up problem can be more or less severe depending on the relative number of companies or suppliers (here we have three companies and two suppliers), how firms model uncertainty (here we have $f(v_i) = U[0,1]$) and the exogenous asymmetry in bargaining power (here we have $\beta = 1/2$).

Recall from the introduction that our goal is to analyze the influence of outsourcing relations in the incentives of firms to invest in specific assets. We think that network theory is useful because it allows us to capture features that are usually absent in the models of the literature: i) that we are dealing with several firms, not only a pair company-supplier; ii) that firms invest in a context of uncertainty; iii) that the way in which companies and suppliers fund the investments, or the asymmetries in negotiation are important; and iv) that companies and suppliers have a strategic motivation to invest in outsourcing relationships, increase their bargaining power.

The hold-up problem is less severe in the case in which the cost of investments is low or it is shared equally between companies and suppliers. In this case, many firms invest in links, creating more oportunities for transactions and reducing the possibility of oportunistic behaviour. This seems to be the case of the japanese automobile industry.

2.5 Extensions

Asymmetric negotiation

In this section, we will show the NPS networks for $\beta = 1/4$ and $\beta = 3/4$.

Case $\beta = 3/4$

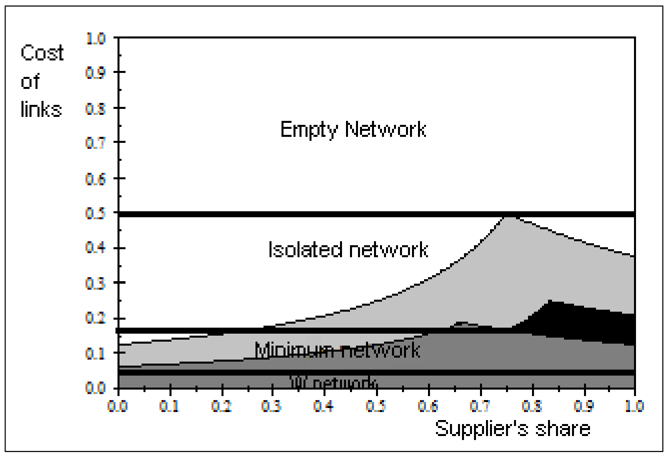
The exogenous asymmetry in negotiation favors suppliers. In search for the NPS networks, we eliminate C, CC, N, Eight and Asymmetric for any probability density function. The expected utilities of companies and suppliers in the rest of the networks and $f(v_i) = U[0,1]$ are:

Table 2.3: possible pairwise-stable networks (case $\beta = 3/4$)

Network	π_a	π_b	π_1	π_2	π_3
W	$\frac{1}{2} - 2\gamma c$	$\frac{1}{2} - 2\gamma c$	$\frac{1}{16} - (1-\gamma)c$	$\frac{1}{8} - 2(1-\gamma)c$	$\frac{1}{16} - (1-\gamma)c$
Min	$\frac{7}{12} - 2\gamma c$	$\frac{3}{8} - \gamma c$	$\frac{1}{24} - (1-\gamma)c$	$\frac{1}{24} - (1-\gamma)c$	$\frac{1}{8} - (1-\gamma)c$
Triple	$\frac{11}{16} - 3\gamma c$	0	$\frac{1}{48} - (1-\gamma)c$	$\frac{1}{48} - (1-\gamma)c$	$\frac{1}{48} - (1-\gamma)c$
Isolated	$\frac{3}{8} - \gamma c$	$\frac{3}{8} - \gamma c$	$\frac{1}{8} - (1-\gamma)c$	0	$\frac{1}{8} - (1-\gamma)c$
Empty	0	0	0	0	0

Note that suppliers charge a higher expected price than in the case of symmetry in negotiation. They get a larger share of the "rest of the cake" (value of input less the sum of outside options). Companies get a smaller expected utility.

The NPS networks are:



For high values of γ the isolated network occupies areas where the minimum were before in the symmetric case, and the minimum occupies areas where the W were before.

Also, for low values of γ the empty network occupies areas where the isolated were before.

Then, the hold-up problem is more severe than the case of symmetry in negotiation. The intuition is that suppliers get a higher expected price. As a result, companies have less incentives to form links.

Case $\beta = 1/4$

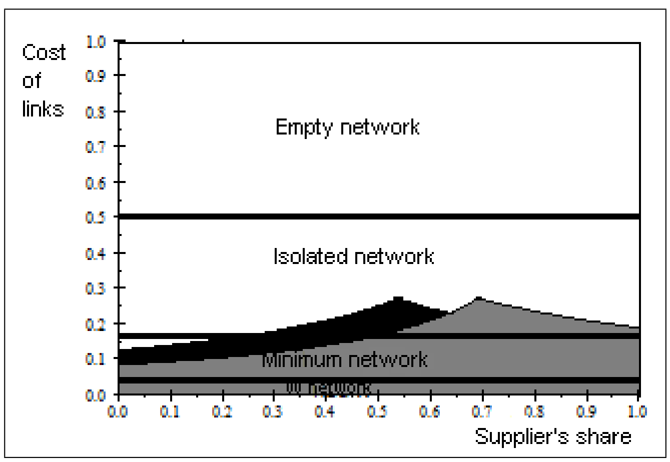
The exogenous asymmetry favors companies. We discard networks C, CC, N, Eight and Asymmetric for any probability density function. The expected utilities of companies and suppliers in the remaining cases are, for $f(v_i) = U[0,1]$:

Table 2.4: possible pairwise-stable networks (case $\beta = 1/4$)

Network	π_a	π_b	π_1	π_2	π_3
W	$\frac{3}{8} - 2\gamma c$	$\frac{3}{8} - 2\gamma c$	$\frac{3}{16} - (1-\gamma)c$	$\frac{5}{24} - 2(1-\gamma)c$	$\frac{3}{16} - (1-\gamma)c$
Min	$\frac{5}{12} - 2\gamma c$	$\frac{1}{8} - \gamma c$	$\frac{1}{8} - (1-\gamma)c$	$\frac{1}{8} - (1-\gamma)c$	$\frac{3}{8} - (1-\gamma)c$
Triple	$\frac{9}{16} - 3\gamma c$	0	$\frac{1}{16} - (1-\gamma)c$	$\frac{1}{16} - (1-\gamma)c$	$\frac{1}{16} - (1-\gamma)c$
Isolated	$\frac{1}{8} - \gamma c$	$\frac{1}{8} - \gamma c$	$\frac{3}{8} - (1-\gamma)c$	0	$\frac{3}{8} - (1-\gamma)c$
Empty	0	0	0	0	0

Note that suppliers charge a lower expected price than the symmetric case because companies have more bargaining power.

The NPS networks are:



Observe that the empty network covers a large area where the isolated were in the symmetric case. But for low values of c the equilibrium networks may have one more link than the symmetric case. This is because companies outnumber suppliers and have more bargaining power: they are more willing to invest in links.

Overall, the area of underinvestment is higher than the symmetric case and the hold-up problem is more severe.

In summary, the hold-up problem is exacerbated with an exogenous asymmetry in negotiation.

Social optimum: comparison with the case of vertical integration

In this section, we would like to reflect the discussion of the introduction about vertical integration and outsourcing. We compare the efficiency of a networked industry vs. a vertically integrated industry.

Following Kranton and Minehart (2001), assume that the integration between a company and a supplier have a fixed cost $\alpha \in [0, 1]$. Because we have two suppliers, there can be at most two integrated firms. Under these assumptions, an integrated firm gets an expected utility of $E(v) - \alpha = 1/2 - \alpha$, the expected value of the input less the fixed cost of integration.

We graph for different values of α (abscissa) and c (ordinate) the best alternative from a social point of view:

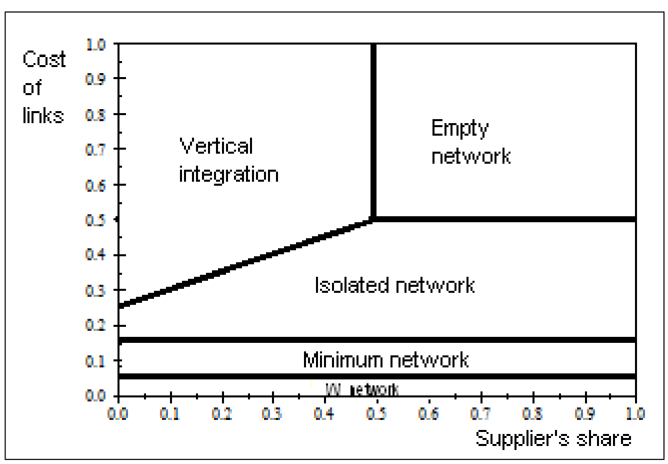


Fig. 2.6: Networks vs. Vertical Integration

Note that the network structure is more efficient than vertical integration when $c = \alpha$ (the cost of both alternatives is similar). The intuition is that firms have more alternatives for transactions in networks. As we have seen in the introduction, given the same costs, networks *diversify business risk better* in a context of uncertainty.

2.6 Analysis

In this chapter, we analyze the incentives of companies and suppliers to jointly invest in specific assets under outsourcing. This is a problem in the context of industries with uncertainty in final demand (automobile, semiconductors, software) because there is the possibility of hold-up. Unlike vertical integration, outsourcing allow firms to reduce aggregate business risk and catch-up faster. Nevertheless, there is no theoretical analysis of the structure of outsourcing relations and the hold-up problem.

This chapter analyzes the issue using network theory. Our hypothesis is that more outsourcing relations generate more alternatives for firms and increase their outside option values. As a result, the bargaining power of different groups is equalized and reduces the possibility of opportunistic behaviour.

We develop a model in which companies and suppliers first invest in specific assets (links), and then negotiate transactions and prices over the forming network. Using a cooperative framework to simplify the analysis of the bargaining stage, we find that there is a unique pairwise-stable matching characterized by a Nash-Bargaining process in which all firms receive at least their outside-option value in a transaction. Then, with the results of the bargaining process, we calculate the equilibrium network structures chosen by firms and compare them with the social optimum networks.

The results show that the hold-up problem is less severe (firms invest in the social optimum network) when companies and suppliers share more evenly the cost of investments or their bargaining power (which depends on the structure of the network and exogenous asymmetries) is similar. Other important factors are the relative number of companies and suppliers and the way in which firms model uncertainty.

With this framework, we capture interesting features of the outsourcing industries: i) that firms invest in a context of uncertainty; ii) that the way in which companies and suppliers fund the investments and external asymmetries in negotiation are important; and iii) that both companies and suppliers can increase the value of their outside-options through their relationships with many partners. There is a strategic motivation of firms to invest in links: improve their bargaining position. When the network has many links, as in the japanese automobile industry, the bargaining power of different groups is equalized and reduces the possibility of oportunistic behaviour.

We also find that a network structure is more convenient for firms than vertical integration when uncertainty in business is high and both alternatives have similar costs. At this point, it is important to note that we are not analyzing the dinamics associated with the make-or-buy decision. It will be interesting as a further step to investigate a dynamic evolution of an industry in which firms choose mixed corporate strategies: some inputs are produced by vertical integration while others are produced by outsourcing.

2.7 Appendix

A. Proof of proposition 2.1

Consider an **assignment game** $(\Lambda, v)^g$ between Λ firms. Firms are organized into pairs company-supplier to trade.[8]

Define a coalition ζ as a subset of Λ which only contains pairs company-supplier. Let ζ_C be the set of companies in the coalition ζ, and ζ_S the set of suppliers in ζ.

Define a *coalitional function* $v^g(\zeta)$ as:

1) $v^g(\zeta) = v_i$ if $\zeta = \{i, j\}$ and $t_{ij} = t_{ji} = 1$

2) $v^g(\zeta) = 0$ if ζ has only companies or only suppliers

3) $v^g(\zeta) = \max(v(i_1, j_1) + v(i_2, j_2) + ... + v(i_k, j_k))$ for arbitrary coalitions ζ in g, with the maximum taken over all the sets $\{(i_1, j_1), (i_2, j_2), ..., (i_k, j_k)\}$of k different pairs in $\zeta_C \times \zeta_S$.

The *core* of the game $(\Lambda, v)^g$ is the set of utilities of firms (u_C, u_S) such that:

i) For every $\{i, j\} \in C \times S$, $\sum_{i=1}^{C} u_i + \sum_{j=1}^{S} u_j = \sum_{i=1}^{C} v_i = v^g(\Lambda)$ (feasibility).

ii) For every coalition of firms $\zeta = \zeta_C \times \zeta_S$, with $\zeta_C \subset C$ and $\zeta_S \subset S$, we have $\sum_{i \in \zeta_C} u_i + \sum_{j \in \zeta_S} u_j \geq \sum_{i \in \zeta_C} v_i = v^g(\zeta)$ (incentive compatibility of coalitions). That is, no coalition of pairs company-supplier have incentives to deviate and make transactions that increase the utilities of their members.

Proposition 2.2 ***Shapley and Shubik (1972)*** *There always exist at least one element in the core of an assignment game.*

[8]Roth, A. y M. Sotomayor (1990). *Two-Sided Matching: A Study in Game-Theoretic Modeling and Analysis.* Cambridge University Press.

Proof. See theorem 8.6 of Roth and Sotomayor (1990), which is based on Shapley y Shubik (1972). ■

Now, consider the following terms of trade between company i and supplier j:

$$u_j = \underline{u_j} + \beta\left(v_i - \underline{u_i} - \underline{u_j}\right) \tag{2.2}$$

$$u_i = \underline{u_i} + (1-\beta)\left(v_i - \underline{u_i} - \underline{u_j}\right) \tag{2.3}$$

A company and a supplier receive at least their outside option in a negotiation, and then bargain over the rest of the "cake" -the total value of the transaction less the sum of their outside options- according to $\beta \in [0,1]$, a parameter which captures exogenous asymmetries in negotiation.

Consider an assignment game in which companies value the same positive amount each object sold by their linked sellers, and zero the objects sold by their non-linked sellers. This game represents exactly the bargaining problem in networks. Because any assignment game has a non-empty *core*, this implies that the set of pairwise-stable transactions in a network is not empty.

We can prove the inverse, that is, any pairwise-stable matching with the terms of trade (2.2) and (2.3) is in the core of $(\Lambda, v)^g$. To do so, we will check the feasibility and incentive compatibility conditions:

i) *Feasibility*: suppose that n'_S pairs trade in the network, with $n'_S \leq n_S$. The utilities of non-trading firms are zero, so the feasibility condition is satisfied trivially. For the rest of the firms, taking expresions (2.2) and (2.3), we have:

$$\begin{aligned}\sum_{i=1}^{n'_S} u_i + \sum_{j=1}^{n'_S} u_j &= \sum_{i=1}^{n'_S}\left(\underline{u_i} + (1-\beta)\left(v_i - \underline{u_i} - \underline{u_j}\right)\right) + \sum_{j=1}^{n'_S}\left(\underline{u_j} + \beta\left(v_i - \underline{u_i} - \underline{u_j}\right)\right) \\ &= \sum_{j=1}^{n'_S}\left(\underline{u_j} + \underline{u_i}\right) + \sum_{i=1}^{n'_S}\left(v_i - \underline{u_i} - \underline{u_j}\right) \\ &= \sum_{i=1}^{n'_S} v_i\end{aligned}$$

ii) *Incentive compatibility*: note that for the smallest coalition $\{i, j\}$, the definition of pairwise-stable matching implies that $u_i \geq 0$, $u_j \geq 0$ and $u_i + u_j = v_i$. But by the definition of $v^g(\zeta)$, this implies that for any coalition $\zeta \rightarrow \sum_{i\in\zeta_C} u_i + \sum_{j\in\zeta_S} u_j \geq \sum_{i\in C_C} v_i = v^g(\zeta)$. Then, if a matching is pairwise stable, no members in a coalition of more than two firms have incentives to deviate.

Now, define a *competitive equilibrium* of $(\Lambda, v)^g$ as a price vector and a feasible assignment at which each supplier maximizes prices, each buyer maximizes net valuations, and markets clear. Let p_j be the price charged by supplier j in the core. Replacing $p_j = u_j$ in (2.2), we have:

$$\begin{aligned}p_j &= \underline{u_j} + \beta\left(v_i - \underline{u_i} - \underline{u_j}\right) \\ p_j &= \beta\left(v_i - \underline{u_i}\right) + (1-\beta)\,\underline{u_j}\end{aligned}$$

But this is **exactly** the price that maximizes the *product of Nash* in a bilateral negotiation, $\left(u_j - \underline{u_j}\right)^{\beta}\left(u_i - \underline{u_i}\right)^{1-\beta}$, with $u_i = v_i - p_j$ and $u_j = p_j$.

Then, the terms of trade in (2.2) and (2.3) correspond to a Nash-Bargaining process which generates a pairwise-stable matching (and it is in the core of $(\Lambda, v)^g$).

B. Nash Pairwise-Stable networks in the case $n_C = 3$, $n_S = 2$, $\beta = 1/2$ and $f(v_i) = U[0,1]$

Using table 2.1 above, we will prove that the networks C, CC, asymmetric, eight and N are not pairwise-stable.

- The network C is not pairwise-stable because supplier b get the same expected price with network CC but incurs in an additional cost γc.
- The network CC is not pairwise-stable because supplier a get the same expected price with network W but incurs in an additional cost γc.
- The asymmetric network is not an equilibrium because supplier a gets the same expected price if he cuts the link with company 3. To prove it, we will use the order statistics relation:

$$(n-k)\,E\left(v^{k:n}\right) + kE\left(v^{k+1:n}\right) = nE\left(v^{k:n-1}\right) \tag{2.4}$$

for every $k, n \in \mathbb{N}$ and $k < n$.[9]

Given $n = 3$ and $k = 2$, we have:

$$\begin{aligned}(3-2)\,E\left(v^{2:3}\right) + 2E\left(v^{3:3}\right) &= 3E\left(v^{2:2}\right) \\ \frac{1}{6}E\left(v^{2:3}\right) + \frac{1}{6}E\left(v^{3:3}\right) + \frac{1}{6}E\left(v^{3:3}\right) &= \frac{1}{2}E\left(v^{2:2}\right) \end{aligned} \tag{2.5}$$

On the other hand, for $n = 3$ and $k = 1$ we have:

[9]See David, H. y H. Nagaraja (2003). *Order Statistics.* Wiley Series in Probability and Statistics (third edition)

$$\begin{aligned}(3-1)\,E\left(v^{1:3}\right)+E\left(v^{2:3}\right) &= 3E\left(v^{1:2}\right)\\ \frac{1}{6}E\left(v^{1:3}\right)+\frac{1}{6}E\left(v^{1:3}\right)+\frac{1}{6}E\left(v^{2:3}\right) &= \frac{1}{2}E\left(v^{1:2}\right) \qquad (2.6)\end{aligned}$$

- Summing up the left and the right hand side of (2.5) y (2.6), we obtain:

$$\frac{1}{3}E\left(v^{1:3}\right)+\frac{1}{3}E\left(v^{2:3}\right)+\frac{1}{3}E\left(v^{3:3}\right)=\frac{1}{2}E\left(v^{1:2}\right)+\frac{1}{2}E\left(v^{2:2}\right)$$

From table 2.1, we see that the L.H.S. is the expected price in the asymmetric network, and the R.H.S. is the expected price in the minimum network.

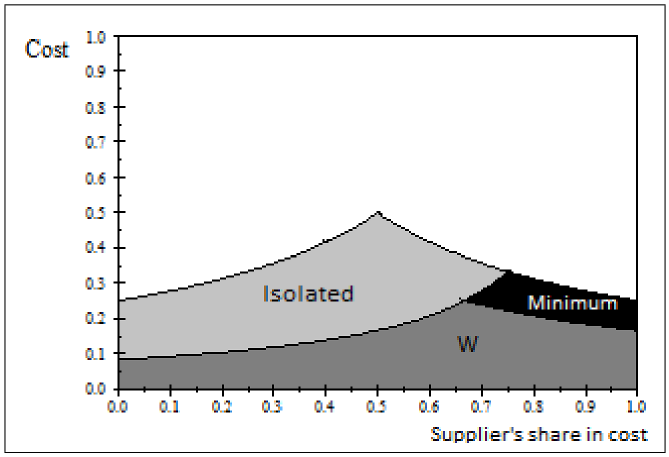
- The eight network is not an equilibrium because supplier b gets the same expected price by dropping a link and forming the network N.

- The network N is not an equilibrium because supplier a gets the same expected price if he drops his link with company 2. To prove it, take (2.4) for $n=2$ and $k=1$:

$$\begin{aligned}(2-1)\,E\left(v^{1:2}\right)+E\left(v^{2:2}\right) &= 2E\left(v^{1:1}\right)\\ \frac{1}{4}E\left(v^{1:2}\right)+\frac{1}{4}E\left(v^{2:2}\right) &= \frac{1}{2}E\left(v^{1:1}\right)\end{aligned}$$

From table 2.1, the L.H.S. is the expected price in the N network, and the R.H.S. is the expected price in the isolated network.

We graph the pairwise-stable networks for $f\left(v_i\right)=U\left[0,1\right]$:



It is easy to show that these networks are in fact a Nash Pairwise-Stable equilibrium (NPS). For being pairwise-stable but not Nash, there are only two possibilities: i) a firm wish to cut two or three links; or ii) a firm wish to accept two or three proposals for links.

Neither case is possible, though. For example, consider the empty network (the analysis for the rest is analogous). Because the empty network is pairwise-stable, the isolated network is not NE. Then, according to the table of utilities above, either $1/4 < \gamma c$ or $1/4 < (1-\gamma)\,c$. Suppose that $1/4 < \gamma c$; then $1/2 < 2\gamma c$ (the minimum network is not a profitable deviation for a supplier with two proposals) and $5/8 < 3\gamma c$ (the triple network is not a profitable deviation for a supplier, either). On the other hand, suppose that $1/4 < (1-\gamma)\,c$; then $1/12 < (1-\gamma)\,c$ (the minimum network is not a profitable deviation for a company) and $1/24 < (1-\gamma)\,c$ (the triple network is not a profitable deviation for a company, either).

Chapter 3

Network formation and incentives in teams

3.1 Introduction

Team production is increasingly important for firms. According to the National Establishment Survey of NBER (2011), 52% of american firms use some form of teamwork. Lazear and Shaw (2007) report that the share of large firms with self-managed teams rose from 27% to 78% between 1987 and 1996. Ledford et all (1995) show that 70% of large firms use some form of team incentives, which vary from contracts based on a share of the profits (Baker, Jensen, and Murphy, 1988; Card, 1990; Kruse, 1993) to team joint performance (Itoh, 1993; Che y Yoo, 2001; Kvaloy and Olsen, 2006). Hamilton, Nickerson and Owan (2003) find that the adoption of teams in Koret increases productivity even after controlling for self-selection of workers.

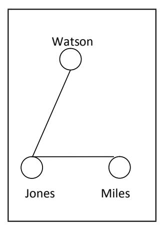
These empirical studies reveal the importance of the structure of teams and contract incentives on optimal levels of effort and production. The literature of incentives in teams started with Alchian-Demsetz (1972) and Groves (1973). The problem of incentives is analyzed within a standard principal-agent framework. A principal does not observe the effort or the productivity of agents, which leads to moral hazard and adverse selection problems. Then, the optimal contract should link individual benefits to variables observed by the principal or reported by the agents. For example, Holmstrom (1982) proposes a contract in which the agents receive nothing if profits fall below a predetermined threshold. McAffe and McMillan suggest a two-part scheme in which the variable part depends on reported productivities of the agents. Rayo (2004) and Lazear and Show (2007) study dinamic environments in which the principal learns the true productivity by observing the level of enforcement with noise (Rayo, 2004; Lazear and Shaw, 2007).

We have also an increasing literature about the optimal structure of teams, which is concerned about team formation by self-interested agents. Examples are found in sports, screenwriting, academics, law, accounting and investment banking (Gershkov, Li and Schweinzer, 2009). In these models, the rewards are based ex-ante on fixed prices (rank tournaments) or are determined later on the basis of productivity (Lazear and Rosen, 1981; Nalebuff and Stiglitz; 1983; Farrell and Scotchmer, 1988; Bandiera et all, 2005). Farrell and Scotchmer (1988) find that the more productive workers search for partners of similar productivities if contracts are based on team joint performance. Bandiera et all (2005) show that workers search for partners with whom they are socially connected if contracts are based on individual performance.

The third chapter is more related to the second stream of literature. We are interested in the way in which agents organize tasks and roles in self-organized teams (academics, law, accounting, sports). Because these teams do not have a principal, the structure of interactions is very important to achieve higher levels of production. Several factors influence these interactions: the productivities of the agents, the disutility of the effort, the sinergy between the agents and the value of team production.

For example, consider three economists, Miles, Jones and Watson, who are willing to write a paper as part of a research project. The product of team x is the *quality* of the paper, measured by the anual impact factor of the publication. The authorities of the project cannot distinguish the contribution of each agent to the quality of the paper. Thus, they give $tx/3$ to each agent (partnership rule), where t is the amount of money per unit of x.

Suppose that the paper requires two tasks: a) theoretical model; and b) econometric estimation. The team divides the activities in the following way: Jones works in both tasks, Watson in the model and Miles in the estimation. We can represent this pattern of interactions as a network:



Note that Watson and Miles do not interact together in the process. It seems that Jones works both in the theory and the econometrics because he is the most capable agent to integrate both parts in the paper. But for this reason, it may happen that Watson and Miles would free-ride on the effort of Jones. This example emphasizes the importance of the structure of interactions in the team.

In this chapter, we develop a model to analyze how the levels of individual effort in a team are influenced by the structure of interactions, given that the level of effort is not monitorable. The model is a non-cooperative game with two stages. In the first stage, agents organize tasks, which result in a pattern of mutual interactions (network formation). In the second stage, given the network, agents decide non cooperatively the level of effort.

We study the equilibrium networks for the case in which individual production is not observable: in this case, we assume that agents use a partnership rule. Then, we compare the equilibrium networks to the (benchmark) situation in which individual production is observable: in this case, we assume agents use a pay-per-production rule, i.e. each agent receives exactly his contribution to the value of team production (tx_i in the example of the economists, where x_i is the production of agent i).

The results show that relative productivities of agents are very important for the structure of networks and levels of production in equilibrium. In particular, *in the case in which individual production is not observable (partnership rule), agents tend to work more in teams than the case in which individual production is observable (pay-per-production rule).* The reason is that under partnership the more productive members are interested in increasing the production of the less productive members.

On the other hand, suppose two teams with the same number of members, one with high dispersion in productivities and the other in which all agents are equally talented. Assume that the average productivity of both teams is the same. *In the case in which individual production is not observable (partnership rule), agents with similar productivities tend to work less in teams than agents with high dispersion in productivities.* The intuition is that under partnership it is less valuable a collaboration for agents with similar talents. This result is reversed when individual production is observable and agents work under a pay-per-production rule: in this case agents with high dispersion in productivities are more reluctant to work in teams.

The rest of this chapter is organized as follows. In the second section, we describe the basic model in which individual production is not observable and the team implements a partnership rule. In the third, we compare it to the benchmark case in which individual production is observable and the team implements a pay-per-production rule. The fourth section discussed the results and present the conclusions. The proofs are relegated to the appendix.

3.2 Individual production is unobservable (partnership rule)

Define $E = \{1, 2, 3\}$ as a team producing a good or service $x \in \mathbb{R}_+$. The team receives t per unit of x. To produce x, the team defines a series of tasks to be done by one or more agents.

A *link* between agent i and agent j is a reciprocal interaction (not necessarily physical) to overcome a series of tasks. A link is formed only with mutual consent of two agents. We denote $t_{ij} \in \{0, 1\}$ as the *intention of link* from i to j. A link between i and j is formed only if $t_{ij}t_{ji} = 1$. A *network* is a pattern of links $g\left(t_{1,}t_2, t_3\right) = \{t_{11}, t_{12}, t_{21,}t_{23}, t_{31}, t_{32}\}$.

Individual production x_i is given by:

$$x_i = a_i e_i + \beta\left(g_{ij} + \beta g_{ik} g_{kj}\right) a_j e_j + \beta\left(g_{ik} + \beta g_{ij} g_{jk}\right) a_k e_k$$

where $a_i \in \mathbb{R}_+$ is a *productivity parameter*, $e_i \in \mathbb{R}_+$ is the level of effort (which is not monitorable), $b \in \mathbb{R}_+$ is the *disutility of the effort* and $\beta \in [0, 1]$ is the *sinergy parameter* (how individual production increases as the result of a link with a partner).[1]

Note that there are two effects of a link with a partner: a direct effect of the interaction, and an indirect effect which depends on the interaction of the partner with the

[1] We assume that the sinergy parameter, the disutility of effort and the cost of link do not vary with the particular structure of the network, just to keep the analysis as simple as possible.

third agent.

We assume that there is a transaction cost associated to work in teams. In order to arrive at decisions that would help increase value, the team usually spend time to review and re-evaluate options and issues. Some tasks require full agreement on smaller matters, and this may be unproductive for other tasks or the whole project. We model this by assuming that each proposal of link *costs* c for each agent, with $c \in \mathbb{R}_+$.[2]

The team pays each agent according to the sharing rule $s_i\left(x\left(e_i, e_{-i}, g\right)\right)$. The utility of agent i is:

$$u_i\left(e_i, e_{-i}, g\right) = s_i\left(x\left(e_i, e_{-i}, g\right)\right) - \frac{b}{2}e_i^2 - cn_i$$

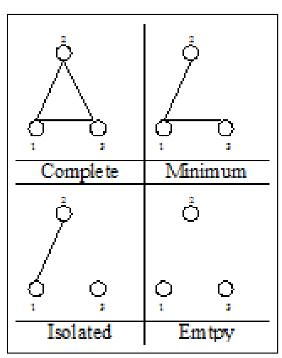
where $n_i = \sum_{j=1}^{2} t_{ij}$ is the number of intentions of link of agent i and $x = \sum_{j=1}^{3} x_j$ is team production.

Game

Consider the following two-stage game:

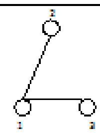
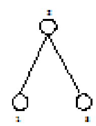
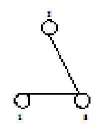
Stage 1 (network formation)

The members of the team play a non cooperative game of network formation and invest in links. The possible types of networs are represented in the figure:



[2]Note that the agent may incur in this cost even if the link is not formed.

For example, while we have only one case of the complete network $\{1,1,1,1,1,1\}$, we may have nine cases of the minimum networks:

Minimum networks	Intention of links
	{1, 1, 1, 0, 1, 0} {1, 1, 1, 1, 1, 0} {1, 1, 1, 0, 1, 1}
	{1, 0, 1, 1, 0, 1} {1, 1, 1, 1, 0, 1} {1, 0, 1, 1, 1, 1}
	{0, 1, 0, 1, 1, 1} {1, 1, 0, 1, 1, 1}, {0, 1, 1, 1, 1, 1}

Stage 2 (effort):

Given the formed network g, each agent $i \in E$ chooses the optimal effort level to maximize his utility, which is given by:[3]

$$\underset{e_i}{Max}\ s_i\left(x\left(e_i, e_{-i}, g\right)\right) - \frac{b}{2}e_i^2$$

Solution:

Typically, we solve the two-stage game by backward induction:

-In the second stage, given the structure of the network and the sharing rule $s_i\left(x\left(e_i, e_{-i}, g\right)\right)$, agent i choose the effort e_i which maximizes their utility. Define π_i as:

$$\pi_i = \underset{e_i}{Max}\ s_i\left(x\left(e_i, e_{-i}, g\right)\right) - \frac{b}{2}e_i^2$$

-Then, with the solution of the second stage, agents choose their optimal investments in links.

[3]The cost of link is sunk at stage 2.

In order to focus only on this stage, we define a simultaneous game of link formation induced by the optimal level of effort of the second stage:

$$G = \{E, T, \Pi\}$$

where the capital letters indicate the set of agents, the set of investments in links and the set of optimal utilities of the second stage.

A set of strategies $t^* \in T$ is a *pure nash equilibrium (NE)* of G if no unilateral deviation is profitable for any agent:

$$\forall_i \in E, t_i \in T_i, t_i \neq t_i^* : \pi_i \left(t_i^*, t_{-i}^*\right) \geq \pi_i \left(t_i, t_{-i}^*\right)$$

We will solve for the Nash-Equilibrium networks (NE) of G for particular cases of interest.

Partnership rule

Recall that under this rule the benefit paid to agent i is the value of team production divided by the number of members:

$$s_i (x) = t\frac{x}{3}$$

Proceeding by backward induction, given a network and the partnership rule, we find the optimal levels of effort chosen by the agents. The utility of agent i is given by:

$$u_i (e_i, e_{-i}, g) = t\frac{x (e_i, e_{-i}, g)}{3} - \frac{b}{2}e_i^2 - cn_i \tag{3.1}$$

The level of effort chosen by agent i solves the problem:

$$\max_{e_i}\left\{\frac{tx\left(e_i,e_{-i},g\right)}{3}-\frac{b}{2}e_i^2\right\}$$

The first-order condition with e_i is:[4]

$$e_i^p=\frac{t}{3b}\left(1+\beta\left(g_{ij}+g_{ik}\right)\left(1+\beta g_{jk}\right)\right)a_i \tag{3.2}$$

The *optimal level of effort* depends positively on the productivity of the agent, the sinergy parameter and the structure of links, and negatively on the disutility of effort.

Observe that not necessarily the agent with the highest productivity a_i has the high e_i^p, it depends also on the structure of the network.

The production of each agent is:

$$\begin{aligned} x_i^p &= \frac{t}{3b}\left(1+\beta\left(g_{ij}+g_{ik}\right)\left(1+\beta g_{jk}\right)\right)a_i^2 \\ &+\frac{t}{3b}\beta\left(g_{ij}+\beta g_{ik}g_{jk}\right)\left(1+\beta\left(g_{ij}+g_{jk}\right)\left(1+\beta g_{ik}\right)\right)a_j^2 \\ &+\frac{t}{3b}\beta\left(g_{ik}+\beta g_{ij}g_{jk}\right)\left(1+\beta\left(g_{ik}+g_{jk}\right)\left(1+\beta g_{ij}\right)\right)a_k^2 \end{aligned} \tag{3.3}$$

Social optimum effort

The socially optimal level of effort is given by:

$$\underset{\{e_i\}_{i=1}^3}{Max}\ t\sum_{i=1}^{3}x_i\left(e_i,e_{-i},g\right)-\frac{b}{2}\sum_{i=1}^{3}e_i^2$$

The first order condition with e_i is:

$$e_i^s=\left(1+\beta\left(g_{ji}+\beta g_{ki}\right)\left(1+g_{kj}\right)\right)\frac{t}{b}a_i \tag{3.4}$$

[4]Because the objective function is the sum of a linear and a concave function in e_i, it is concave in e_i and the second-order condition for a maximum is satisfied.

The socially optimal level of individual production is:

$$x_i^s = a_i e_i^s + \beta\left(g_{ij} + \beta g_{ik} g_{kj}\right) a_j e_j^s + \beta\left(g_{ik} + \beta g_{ij} g_{jk}\right) a_k e_k^s$$

Note that $e_i^p < e_i^s$ and $x_i^p < x_i^s$. Given a network structure, the partnership rule is suboptimal from a social point of view.

Nash-Equilibrium Networks

By backward induction, we replace (3.2) and (3.3) in the utility function of agent i (3.1) to get:

$$\begin{aligned} u_i^p\left(g_i, g_{-i}\right) &= \frac{t^2}{9b}\left(x_i^p + x_j^p + x_k^p\right) \\ &\quad - \frac{t^2}{18b}\left(\left(1 + \beta\left(g_{ij} + g_{ik}\right)\left(1 + \beta g_{jk}\right)\right) a_i\right)^2 - c \sum_{j=1}^{3} g_{ij} \end{aligned}$$

The utility of agent i depends positively on his own productivity and that of the rest of the team (through the links), and negatively on the disutility of effort and the cost of link.

Observe that investing in an additional link has a trade-off for an agent: it increases his level of effort and production (and the effort and production of the other agents, depending on the structure of the network), but at the cost of an additional interaction.

We calculate the utilities of firms in any type of network:

Table 3.1: Expected utilities of agents, partnership

Network	Agent 1	Agent 2	Agent 3
	$\frac{t^2}{9b}\left(\frac{1}{2}a_1^2+a_2^2+a_3^2\right)$	$\frac{t^2}{9b}\left(\frac{1}{2}a_2^2+a_1^2+a_3^2\right)$	$\frac{t^2}{9b}\left(\frac{1}{2}a_3^2+a_1^2+a_2^2\right)$
	$\frac{t^2}{9b}\left((1+\beta)^2\left(\frac{1}{2}a_1^2+a_2^2\right)+a_3^2\right)-c$	$\frac{t^2}{9b}\left((1+\beta)^2\left(\frac{1}{2}a_2^2+a_1^2\right)+a_3^2\right)-c$	$\frac{t^2}{9b}\left((1+\beta)^2(a_1^2+a_2^2)+\frac{1}{2}a_3^2\right)$
	$\frac{t^2}{18b}(1+2\beta)^2a_1^2+\frac{t^2}{9b}(1+\beta(1+\beta))^2(a_2^2+a_3^2)-2c$	$\frac{t^2}{18b}(1+\beta(1+\beta))^2a_2^2+\frac{t^2}{9b}(1+\beta(1+\beta))^2a_3^2$ $+\frac{t^2}{9b}(1+2\beta)^2a_1^2-c$	$\frac{t^2}{18b}(1+\beta(1+\beta))^2a_3^2+\frac{t^2}{9b}(1+\beta(1+\beta))^2a_2^2$ $+\frac{t^2}{9b}(1+2\beta)^2a_1^2-c$
	$\frac{t^2}{9b}(1+2\beta(1+\beta))^2\left(\frac{1}{2}a_1^2+a_2^2+a_3^2\right)-2c$	$\frac{t^2}{9b}(1+2\beta(1+\beta))^2\left(\frac{1}{2}a_2^2+a_1^2+a_3^2\right)-2c$	$\frac{t^2}{9b}(1+2\beta(1+\beta))^2\left(\frac{1}{2}a_3^2+a_1^2+a_2^2\right)-2c$

Consider the case in which $a_1 = a_2 = a_3 = a$, with $a > 0$. We state the following proposition:

Proposition 3.1 *If agents have the same productivity $a_1 = a_2 = a_3 = a$, under a partnership rule the NE network is the complete network if $k^p \geq c$ and the empty network if $k^p < c$, where:*

$$k^p = \frac{a^2t^2}{b}\beta\left(\frac{17}{18}\beta^3 + \frac{17}{9}\beta^2 + \frac{23}{18}\beta + \frac{1}{3}\right)$$

Proof. See appendix, subsection A. ■

Note that an increase in t (the value of team production) also increases k^p. This is intuitive: for example, in the case of the three economists, if the authority increases the total amount paid for the paper, the collaboration is more valuable.

Although we do not have a formal proof yet for the case in which $a_1 < a_2 < a_3$, it is intuitive to show that for each combination of parameters $\{\beta, b, a, c\}$ there is a unique NE network. Note that when the cost of link is zero the complete network is an equilibrium because individual production rises with any additional link. As c rises, the marginal benefit of having two links (that is, the net gain from having two versus one link) is the same but the marginal cost is higher. Then, at some point an agent will cut one or two links, and the minimum or the isolated network will be the new equilibrium (it depends on parameters β, b and a). When c is high it becomes convenient for the agents to work separately.

Simulation and results

It is interesting to analize how the equilibrium networks change with different *productivity parameters*.[5] With this idea, we solve for these cases:

1) *Lider*: $a_1 = a$, $a_2 = a_3 = 0$, with $a \in \{1, 2\}$.

In this situation, one agent (the lider) have the whole inherent productivity. We will show that not necessarily the lider would refuse to form links, because his benefit also depends on the production of the free-riding agents.

2) *Similar talent*: $a_1 = a_2 = a_3 = a$, with $a \in \{1/3, 2/3\}$.

In this case, we study if it is convenient for the agents to work together, given that they are equally talented.

In the following, we fix the values of $t = 1$ and $b = 1$ for the comparative analysis.

Lider case (a=1)

We calculate the NE networks and compared them with *the socially optimal networks* (which maximize the sum of utilities less the total cost of links).

We plot in a two-dimentional graph the equilibrium networks (separated with a thin line) and the socially optimal networks (separated with a dashed line) for different

[5]The other parameters are not interesting for the analysis. For example, if $t \to \infty$ or $c \to 0$, the obvious equilibrium is the complete network, for any values of the other parameters. Also, if $\beta = 0$ the equilibrium is the empty network because any link is useless.

values of the sinergy parameter β (abscissa) and the cost of link c (ordinate):

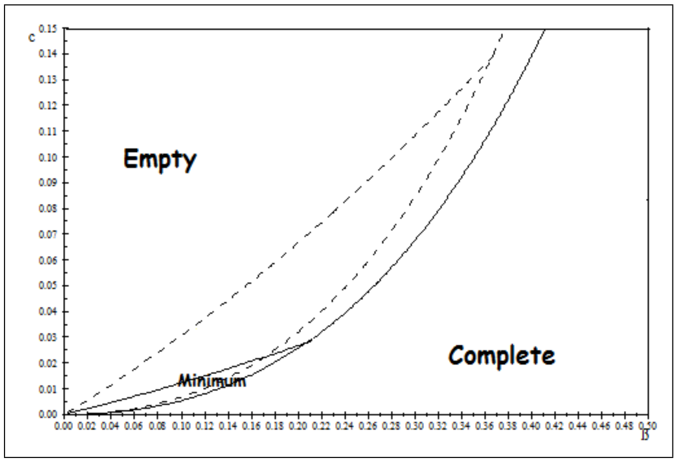


Fig 3.1: Equilibrium vs. Efficient Networks in Partnership, Lider Case

Observe that it may be convenient for the lider to work in teams. The reason is that under partnership the benefit perceived by this agent increases with total production and not only with his individual production. Although the other agents have no intrinsic productivity ($a_2 = a_3 = 0$), their production is positive through the interaction with the lider.

Comparing the equilibrium networks with the socially optimal networks, there is a tendency to underinvest in links under partnership because it is better for the free-riding agents than for the lider to make connections.

Similar talent (a=1/3)

The socially optimal networks for the case of equally talented agents can also be the empty or the complete. We graph together the NE networks and the socially optimal networks:

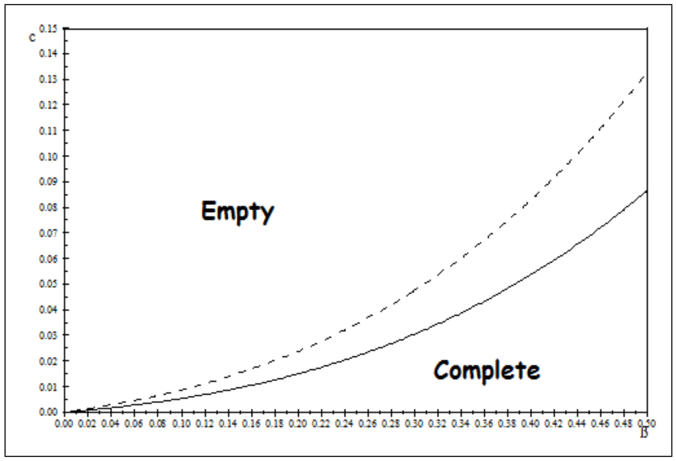
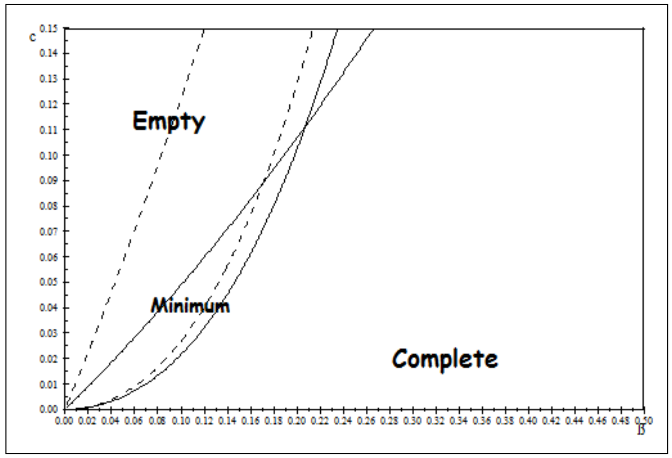


Fig 3.2: Equilibrium vs. Efficient Networks in Partnership, Similar Talent

Note that in the area between the dashed and the thin line, the empty network is an equilibrium but the complete network is socially optimal: there is also a tendency to underinvest in links with respect to the social optimum network.

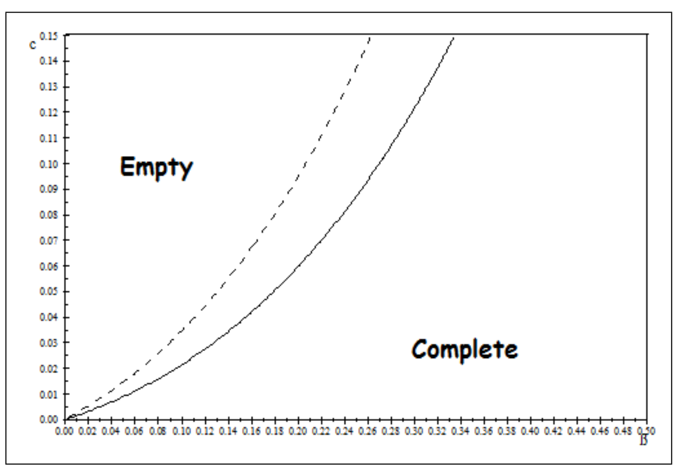
Comparing fig. 3.1 and 3.2, we observe that under partnership equally talented agents ($a_1 = a_2 = a_3 = 1/3$) have less incentives to invest in links than agents with very different productivities ($a_1 = 1$, $a_2 = a_3 = 0$). That is, if we have two teams with the same number of members and overall productivity, one with high dispersion in productivities and the other with equally talented agents, the latter is less likely to work in teams. The intuition is that under partnership it is less valuable a collaboration if the agents have the same capabilities.

Lider case (a=2)



Observe that the pattern of curves is similar to the fig. 3.1 (lider case, $a = 1$). The difference is that the minimum and the complete network are NE in more cases than before. Because the productivity of the lider is higher, the agents are more willing to invest in links.

Similar talent (a=2/3)



Note that, compared to fig. 3.2, the complete network is equilibrium in more cases because all the agents are more productive (recall that they have the same abilities).

3.3 Individual production is observable (pay-per-production rule)

In this section, we will consider the case in which the team can observe not only total production but also individual production. Although not realistic, we develop this case as a benchmark because it is desirable to pay each agent exactly the value of his contribution to total production. This is the pay-per-production rule:

$$s_i\left(x_i\left(e_i, e_{-i}, g\right)\right) = tx_i\left(e_i, e_{-i}, g\right)$$

The utility of agent i associated with this rule is:

$$u_i\left(e_i, e_{-i}, g\right) = tx_i\left(e_i, e_{-i}, g\right) - \frac{b}{2}e_i^2 - cn_i \tag{3.5}$$

Solving for the optimal levels of effort and production, we have:

$$e_i^* = t\frac{a_i}{b} \tag{3.6}$$

$$x_i^* = t\frac{a_i^2}{b} + t\beta\left(g_{ij} + \beta g_{ik}g_{kj}\right)\frac{a_j^2}{b} + t\beta\left(g_{ik} + \beta g_{ij}g_{jk}\right)\frac{a_k^2}{b} \tag{3.7}$$

Note that $e_i^* < e_i^s$ and $x_i^* < x_i^s$. Both the pay-per-production and the partnership rules do not implement the socially optimal level of effort. This result is general: in fact, it is well known from the literature of incentives in teams that there is no sharing rule in which agents privately choose (3.4) and the balance constraint $\sum_{i=1}^{3} s_i = tx$ is satisfied (Holmstrom, 1982).

By backward induction, we replace (3.6) and (3.7) in the utility function of agent i (3.5) to get:

$$u_i^*\left(g_i, g_{-i}\right) = t^2 \frac{a_i^2}{2b} + t^2 \beta \left(g_{ij} + \beta g_{ik} g_{kj}\right) \frac{a_j^2}{b} + t^2 \beta \left(g_{ik} + \beta g_{ij} g_{jk}\right) \frac{a_k^2}{b} - c \sum_{j=1}^{3} g_{ij}$$

We calculate the utilities of firms in any type of network:

Table 3.2: Expected utilities of agents, pay-per-production

Network	Agent 1	Agent 2	Agent 3
	$\frac{t^2}{b}\left(\frac{1}{2}a_1^2\right)$	$\frac{t^2}{b}\left(\frac{1}{2}a_2^2\right)$	$\frac{t^2}{b}\left(\frac{1}{2}a_3^2\right)$
	$t^2 \frac{a_1^2}{2b} + t^2 \beta \frac{a_2^2}{b} - c$	$t^2 \frac{a_2^2}{2b} + t^2 \beta \frac{a_1^2}{b} - c$	$t^2 \frac{a_3^2}{2b}$
	$t^2 \frac{a_1^2}{2b} + t^2 \beta \frac{a_2^2}{b} + t^2 \beta \frac{a_3^2}{b} - 2c$	$t^2 \frac{a_2^2}{2b} + t^2 \beta \frac{a_1^2}{b} + t^2 \beta^2 \frac{a_3^2}{b} - c$	$t^2 \frac{a_3^2}{2b} + t^2 \beta \frac{a_1^2}{b} + t^2 \beta^2 \frac{a_2^2}{b} - c$
	$t^2 \frac{a_1^2}{2b} + t^2 \beta(1+\beta) \frac{a_2^2}{b} + t^2 \beta(1+\beta) \frac{a_3^2}{b} - 2c$	$t^2 \frac{a_2^2}{2b} + t^2 \beta(1+\beta) \frac{a_1^2}{b} + t^2 \beta(1+\beta) \frac{a_3^2}{b} - 2c$	$t^2 \frac{a_3^2}{2b} + t^2 \beta(1+\beta) \frac{a_1^2}{b} + t^2 \beta(1+\beta) \frac{a_2^2}{b} - 2c$

Proposition 3.2 *If agents have the same productivity $a_1 = a_2 = a_3 = a$, under a pay-per-production rule the NE network is the complete network if $k^* \geq c$ and the empty network if $k^* < c$, where:*

$$k^* = \frac{a^2 t^2}{b} \beta \left(1 + \beta\right)$$

Proof. Similar to proposition 3.1 ∎

Lider case (a=1)

The NE is the empty network. A link is not valuable for the lider because the other agents contribute nothing to the production of the lider.

The consecuence of a pay-per-production rule is that agents only care about their own production, which may be not socially optimal. To see this, we graph the socially optimal networks:

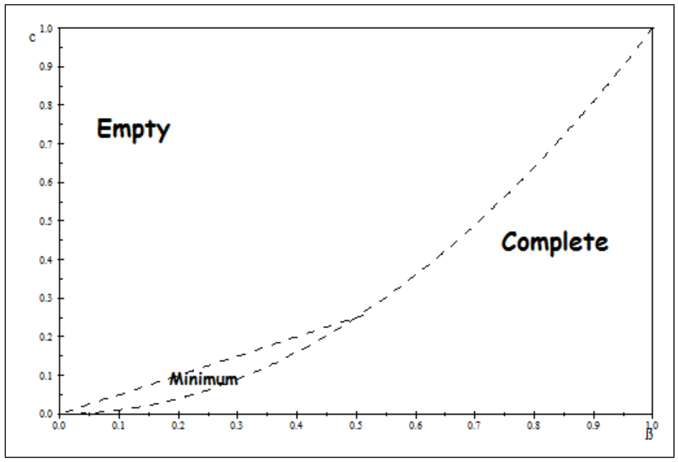


Fig 3.3: Equilibrium vs. Efficient Networks in Pay-Per-Productivity, Lider Case

Observe that both the minimum and the complete network can be socially optimal. The reason is that for agents 2 and 3 a link with the lider is valuable because it increases their individual production and benefits (although it is not convenient for the lider to form links).

Similar talent (a=1/3)

We graph together the NE networks (separated with the thin line) with the socially optimal networks (separated with the dashed line):

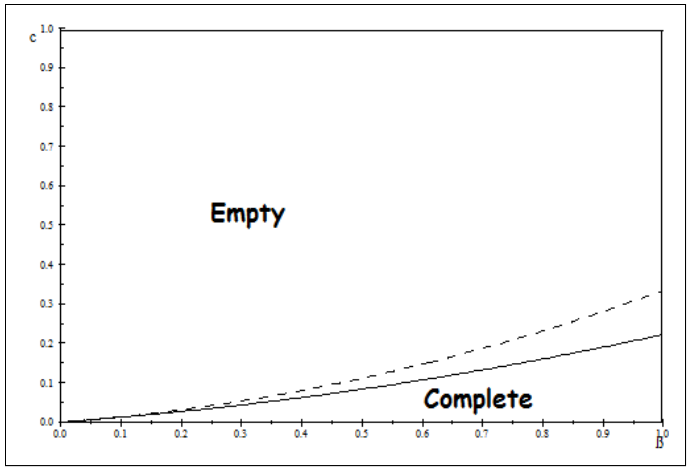
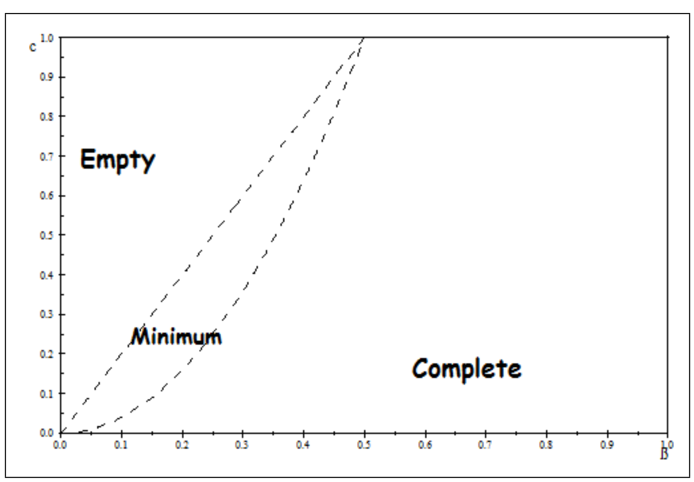


Fig 3.4: Equilibrium vs. Efficient Networks in Pay-Per-Productivity, Similar Talent

Comparing fig. 3.2 and 3.4, we note that agents with similar talent ($a_1 = a_2 = a_3 = 1/3$) work more in teams under partnership than under a pay-per-production rule.

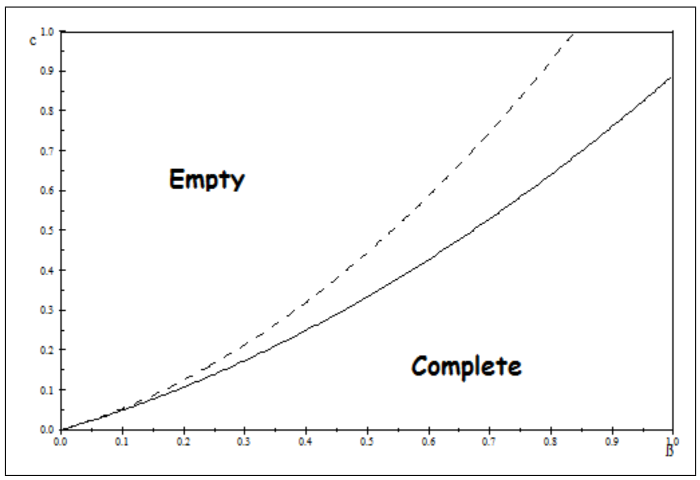
Also, observe that under a pay-per-production rule, agents with similar talent ($a_1 = a_2 = a_3 = 1/3$) work more in teams than agents with high differences in productivities ($a_1 = 1$, $a_2 = a_3 = 0$). This result is the opposite of the partnership rule.

Lider case (a=2)



Observe that the pattern of curves is similar to the fig. 3.3 (lider case, $a = 1$). The difference is that the minimum and the complete network are equilibrium in more cases than before. Then, as the productivity of the lider rises, the agents invest more in links.

Similar talent (a=2/3)



Note that, compared to fig. 3.4, the complete network is equilibrium in more cases because all the agents are more productive (they have the same abilities).

In summary, relative productivities of agents are very important for the structure of networks and levels of production in equilibrium. Comparing the different graphs, we observe that:

1) *In the case in which individual production is not observable (partnership rule), agents tend to work more in teams than the case in which individual production is observable (pay-per-production rule).* The reason is that under partnership the more productive members are interested in increasing the production of the less productive members.

2) On the other hand, suppose two teams with the same number of members, one

with high dispersion in productivities and the other in which all agents are equally talented. Assume that the overall productivity of these teams is the same. *In the case in which individual production is not observable (partnership rule), agents with similar productivities tend to work less in teams than agents with high dispersion in productivities.* The intuition is that under partnership it is less valuable a collaboration for agents with similar talents. This result is reversed when individual production is observable and agents work under a pay-per-production rule: in this case agents with high dispersion in productivities are more reluctant to work in teams.

Farrell and Scotchmer (1988) develop a cooperative game of team formation with partnerships. In their model, there can be many teams and the enhancement of member's production depends only on team size They find that if the distribution of abilities is simetric, the core consists of larger groups with more able agents and smaller groups with less productive agents. In our paper, the enhancement of member's production depends on the externality in the production function generated by a connection. We are not interested on team size but on the structure of interactions made inside a team.

3.4 Analysis

In this chapter, we analyze the influence of the structure of interactions in self-organized teams (academics, law, accounting, sports) on individual levels of effort and production. Traditionally, the literature analyzes the optimal contract under moral hazard and adverse selection. But in teams without a principal, the agents organize the tasks and roles and the structure of these interactions becomes important because they shape individual levels of effort and production. Several factors influence these interactions: the productivities of the agents, the disutility of the effort, the sinergy between the agents and the value of team production.

To analyze this hypothesis, we develop a two-stage game of network formation. In the first stage agents organize tasks, which results in a pattern of mutual interactions (network). In the second stage, given the network and the sharing rule, agents decide non cooperatively the level of effort. We study the equilibrium networks and optimal levels of effort for the case in which individual production is not observable (agents use a partnership rule) and the case in which individual production is observable (agents use a pay-per-production rule).

The results show that relative abilities (productivities) of agents are very important for the structure of networks and levels of production in equilibrium. In particular, *in the case in which individual production is not observable (partnership rule), agents tend to work more in teams than the case in which individual production is observable (pay-per-production rule).* The reason is that under partnership the more productive members are interested in increasing the production of the less productive members.

On the other hand, suppose two teams with the same number of members, one with high dispersion in productivities and the other in which all agents are equally talented. Assume that the average productivity of both teams is the same. *In the case in which individual production is not observable (partnership rule), agents with similar productivities tend to work less in teams than agents with high dispersion in productivities.* The intuition is that under partnership it is less valuable a collaboration for agents with similar talents. This result is reversed when individual production is observable and agents work under a pay-per-production rule: in this case agents with high dispersion in productivities are more reluctant to work in teams.

Finally, it is important to note that we assume that the costs associated with the decision making process (the cost of links) are not dependant on the identity of the agents. It would be interesting as a further step to investigate the case in which these costs differ. More generally, we may allow the possibility of side payments in which agents negotiate the bearing of the cost. It remains as future work.

3.5 Appendix

A. Nash-Equilibrium networks, unobservable individual production, same productivities

Proposition 3.1: *Under a partneship rule, if agents have the same productivity, the Nash-Equilibrium network is the complete network if* $k^p \geq c$ *and the empty network if* $k^p < c$*, where*:

$$k^p = \frac{a^2t^2}{b}\beta\left(\frac{17}{18}\beta^3 + \frac{17}{9}\beta^2 + \frac{23}{18}\beta + \frac{1}{3}\right)$$

Proof. Starting from $c = 0$, the *marginal benefit* of having two links in the complete network is, working with the utilities of the case $a_1 = a_2 = a_3$:

$$k^p = \frac{a^2t^2}{b}\beta\left(\frac{17}{18}\beta^3 + \frac{17}{9}\beta^2 + \frac{23}{18}\beta + \frac{1}{3}\right)$$

Note that the marginal benefit is higher if the team parameter and the productivity parameter are higher, and the disutility of effort is lower.

Also, the benefit of having two links versus none in the complete network is:

$$k^+ = \frac{a^2t^2}{b}\beta\left(\frac{5}{9}\beta^3 + \frac{10}{9}\beta^2 + \beta + \frac{1}{3}\right)$$

Note that $k^+ < k^*$. Start rising c. When $c = k^+$ the three agents simultaneously wish to cut two links. Suppose they agree that agent 1 will cut his links. In this case, the marginal benefit of agents 2 and 3 of having a link together is:

$$\widetilde{k^p} = \frac{a^2t^2}{b}\beta\left(\frac{1}{6}\beta + \frac{1}{3}\right) < k^+$$

Then, both 2 and 3 have incentives to cut their link and the equilibrium is the empty network.

In summary, if $k^p \geq c$ the NE network is the complete network, and if $k^p < c$ the NE network is the empty network. ■

CHAPTER 4

Conclusion

Network structures are important in the organization of some significant economic relationships in which *the transactions are not anonymous*, i.e. agents are "linked" by specific comercial, technological, financial and social relationships. For example, personal contacts play critical roles in obtaining information about job, business and finance opportunities (Bala and Goyal, 2000) or firms sign collaborative agreements in R&D (Goyal and Moraga, 2001) and market-sharing (Belleflamme and Bloch, 2004).

In this thesis, we analyze two economic problems using *network theory*. The second chapter is devoted to the study of the hold-up problem in outsourcing industries. Typically, in automobiles, semiconductors and software, companies and suppliers of inputs jointly invest in specific assets and develop outsourcing relationships before making transactions. In industries with uncertainty in final demand there is the possibility of hold-up. Unlike vertical integration, outsourcing allow firms to reduce aggregate business risk and catch-up faster. Nevertheless, there is no theoretical analysis of the *structure* of outsourcing relations and the hold-up problem.

The second chapter analyzes this issue using network theory (Kranton and Minehart, 2001; Elliott, 2010). Our hypothesis is that more outsourcing relations generate more alternatives for transactions and increase outside option values. As a result, the bargaining power of different groups is equalized and the possibility of opportunistic behaviour is reduced. We model joint investments in specific assets as links between companies and suppliers. After investments in links are made, companies and suppliers negotiate bilateral transactions over the forming network. Using a cooperative framework to simplify the analysis of the bargaining stage, we find that there is a unique pairwise-stable matching characterized by a Nash-Bargaining process in which all firms receive at least their outside-option value in a transaction. Then, we calculate the optimal network structures and compared with the social optimum.

The results show that the hold-up problem is less severe (firms invest in the social optimum network) when companies and suppliers share more evenly the cost of investments and when there are no exogenous asymmetries in bargaining power. Other important factors are the relative number of companies and suppliers and the way in which firms model uncertainty.

With this framework, we capture interesting aspects of the outsourcing industries: i) that firms invest in a context of uncertainty; ii) that the way in which companies and suppliers fund the investments or external asymmetries in negotiation are important; and iv) that both companies and suppliers increase the value of their outside-options through relationships with many partners. There is a strategic motivation of firms to invest in links: improve their bargaining position in a network. When the network has many links, as in the japanese automobile industry, the bargaining power of different group is equalized and reduces the possibility of oportunistic behaviour.

In the third chapter, we analyze the influence of the structure of interactions in self-organized teams (academics, law, accounting, sports) on individual levels of effort and production. Traditionally, the literature analyzes the optimal contract under moral hazard and adverse selection. But in teams without a principal, the agents organize the tasks and roles and the structure of these interactions becomes important to achieve higher levels of production. Several factors influence these interactions: the productivities of the agents, the disutility of the effort, the sinergy between the agents and the value of team production.

To analyze this hypothesis, we develop a two-stage game of network formation. In the first stage agents organize tasks, which results in a pattern of mutual interactions (network). In the second stage, given the network, agents decide non cooperatively the level of effort. We study the equilibrium networks and optimal levels of effort for two cases: i) the case in which individual production is not observable and agents use a partnership rule; and ii) the case in which individual production is observable and agents use a pay-per-production rule.

The results show that relative abilities (productivities) of agents are very important for the structure of networks and levels of production in equilibrium. In particular, *in the case in which individual production is not observable (partnership rule), agents tend to work more in teams than the case in which individual production is observable (pay-per-production rule).* The reason is that under partnership the more productive members are interested in increasing the production of the less productive members.

On the other hand, suppose two teams with the same number of members, one with high dispersion in productivities and the other in which all agents are equally talented. Assume that the average productivity of both teams is the same. *In the case in which individual production is not observable (partnership rule), agents with similar productivities* *tend to work less in teams than agents with high dispersion in productivities.* The intuition is that under partnership it is less valuable a collaboration for agents with similar talents. This result is reversed when individual production is observable and agents work under a pay-per-production rule: in this case agents with high dispersion in productivities are more reluctant to work in teams.

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