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SUPPLIER-BUYER NETWORKS AND BUYER'S INNOVATION

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INTRODUCTION

The primary aim of the research project is to explore the effects of a firm's network of vertical relationships on innovation. Specifically, the research focuses on the causal relation between the supplier's network of ties (with buyers and suppliers) and the buyer's innovation output.

In this context, from a social network perspective, I basically prove that ego's innovation is affected by alters' alters in a manner that is contingent on some factors. The contingencies analyzed are the type of nodes involved in indirect ties (with reference to their role in the supply chain: suppliers or buyers) and the strength of the ties (based on the type of relationships, i.e. arm's length ties or alliances or both). Therefore, the study analyzes a multiplex network, with multiple types of edges and nodes.

The addressed research problem investigates whether and how the *characteristics of the supplier's network affect the buyer's innovation output*. I examine two research questions: (1) *What effect does supplier's centrality in its network of buyers and suppliers have on buyer's innovation output?* (2) *What is the effect of the strength of the ties in the supplier's network on buyer's innovation output?*

This perspective can open a novel pathway in social network literature, in fact the research enriches under-explored topics in social network literature in the following ways.

First, while prior research in the field mainly focused on the effect of horizontal collaborative relationships on firm innovation, the study analyzes vertical relationships.

Second, while prior research only highlighted the benefits of indirect ties, the work introduces a contingent approach to evaluate the effect of indirect ties, which is not always positive. The commonly acknowledged conclusion that selecting alters with many other partners is a good mechanism to follow is called into question. It turns out that the type of actors involved in indirect ties is the discriminating factor.

Third, the research distinguishes between the collaborative and the competitive dimension of a supplier-buyer network, depending on the presence of suppliers or buyers as alters' alters, stressing the concept of supplier mediated cooperation/competition and of the direction of knowledge flow (trade-off between inflow/outflow of knowledge) in the context of indirect ties. The buyers indirectly linked through the same supplier compete for the use of innovation that is often exclusive while indirectly cooperating to contribute to building a common knowledge base and the competences of the supplier. The dynamics of competition in the network were largely under-examined in relation to the innovation output. While the network approach focused mainly on the creation of value through win/win benefits based on exchange and pooling competencies, the research tries to enrich one under-explored line of investigation, that which reverses the usual logic of social capital and examines the negative consequences of social capital, the so-called "dark side".

Fourth, the work contributes to the debate on the trade-off between strong and weak ties, in place among network scholars: the effects of tie strength (depending on the type of tie) on the innovation output is shown to be contingent on the context (e.g., competition for information).

Finally, by using a multiplex network, the study tries to provide answers to the emerging need in social network analysis to enrich the analyses with more complex modelling constructs. It sets up the grounds for the study of multiplexity.

The theoretical contribution derives from the integration and extension of *network theory, supplier-buyer relationships literature,* and *transaction costs economics.*

First, bridging *network theory* and *supplier-buyer relationship literature* is useful in integrating in a single framework the concepts of *relational embeddedness* and *structural embeddedness* in a context of vertical ties, in fact to build my theoretical framework, I rely on both a relational and a positional approach. This also implies an extension of the supplier-buyer relationship literature through the introduction of network-level characteristics for supplier selection and the concept of the supplier as a strategic broker through which proprietary knowledge can potentially flow. In fact, in that literature innovation output has been traced back to firm-level technical capabilities and supplier dyadic relationships.

Second, the adoption of two perspectives, *network theory*, particularly *social capital theory*, and *transaction cost economics*, and their interplay in the study of supply relationships, provide new insights on the drivers of actors' payoff focusing both on knowledge sharing and opportunistic threat. The mechanism underlying the hypotheses is basically the trade-off between benefits from positive knowledge leakage

(flow of knowledge from the network to the ego) and opportunistic threats from negative knowledge spillover (flow of knowledge from the ego to the network) in a context of indirect ties. The thesis deepen the understanding of suppliers' network characteristics, favoring the positive leakiness and positive stickiness for the focal buyer and, consequently, spurring buyers' innovation output. This is in line with TCE, according to which collaborative efficiency and efficacy is assumed to be achieved on the part of the firm when the firm can limit its partner's opportunistic behavior. The advice is to be suspicious of one's own partners and of the results of collaborative arrangements.

Finally, with respect to innovation, the theoretical framework stresses that there is a trade-off between generation and appropriability of knowledge. While knowledge is inherently a public good, innovation output in the form of a patent is private. The work refer to the innovation function and particularly to the spillover and congestion effects.

As for this study's contribution to managerial practice, it is important to point out that the research problem addressed in the thesis is "grounded in reality". "Deconstructed" firms are emerging and rebuilding value chains is becoming a fundamental strategic tool, accordingly, the focus on vertical relations characteristics is of greater significance. There is significant evidence that many companies view building partnerships in this critical vertical dimension of the value chain (from simple purchasing to joint research and development and sharing of strategic information) as crucial to their success (e.g. Gulati, 2005). Even in a traditional supply tie there can be different types of exchange such as product exchange, information exchange, and social exchange. The supplier's selection should no longer be based only on firm-level characteristics (e.g., technical capabilities) or on dyadic supplier-buyer relationship characteristics but also on the suppliers' network of ties.

CHAPTER II - Conceptual framework and Literature

The topic is at the confluence of two lines of research: network theory and supplier-buyer relationships literature. To build a theoretical framework for my hypotheses, I also rely on transaction-costs economics and research on competition. These theories have provided two competing ways of looking at networks; according to TCE, networks are a form of organization through which assets are allocated and transactions are governed, whereas according to network theory (particularly, social capital theory), they are a conduit of resources and information, with an emphasis on social aspects and collaboration.

I shortly report the main conclusions deriving from the literature review, that are the input for the subsequent hypotheses development.

Network Theory

Network research presents two streams of works: works assuming a structuralist perspective and works adopting a connectionist perspective (Borgatti & Foster, 2003). The structuralist paradigm maintains that actors can exploit their positions in the network to maximize gain, and it centers on the concepts of power and influence. The connectionist approach looks at the interpersonal transmission process that occurs in social ties; using micro-mechanisms, it focuses on the content of the relation and on the resources that flow through it (Stinchcombe, 1990; Gulati, 1999).

When the aim of the analysis is the understanding of the network configuration that is more suitable for knowledge gathering, it is natural to overlap the two perspectives explained above, referring to *structural capital* and to *social capital*. However, as an intrinsic issue, given that the *structure* is just a proxy of the *content* of the ties, some positive or negative mechanisms can be just inferred. Hence, in the network literature, several trade-offs and debates are still in place (e.g., the strength of strong vs weak ties). To infer a definite causal relationship between some networking/nodal characteristics and the node's performance or innovation output a *contingent approach* is needed, and in this field, some aspects have not been covered by the existing literature.

In particular, vertical ties are rarely considered in the pure network literature; a contingent approach to evaluate the effects of indirect ties is never assumed. A contingent approach to assess the effects of structural holes has already been adopted (Ahuja, 2000). On the contrary, little is known about whether, why, and how network architectures that differ in the strength of their ties can exert different impacts on the innovative capability of the lead firm in a network (Capaldo, 2007). Relational and structural embeddedness could be joined together. Firms may be connected through a multitude of connections,

each of which could be a social network, and researchers have rarely focused on more than one network at a time (Gulati & Gargiulo, 1999), this field should be further developed. Under-examined lines of investigation are also the one which examines the negative consequences of social capital, the so-called "dark side", and the one that examines the dynamics of collaboration and competition in the network.

Supplier-Buyer Ties Literature

Shapiro (1985) considers "purchasing as a conduit for innovation to take advantage of the best design concepts and technical expertise available". Ellram and Cooper (1990) discuss three types of purchasing relationships: arm's length, supportive, and coalitional. The buyer, in order to gain a competitive advantage, can exploit the contact points between its value chain and the supplier's value chain. A buyer can even operate simultaneously at multiple levels of collaboration with a given supplier, but this topic has received little attention in previous studies. In the literature on supplier-buyer relationships, a causal relationship has been established between innovation output and two main aspects: *supplier selection*, underlining the firm's technical characteristics , and *supplier relationship development and adaptation*, focusing on the dyadic dimension. Some scholars have advocated the opportunity to introduce the concept of embeddedness in the overall network in this field. The literature has never emphasized the supplier's intrinsic role as a gatekeeper and a strategic broker among buyers and other suppliers. A contingent approach could be applied to evaluate this role, depending on the context, as cooperative or competitive.

TCE

TCE's central idea of the existence of two extremes, market and hierarchy, as governance mechanisms of the economic activity, is a reference point to organize a framework for the analysis of networks and alliances. The theory highlights the need to consider the cost-minimizing, competitive, and profitability aims even in the context of linkages and emphasizes the risky side of collaboration. The main constructs used in the theory are bounded rationality and opportunism.

Collaborative efficiency and efficacy are assumed to be achieved when the firm can limit its partners' opportunistic behaviors. The goal is not only to "create the positive" but also to "avoid the negative." This assumption is antithetical to the approaches that emphasize social considerations. Basically, TCE neglects the generation of new areas of value in a transaction, the aspects of effective learning between firms, of trust; it ignores the differences in firms' capabilities. When Williamson presented vertical integration as a preferable solution, he paid no attention to the production costs that are also a function of a firm's capabilities. TCE considers many facets, such as capabilities and knowledge to be given exogenously (Noteboom, 1992). Clearly, specific questions about how cooperative arrangements affect innovation have been under-examined. In the end, TCE focuses on the allocation of resources. This is not satisfying; however, this shows that TCE must be included in any study on innovation that would consider the exploitation of the new idea and not just the generation of it. Later theorists have identified further potential in marrying the two perspectives of networks and TCE (Blumberg, 2001; Jones, Hesterly, & Borgatti, 1997). An important remark is that when adding a network perspective, transaction costs for a node are a function of the attributes of the other transactions of its partners.

Competition and Cooperation

There is an inherent dilemma between a firm's competitive aims and its cooperative means. The starting point of the analysis is that collaborative agreements alter the competitiveness of the partners and that competition alters the cooperative dynamics inside a network of ties. The topic of the coexistence and interplay of collaboration and competition in shaping firms' payoff spans different streams of research, and it is central in the "coopetition" approach. This perspective primarily seeks to join the value-creation and value-sharing processes in firms' interdependences (Dagnino & Rocco, 2009).

Even if competition occurs between two parties, each party is involved in multiple forms of cooperation. In a collaboration network, firms are often engaged in close but not exclusive relations with other companies. Therefore, the unit of analysis of competition is shifted, in some way, from the firm to the ties; competition does not occur on a firm-to-firm basis but rather among different alliances, on a project-by-project basis. In the end, networks also compete with one another.

From industrial organization we know that the more the situation seems monopoly-like, the better the prospects of appropriation of the value are. From RBV we derive that the greater the ownership of a scarce resource, the higher the appropriation. In the thesis I try to consider the first view by introducing the

number of relationships (centrality in the network) and the second view by introducing the strength of relationship (determining the level of idiosyncratic assets).

Since the TCE and social capital approaches are both incomplete, I adopt a more balanced alternative for studying inter-organizational relationships by integrating the two perspectives. This perspective will also shed light on cooperation and competition dynamics.

CHAPTER III - Hypotheses Development

Network models have been proposed mainly through two analytical approaches, differing in the frame of reference with which an actor is analyzed (Burt, 1982): the relational and the positional approaches. In a *relational approach*, network models analyze the intensity of relationships between pairs of actors. The *positional approach* describes the patterns of relations defining an actor's position in a system of actors (Burt, 1982). My propositions and hypotheses development is built on both, analyzing the position of a node going beyond its ego-network and the role of centrality (positional perspective) as well as considering the strength of the relationships in which it is involved (relational perspective). The interaction of these two approaches will be applied, considering also the different outcomes in a cooperative and in a competitive context. In fact, from Burt's (1982) "structural theory of action," we know that actors jointly occupying a position and, therefore, pursuing similar structural interests can realize their common interests to the extent that their relational patterns ensure low competition with one other. Therefore, I introduce the competitive element into the picture and explore how the relational approach helps in solving this structural equivalence issue inherent in the positional approach.

I adopt a positional network approach to postulate two main effects regarding the impact of the supplier's network centrality on the buyer's innovation output. Supplier's centrality in a network of suppliers has a positive impact on the buyer's innovative performance, while supplier's centrality in a network of buyers has a negative influence. This suggests that the effect of centrality in a network is dependent on the type of nodes involved in the indirect ties. Then, I adopt a relational network approach to argue that these two main effects are moderated by the strength of the ties in the direct relationships. The strength of the focal buyer-supply tie negatively moderates the first main effect while the relative strength of the focal buyer-supplier tie versus the strength of supplier-other buyers ties positively moderates the second main effect. In this way, I find support for the strength of weak ties in a collaborative context and for the strength of strong ties in a competitive context, where the actors compete for the information and for the exploitation of the innovation.

To improve clarity, I include below a schematic illustration of the analytical framework of the research (Fig 1). The model postulates that the buyer's innovation output is a function of the supplier's characteristics at the network level.

When analyzing a supplier's network, two fundamental distinctions are needed between:

1) Relationships involving the upstream or downstream side of the value chain, meaning that the supplier is linked to other suppliers or to buyers. This, in turn, means that the focal buyer is linked through the supplier (in the figure, *supplier_1*) to suppliers (*suppliers_2*) that are not competitors or to other buyers (*buyers_2*), which are competitors. The predictions of the effects of the supplier's network centrality on innovation in the two cases (in the figure, *collaborative side* and *competitive side*) constitute the main effects, summarized in hypotheses 1 and 3;

2) Relationships characterized by different strength (measured here by the kind of tie: arm's-length ties, alliances, or both). This element constitutes the moderation effects, summarized in hypotheses 2 and 4, altering the intensity of the main effects. In particular, while, on the cooperative side, only the strength at step 1 between buyer and supplier can be analyzed to infer a given impact on innovation, on the competitive side, the relative strength of the tie between the focal buyer and *supplier_1* versus the ties between *supplier_1* and *buyer_2* must be considered, owing to a context of competition.

Drawing on this basis, I will develop four hypotheses, two about main effects and two about moderation.
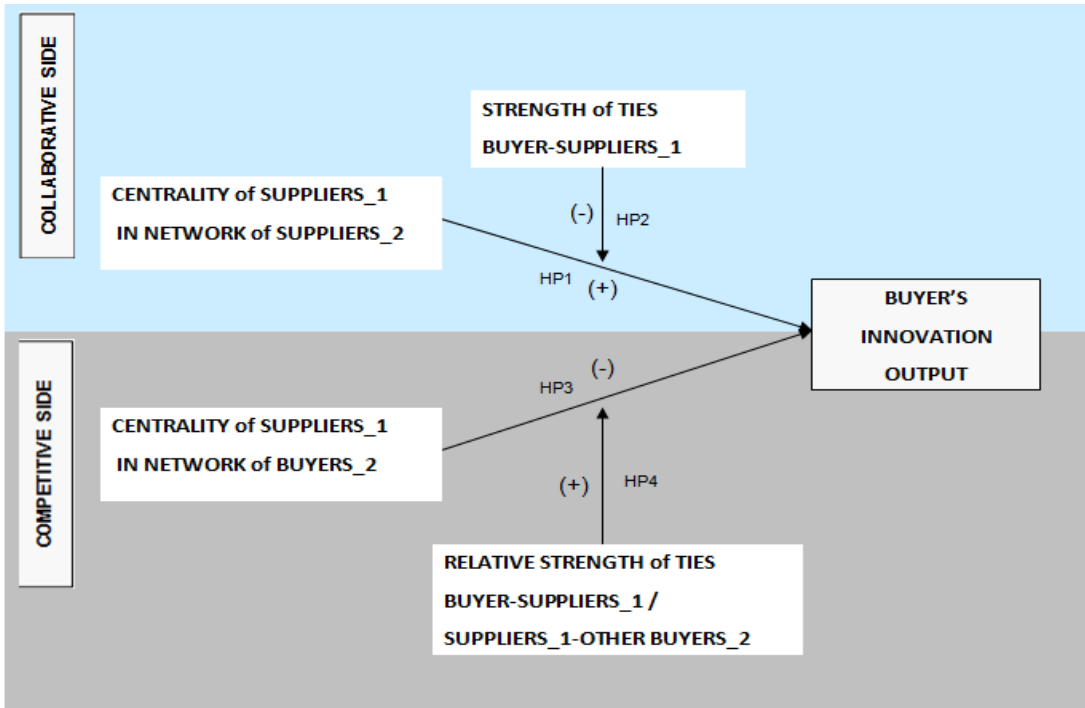
Fig 1. The model

The line of reasoning behind the theoretical framework and each hypothesis is presented next.

Starting with a focal buyer firm, I consider its suppliers and how each supplier's network of ties affects the focal buyer's innovation (see Fig.2). The center of the network is the focal buyer; suppliers are linked directly to it, and through these suppliers, the focal buyer is linked indirectly to other suppliers or buyers. All the ties in the network involve buyers and suppliers, and they can be supply agreements, alliances, or both. The horizontal ties between two buyers are considered in the model but as a control variable.
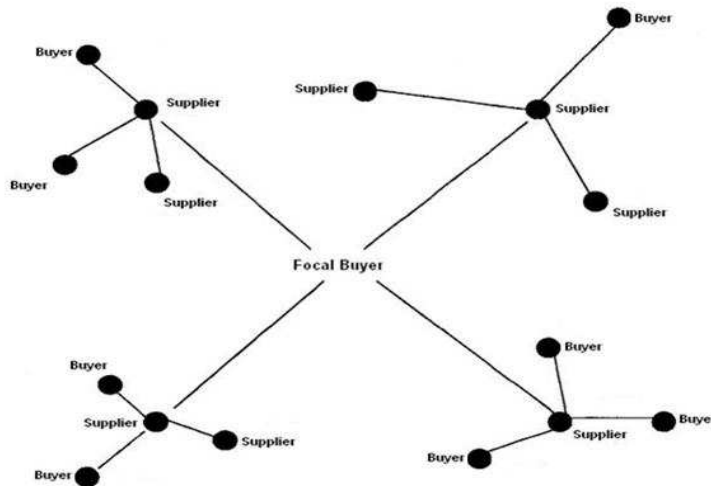

Fig 2. The network

All these relationships involve a knowledge flow, though they may vary in intensity. Since I am interested in studying the impact of these inter-firm ties on firm innovation performance, I need to investigate the dynamics of knowledge flow through the ties and to analyze the innovation production function.

Knowledge is a fluid and portable good; it is difficult to make it exclusive or to completely control it; it is intrinsically a public good. Knowledge continuously escapes from the entities producing it; thus, it can be used freely by rivals (Foray, 2004). This explains why inter-firm ties, as conduits of knowledge, can be both beneficial (through the incoming flow) and detrimental (through the outgoing flow) for innovation output.

5

Firms face the challenge of managing incoming and outgoing knowledge flows (positive and negative leakiness) simultaneously. The point is also that, while knowledge is inherently, to a large extent, a public good, innovation output tends to be a private good through intellectual property rights application. This dichotomy makes it difficult to determine ex-ante the impact of inter-firm collaboration on firm innovation performance.

In conclusion, it is likely that, in the context of inter-firm collaboration, three processes take place. First, a firm can benefit from external knowledge. Second, it can be damaged by the negative spillovers of its own knowledge to alters. Finally, it is in competition with alters for the exploitation of knowledge through innovation patenting. These three elements are the core of the innovation production function: knowledge capital, spillovers, and congestion.

The model of the innovation production function from the literature on innovation and technological change can be represented as: $I = f(R\&D, HK)$

where I stands for the degree of innovative activity, $R\&D$ represents R&D inputs, and HK represents human capital inputs (Audretsch & Feldman, 2004).

Given this general form, I refer in particular to the innovation production function formulated by Romer (1990) where innovation is a function of R&D, spillovers, and congestion.

(1) $\quad A = \overline{\delta} L_A \quad$ where (2) $\quad \overline{\delta} = \delta A^\phi L_A^{\lambda-1}$, therefore (3) $\quad A = \delta A^\phi L_A^\lambda$

(1) Innovation (new ideas over time): A is a function of labor inputs L_A and the average research productivity, the rate at which an individual researcher discovers new ideas, $\overline{\delta}$. (2) This rate is modeled, in turn, as a function of the existing stock of knowledge/ideas, A; a "spillover" parameter, ϕ; and a "congestion" parameter, λ. (3) Finally, the number of new ideas at any given point in time depends on the existing stock of knowledge available and on the number of researchers according to the following dynamics: (1) positive or negative spillovers from existing knowledge, so a high A might increase or reduce $\overline{\delta}$; (2) congestion effects: if more people do research competitively, efforts might be duplicated or wasted; higher L_A might reduce $\overline{\delta}$ for all the researchers.

Focusing on a firm, I can rewrite the formula as follows: $A_{FIRM} = \delta (A_{INT} + A_{EXT})^\phi L_A^\lambda$

where A_{INT} is the existing knowledge inside the organization; Incremental innovation will naturally come up, drawing upon past knowledge, and path dependency also occurs. A_{EXT} is the knowledge derived from its inter-firm ties: from relationships with other firms through collaboration and knowledge sharing or through knowledge flow in the form of spillovers. The external knowledge can be further decomposed in the stock of knowledge owned by the individual firms and in the knowledge created in the interactions in the relationships themselves: $A_{FIRM} = \delta (A_{INT} + A_{EXT-FIRMS} + A_{EXT-INTERACTION})^\phi L_A^\lambda$.

(a) A^ϕ component in the supply network context

The stock of knowledge available to a focal node in a network, A, is the result of two main categories of processes: *exchange processes* and *adaptation processes* (Forsgren, Hagg, Hakansson, Johanson, & Mattsson, 1995). Exchange increases the value of each party (Alderson & Martin, 1965; Bagozzi, 1974) and it is often considered the core of business relationships. In particular, the exchange processes can be substantiated in three types of exchange: *product exchange, information exchange,* and *social exchange* (Cook & Emerson, 1978; Håkansson, 1982). In all exchanges between two firms, there are elements of all three aspects of exchange. Thus, in product exchange, there is also an element of information exchange and social exchange. This means that the supply ties also convey a form of knowledge from one party to another. *Adaptation processes* imply an effort of the parties to meet mutual needs. Adaptations strengthen the bonds between the firms, the firms become increasingly dependent on each other, with higher switching costs, i.e. relation-specific investments. This implies higher commitment; in turn, this is an incentive to share information and behave on behalf of the other party. Generally, the exchange processes and the adaptation processes are highly correlated.

Knowledge spillovers, ϕ, can be defined as any original, valuable knowledge generated somewhere that becomes accessible to external agents (Foray, 2004). In the case of internal knowledge, the positive spillover effect means that current research productivity is positively affected by past research; negative spillover means that the most obvious ideas are discovered first and new ideas become harder to find (Abdih & Joutz, 2006). In the case of external knowledge, the positive spillover is the flow of knowledge into the firm, or positive leakiness, while negative spillover is the flow out of the firm to competitors, or negative leakiness.

(b) L_A^λ component in the supply network context
This component representing the *congestion* effect, captures the dependence of research productivity on the number of people searching for new ideas at a point in time. It is quite possible that the larger the number of people seeking ideas is, the more likely the occurrence of duplication in research will be. This notion of duplication in research placed in an inter-firm network is even more significant in the case of connections among different researchers that are competitors for the achievement of an idea or a patent and that can benefit from knowledge spillover through the ties. The congestion effect is higher when the parties are competing for patents with applications at the same level of the value chain.

In conclusion, basically I argue that knowledge flow in the network generates opportunities and threats for the parties, and I assert that the final innovation output for one party depends on its capability to respectively exploit or reduce them. This capability, in turn, is a function of certain characteristics of its network that I identify by adopting both a positional and a relational approach.
I argue that indirect ties in a network have a leverage effect on both opportunities and threats.
As for threats, while in a direct connection, the parties can safeguard against direct transmission of knowledge by establishing some rules and can protect themselves from the improper use and exploitation of the partner's knowledge, in an indirect connection, there will be intrinsically less control over knowledge transmission. Also, I am investigating the impact of network characteristics of a party (supplier) on the innovation of the other party (buyer). This means that the process must involve not just knowledge sharing or flow but also the voluntary behavior of the first party (supplier) to act on behalf of the second (buyer).
As for opportunities, of course the indirect contacts are a source of positive spillovers of a pool of knowledge and not just of a single company's knowledge. Moreover, they contribute to building the competences of the direct contacts. Also, the possibility of knowledge creation is multiplied by the potential synergies occurring in several different relationships.
Therefore, it is interesting to investigate knowledge flow dynamics in indirect ties and their impact on a firm's innovation. While many studies have established a causal relation between the centrality of a node and its innovation output, it is interesting to explore how the centrality of the partners of the node affects the node's innovation outcome. In conclusion, I predict the following three effects:

Proposition One: A supplier's centrality determines the incoming and outgoing knowledge flow between the buyer and the supplier's partners and, hence, affects the buyer's innovation output.

Proposition Two: A supplier's centrality has a positive effect on the focal buyer's innovation output to the extent that the context determines an *increase in positive leakiness and a reduction in negative leakiness* for the buyer. This means more available resources and fewer negative spillovers.

Proposition Three: The strength of the relationships enhances or reduces the effect of a supplier's centrality on the focal buyer's innovation depending on whether the context requires prevailingly *fostering positive leakiness or preventing negative leakiness*.

3.1 The collaborative dimension in buyer-supplier networks and knowledge-flow

In this paragraph, based on the collaborative side of the supplier-buyer network, I focus on the case in which the indirect nodes reached by the buyer through the supplier are not competitors, but other suppliers.
I predict that the supplier's centrality in its network of suppliers will enhance the buyer's innovation output, as measured by patenting frequency. Innovation depends on the knowledge flow to ego. The knowledge transfer from the alter (supplier) to the ego (buyer) and the other way around occurs through the contact points between the supplier's value chain and the buyer's value chain that provide several opportunities (Porter, 1985) or through an alliance tie with cooperation. In the first case, the buyer firm's inbound logistics share an interface with the supplier's order entry system, the supplier's applications engineering staff works with the buyer's technology development group, and the supplier's finished goods inventory is

linked to the buyer's work-in-process. In the second case, there is joint involvement in manufacturing or R&D. The knowledge flow extends beyond the direct tie. Therefore, the position of the supplier in its network matters.

I argue that, when the ego is a buyer and an alter that is a supplier is central among suppliers, positive knowledge leakage is enhanced and negative knowledge spillovers are reduced. As stated in proposition two, the occurrence of these two conditions will result in a positive effect of the alter's centrality on the ego's innovation output.

(a) Increase in positive leakage

The increase in positive leakage is determined by several mechanisms: the supplier's (1) gatekeeping role; (2) the availability of a wider pool of knowledge coming from the individual connected actors and from their interactions, i.e. technical embeddedness; (3) the increase in the supplier's capabilities; (4) the availability of better products; (5) the scale effect; (6) the exploitation of horizontal ties' benefits; and (7) the option of transitivity. I next examine them.

(1) The supplier assumes the role of *gatekeeper,* opening access to a wider network of suppliers. This is critical to importing information from the outside context and to linking the organization with its environment (Allen, 1977). Indirect ties provide access to knowledge even if they do not provide formal resource sharing benefits (as direct ties) (Ahuja, 2000).

(2) This structure allows reliance on a wider pool of product and process technologies during the innovation process, even if it is indirect. The additional knowledge capital comprises: the single knowledge of the supplier's contacts and the knowledge from the synergies achieved in the relationships with these contacts. The supplier benefits from a specific form of embeddedness: technical embeddedness, which is defined as the "interdependencies between firms in terms of their product and production development processes" (Andersson, Forsgren, & Holm, 2002). In these interdependencies in the supplier-supplier relationships, new valuable knowledge is likely to arise and this, in turn, can be transferred to the buyer.

(3) The process of knowledge accumulation will be higher on the part of the supplier, which will be, a more qualified partner with greater experience, better capabilities and competences, thanks to its relationships. Furthermore, considering that networks promote innovation indirectly by facilitating increased specialization and division of labor, which leads to more focused expertise development (Piore & Sabel, 1984; Saxenian, 1991), a supplier with a wider network can also benefit from this positive aspect.

(4) The greater knowledge will also be embedded in the supplier's products. They have a higher likelihood of incorporating the advancements present in components coming from a high number of different firms. These products will, in turn, be incorporated in the buyer's final product, leading to greater innovation.

(5) Having many indirect ties also allows a node to enjoy the benefits of network size without paying the costs of network maintenance associated with direct ties (Burt, 1992). The scale effect affects the transformation function *f* of the innovation function. Basically, if technology has increasing returns to scale, increases in inputs are rewarded with more than proportionate increases in output. The scale effect is more likely to arise in supplier-supplier relations (hence, when the supplier connected to the buyer is central among suppliers) because a precondition for increasing returns to scale is the collaboration between firms providing similar inputs.

(6) The supplier can have a supply tie, an alliance tie, or both with the other suppliers. This means that it will benefit both from horizontal and vertical ties, and these resources will, in turn, be advantageous for the buyer. A horizontal tie between two suppliers can be really advantageous in terms of R&D outcomes. This is evident also considering the increasing tendency of buyers in managing their supply chain by fostering linkage creation among their own direct suppliers.

(7) It is also possible that the buyer will have more possibilities to widen its suppliers' base, if needed. This is due to the transitivity phenomenon: if two organizations are linked to a common third party, there is an increased probability that they will establish a relationship. Therefore, the buyer could potentially benefit from the opportunity to identify suppliers of known quality easily, useful to increase its innovation output.

(b) Reduction in negative spillovers

The reduction in negative spillovers is determined by two main factors: the absence of competition and the the difference in the knowledge scope between the indirect partners.

First, the nodes linked through the indirect ties are located at a different level of the value chain, and they are not competitors. This means that the focal buyer benefits from the suppliers' deep specialization and, at the same time, does not experience the negative effect of competition in innovation or patent race. The patents of suppliers and buyers revolve around different knowledge applications. Also, the control of a particular market is a kind of complementary asset that is essential to the exploitation of an innovation (Foray, 2004). More specifically, the negative spillovers will be in place, but their exploitation is not likely to be harmful. It is true that these indirect suppliers can be, in turn, related to other buyers, thus having opportunities to exploit these spillovers, but the effect will be weaker, given that the path is longer.

Second, I argue that the detrimental exploitation of the buyer's negative spillovers is limited by the asymmetry in the knowledge scope between buyers and suppliers (that are indirect partners). The assembler's knowledge is at an aggregate level, so it is less exploitable by a supplier, which typically has specialized knowledge and consequently a low absorptive capacity of the buyer's knowledge.

For the aforementioned reasons, in the case examined, the externality is likely to be artificial. Although knowledge is diffused, the benefits associated with its implementation remain internal. Therefore I can assume a final positive effect on the innovation output.

HP 1: *The higher the supplier's centrality in the network of suppliers, the higher the buyer's innovation output*

I analyze how the impact of tie strength can amplify or reduce the main effect showed in the previous hypothesis. To increase the effect of the supplier's centrality in a network of suppliers on a buyer's innovation output, a further increase in positive leakage can be useful. I am considering here a cooperative context in which nodes indirectly linked to a motor vehicle company are not its competitors. The context requires more to foster positive knowledge leakage than to prevent the knowledge spillover. This, as stated in proposition three, helps in determining the influence of the strength of the ties.

(a) *No need to prevent negative knowledge spillovers. Consequences.*
From the TCE perspective, I derive the notion that a strong tie, as an alliance, functions mainly as a means to prevent the "negative," as a defense mechanism to tackle the problem of strategic uncertainty. I can argue that this strategic uncertainty is lower in the specific context considered here. Hennart (1988) stressed that an alliance is not successful if it cannot be transformed to help reduce behavioral uncertainty and consequential requirements for the sake of monitoring. Kogut (1988) demonstrated that high levels of uncertainty stimulate the formation of joint ventures when a firm's performance is critically affected. From this argument, I can conclude that there is no incentive to establish a strong tie.

(b) *Need to foster positive knowledge leakage. Consequences.*
Indirect relationships comprise two steps: one step from the ego to the alter (internal direct tie) and the other step from the alter to the alter's alters (external network). To enhance the positive knowledge leakage flowing from the network toward the ego, two mechanisms must occur: (1) the increase in the alter's knowledge accumulation from the external network and (2) the increase in the capability of the ego to appropriate and exploit the alter's knowledge through the direct tie. There is a condition that allows the achievement of both, even involving just one step of the indirect relationship: the presence of a weak tie between ego and alter (internal direct tie).
This is the case at least for two reasons. (1) First, in the internal direct tie, this allows the opportunistic behavior of the ego to exploit the alter's knowledge and involves informal forms of knowledge transfer that can have positive effects on ego innovation. (2) Second, in the external network, it avoids the lock-in effect and favors the openness of the alter to the network.
(1) First, the TCE perspective can be applied to catch the advantages of the opportunistic behavior of the focal buyer in the direct tie with the supplier. Buyers can adopt actions and practices that reflect a short-term mentality in regard to pricing, warranty, and intellectual property. Suppliers often report the opportunistic methods and behavior used by buyers. Some manufacturers demand that suppliers contractually waive their rights to intellectual property and will shop the technology at the first opportunity. In this way, they can exploit more innovations developed by different suppliers and get

opportunistic advantages from the presence of a weak relation. One could argue that this opportunism can be applied also by the supplier, who may take advantage of the buyer's knowledge. However, as explained in the previous hypothesis, the possibilities for exploiting buyer's knowledge in a harmful way are lower for the suppliers.

Moreover, a weak tie allows fewer rules and the transfer of knowledge in informal ways. The relative importance of informal networking is highlighted by several authors. MacDonald (1992) suggested that formal collaboration may actually undermine the informal transfer of knowledge. Some types of tacit knowledge are quite extensively shared through informal interaction. This is in line with Granovetter's (1973) concept of the strength of weak ties, according to which the most valuable knowledge flows generally take place as a result of the least visible forms of networking.

(2) Second, the strength of weak ties seems to be essential in managing the risks of lock-in or hold-up. To get effective innovation results, the availability of different knowledge sources and the openness of the central nodes to new ideas are the most relevant elements. If organizations concentrate too narrowly on the strong ties and are unable to take a broader view on the external environment, becoming too tight with the focal buyer, they are less likely to respond effectively to the changing needs. Their absorptive capacity, useful for catching knowledge from the external actors, is likely to drop.

The strength of ties enhances the pressure on actors to maintain non-advantageous ties due to the amplified reciprocity mechanism (Soda & Usai, 1999; Gargiulo & Benassi, 2000). Uzzi (1997), in his work on the paradox of embeddedness, shows how overembeddedness can ossify the network and keep it locked away from the demand of its environment. This suggests that strategic networks composed mostly of strong ties may threaten innovation rather than enhance it. This line of reasoning is consistent with the literature examining the negative consequences of social capital (Putnam, 2000; Volker & Flap, 2001).

In conclusion, I consider the interaction between a firm's centrality and the strength of the ties surrounding it. If the supplier is too much involved and locked into the relationship with the focal buyer, it is likely to have a lower chance of developing experience and investing in asset specificity and less commitment in its own external relationship. This means that its role of gatekeeper will be dampened. The strong tie reduces opportunism in the direct tie (positive for the buyer) and limits the search for knowledge in the external network.

HP 2: *The impact of supplier's centrality in the network of suppliers on buyer's innovation output is moderated by the strength of the buyer's direct tie with the supplier:*
the higher the strength of the buyer's direct tie with the supplier the lower the positive impact of supplier's centrality in the network of suppliers on buyer's innovation output.

3.2 The competitive dimension in buyer-supplier networks and knowledge-flow

In this section, based on the competitive side of the supplier-buyer network, I focus on the case in which the indirect nodes reached by the buyer through the supplier are competitors.

I predict that the supplier's centrality in its network of buyers will reduce the buyer's innovation output, as measured by patenting frequency. Innovation depends on the knowledge flow to the ego. I argue that, when the ego is a buyer and the alter that is a supplier is central among buyers, negative knowledge spillovers are enhanced, and they are able to overcome the benefits of positive knowledge leakage, which are also partially reduced in this case. As stated in proposition two, the occurrence of these two conditions will result in a negative effect of the alter's centrality on the ego's innovation output.

(a) *Increase in positive leakage at a decreasing rate*
Suppliers of parts and components will actively seek to supply more than one producer. From a network perspective, this implies that it is likely to have out-stars in the supply network, i.e. structures in which a supplier is connected to multiple producers (Lomi & Pattison, 2006).

Nobeoka et al. (2004) demonstrated that, from the point of view of the supplier, a broad "customer scope strategy" leads to superior performance because of learning opportunities. They predicted a positive relationship between the number of a supplier's customers and the supplier's knowledge. This is the positive effect on the supplier. This means that, potentially, the buyer can benefit from a more experienced

supplier and from a wider pool of knowledge. However, in the context of competition among the indirectly linked nodes, additional elements must be taken into consideration.

There is a *congestion* effect, represented by the already explained λ parameter of the innovation production function. An increase in the number of researchers corresponds to a less than proportionate increase in the number of unique ideas or discoveries. Therefore, there can easily be duplications between the focal buyer's knowledge and other buyers' knowledge, and this can reduce the positive impact of the flow of knowledge to the focal buyer. Moreover, while it is quite natural for a supplier to transfer the knowledge it gets from other suppliers to a buyer, it is a less obvious matter to transfer the knowledge it gets from other buyers to a buyer. The buyers, from the perspective of the supplier, are, in principle, all comparable actors at the same level. The supplier must have an incentive to behave on behalf of one buyer more than in favor of another buyer given the detrimental effect that this transfer can have for one of its partners. In this case, it could be more appropriate to say that there is a certain degree of potential stickiness in the flow of knowledge.

(b) Increase in negative spillovers

A supplier having relationships with buyers of the same industry creates problems of *negative leakiness* (Bengtsson & Eriksson, 2002) due to competition. Each tie represents for the actor a source of information and resources but also a weak point through which knowledge and resources could drain (Gnyawali & Madhavan, 2001). If the supplier operates in a non-exclusive way, innovations developed inside the industry can be transferred to all competitors, and we cannot conjecture regarding who benefits from innovation. Strategy theorists have described the search for competitive advantage as a distributive game (Williamson, 1975; Porter, 1980). The business press has coined the term "pie expansion" to refer to the collaborative process of creating mutually beneficial strategic outcomes between buyers and suppliers, originally considered to be antagonists (Jap, 1999). However, I suggest that this expansion can be dampened by the presence of competitors as indirect nodes linked to the firm.

The increase in the effect of negative spillovers is determined by several mechanisms: (1) the patent race, (2) the saturation process in patent generation, (3) the supplier's power, and dependence. The latter element determines not only the level of spillovers but also introduces the argument of the supplier's commitment. Moreover, it is related to Bonacich's (1987) distinction between centrality and power.

(1) First, from the patent race literature, we know that firms compete to develop and bring to market a product and that only the first mover makes a profit on the innovation. The discoverer, by patenting the innovation, can bar others from exploiting that idea (Baiman & Rajan, 2002). Here, the *timing* benefit of networks identified by Burt (1992) assumes a crucial meaning. In many industries, the temporal lag between the invention and its official diffusion through patents can be significant (Almeida & Kogut, 1995), and some inventions are also not patentable at all. The network allows the early, unofficial of inventions, that will, in turn, take years to become common knowledge. We are analyzing a typical zero-sum game, where the participants are struggling over a fixed asset and one player's gain is the other's loss. Therefore, the likelihood of having an invention exploited is reduced with the increase in the number of competitors.

(2) Second, the literature on patent generation states that each new patent requires a certain amount of new knowledge, and the closer the scientists get to the maximum number of patents achievable in their field, the more difficult it is for them to do further related research (Kapmeier, 2006). The relationship with the shared supplier tends to create a common knowledge base between the competitor buyers that, in some way, enhance and speed up this saturation process.

(3) Third, another argument to evaluate the effect of the supplier's centrality among buyers on the focal buyer's innovation is one of power or dependence: in the presence of a smaller number of buyers, the supplier is more dependent on buyers, and it can be more willing to spur innovation. A network composed of relationships with partners with few ties to others will facilitate control over exchange partners.

There is a relation between dependence and commitment: a highly dependent supplier would be expected to have a substantial commitment to innovation, based on the intention to retain the focal buyer's business and to open new technological/market occasions, consequently reducing its dependence. Therefore, the higher is the centrality of the supplier among other buyers, the less the supplier is dependent on the single buyer, the lower the supplier's commitment to focal buyer's innovation and the higher the opportunistic behaviour propensity will be. Consequently the focal buyer's innovation will be lower.

I am investigating the effect on a firm's innovation output not of its centrality but of the centrality of its partners (suppliers). The centrality of the firm's partners is often considered to be equivalent to the centrality of the firm, but I am questioning this assumption by showing that it is contingent on the type of actors related to the central actor linked to the focal firm and to the types of ties in the network of this central actor. This argument is, in some ways, in line with Bonacich's (1987) distinction between the concept of centrality and power. He highlighted that being related to a central node can be both positive and negative. Bonacich (1987) asserted that a node may be considered central if it is connected to nodes that have connections to many other nodes; a node may be considered powerful if it is connected to nodes that have connections to few other nodes (Hanneman & Riddle, 2005). Bonacich's (1987) basic principle is that, in bargaining situations, it is advantageous to be connected to those who have few options; power comes from being connected to those who are powerless. (Bonacich, 1987).
Hence, I formulate the following hypothesis.

HP 3: *The higher the supplier's centrality in the network of buyers, the lower the buyer's innovation output*

I analyze how the impact of the strength of ties can amplify or reduce the main effect shown in the previous hypothesis. To increase the effect of the supplier's centrality in a network of buyers on the buyer's innovation output, the reduction of negative knowledge spillovers is crucial. The competitive context under analysis (where the nodes indirectly linked are competitors) requires mainly prevention of the negative knowledge spillover, and as an additional element, enhancement of the positive knowledge leakage. This, as stated in proposition three, is the basic principle to determine the influence of the strength of the ties.

To find a solution that ensures a certain benefit to the focal buyer in the context of competition, I can focus on the relative strength of the focal buyer-supplier versus the strength of supplier-other buyers ties. In fact, the central actor can be of strategic importance to networks of innovators by playing a pivotal role in ensuring an equitable distribution of value (Dhanaraj & Parkhe, 2006). This means that the type of relationship that each competitor establishes with the central supplier matters because it can be determinant in shaping the supplier's behavior. It is evident that the focal buyer payoff depends on the focal tie (focal buyer-supplier) and on the supplier's other ties, considered in a relative perspective.

The general reasoning I can present is that, the less exclusive the relationship of the focal buyer with the supplier is the more a strong tie helps. In other words, the marginal return of a strong tie is higher.

I examine how the different characteristics of weak and strong relationships have an impact on a buyer's innovation in a context like this, I identify the optimal solution in terms of the strength of the ties and, finally, I show that this solution is the one that allows the prevention of negative knowledge spillover and the fostering of positive knowledge leakage.

(a) *Impact of the characteristics of weak and strong relationships on buyer's innovation*
In the context of all weak ties, i.e. arm's-length ties, the supplier could receive information on competitors, that can be used in customer relationships elsewhere (Jap, 1999). The standardization of products facilitates the patent race among buyers. There are non-specific investments, minimal coordination mechanisms, and low interdependence between actors (Dyer & Singh, 1998); therefore, the content and the outcomes of the relationships are easily *imitable*. The supplier's resources are available for all the actors, with a greater concern for the appropriability of innovation developed thanks to the supplier. There is a high level of opportunism and potential misappropriation of information, also characterized by low legal bonds. Actors' behavior is more likely to be *efficiency-driven*. A supplier can answer to a buyer's demand of price reduction, by lowering the resources invested in the buyer's business (Hatfield et al., 1979). Therefore, we can presume that, in such a context, the centrality of the supplier in a network of other buyers has a negative impact on the buyer's innovation output.

When we consider strong ties (in our specific case, alliances), new positive elements come up: idiosyncratic, dedicated, specific investments, customized products, and the aim of creating mutual beneficial strategic outcomes. Factors that induce the supplier to act on behalf of the buyers can be detected both on the input side (supplier's relation-specific investments) and on the output side (common aims and expectations) of the relationship. In sum, with an alliance, the three dimensions of social capital are increased: (1) the

relational one (trust, identification, obligation, commitment); (2) the cognitive one (shared ambition, vision, values); (3) the structural one (strength and number of ties between actors). These elements are useful in minimizing opportunistic behavior and spillover effect and result in greater innovation.

If the strength here is measured in terms of the type of tie, where the highest strength is the combination of alliance plus supply, the maximum strength also includes multiplexity. Multiplexity is the occurrence of different types of ties between two nodes (Carrington et al., 2005). According to RBV theory, it is a valuable resource that is rare and difficult to imitate or substitute, it gives greater stability, enforcing each relationship. In the end, a supplier will act on behalf of a buyer and the relationship favors innovation. However, we have several customers with the same supplier as a partner; all the buyers linked to the supplier will potentially benefit from this situation. The situation in which the payoff for the focal buyer will undoubtedly be positive is given by an advantage in strength: a focal buyer-supplier tie that is stronger than supplier-other buyers ties. Hence, the optimal case is the one in which the focal buyer has a strong tie with a supplier that is central in a network of weak ties. This option allows the prevention of negative knowledge spillovers and the fostering of positive leakiness.

(b) *Need to prevent negative knowledge spillovers*

On one hand, the strong focal buyer-supplier tie permits the occurrence of positive "stickiness" (Bengtsson & Eriksson, 2002). The most obvious reason is that, from TCE, we know that a strong tie is a tool to establish enforcing mechanisms that protect against opportunistic behaviors. A reduction in transaction costs can be achieved in this way.

The second reason is that it is likely that the elements characterizing a strong tie are the foundation for inimitable aspects of the collaboration outcomes. From the RBV theory, I posit that the content of a strong relationship becomes not easily transferable to other ties due to the specialization of the relationship (unlike weak ties). Coordination efforts and idiosyncratic investments make it possible for firms to combine their resources in unique ways (Jap, 1999). We know that, in RBV theory, unlike TCE, there is not a focus on the avoidance of opportunism: the firm is seen as a "creator of the positive," of rare inimitable resources (Prahalad & Hamel, 1990). However, here, I want to stress that it is just this uniqueness that prevents negative leakiness. Strong ties foster a normative environment against opportunism that raises barriers to resource mobilization and competitive practices (Obstfeld, 2005).

Furthermore, the greatest strength corresponds in my network to multiplexity characterized by solidarity and private information. Solidarity implies that an actor has more difficulties in breaking a tie if it has also another tie with the same partner. Relationships with high solidarity are viewed as entry barriers that are "almost impenetrable by rivals" (Tuli et al., 2010). Private information implies that the parties know each other from different perspectives and get richer and non-redundant information from the different kinds of ties. This allows greater idiosyncratic solutions. The presence of multiplexity is more beneficial in a context of competition: the association between a change in relationship multiplexity with a customer and a change in costumer performance is more positive when the competition intensity in the customer's industry increases. (Tuli et al., 2010).

(c) *Need to foster positive knowledge leakage*

On the other hand, a voluntary agreement between the focal buyer and the supplier (strong tie) implying joint involvement in product development spurs the flow of information and knowledge from other buyers to the focal buyer through the shared supplier. The strength of the tie is fundamental in this context, where the shared supplier must have a preference to behave in favor of a single buyer and where it is important to adopt a relative perspective to evaluate the advantage of the buyer with respect to the other buyers. The weak ties among the supplier and the other buyers allow the occurrence of positive "leakiness" (Bengtsson & Eriksson, 2002): the flow of information outside the single supplier-other buyers relations, through the supplier, as well as the accumulation of broader knowledge on the part of the supplier. Information and re-deployable knowledge on the different applications of a given component can flow out of supply relationships. The supplier will have an increase in competencies because it is important for a supplier to have contacts with which it can try new products and redeploy them. Often, a firm in a component business cannot develop new products on its own but needs a vehicle manufacturer to work with. This means, in our case, that if the supplier has direct ties with many buyers (high centrality), it has

greater potential innovation output; however, the competition for information and innovation bars the focal buyer's positive payoff. The strength becomes an important element.

In the end, the best situation is one in which the focal buyer has a strong tie with a supplier that is central in a network of weak ties. In this case, the combination of positive "stickiness" and positive "leakiness" (Bengtsson & Eriksson, 2002) explained above engenders a positive leverage effect that moderates the main effect shown in hypothesis 3. This is a solution that allows for exclusive solutions developed by the supplier for the focal buyer, ensuring protection from the competition, but allowing also the supplier's knowledge enrichment with other buyers. For the focal buyer, there is only the benefit of innovation creation without the problem of exploitation and patent race.

If I consider the other possible value of the ratio (strength in focal buyer-supplier on strength in supplier-other buyers), I find other scenarios. If the supplier-focal buyer tie is weak and the supplier is simultaneously involved in many strong ties with other buyers, we have the opposite situation with respect to the one described above, and I can presume a negative effect on the focal buyer's innovation. This asymmetric information flow is not favorable for the focal buyer. Finally, the strength can be similar both in the focal relation and in the external relations involving the supplier – with either strong or weak ties. This situation seems to engender a neutral effect. Consequently, it will not alter the original main effect of the supplier's centrality on the buyer's innovation output.

The explained line of reasoning leads to the formulation of the following hypothesis.

HP 4: *The impact of supplier's centrality in the network of buyers on buyer's innovation output is moderated by the relative strength of the direct tie between the buyer and the supplier versus the strength of the ties between this supplier and other buyers:*
the higher the relative strength of the direct tie between the buyer and the supplier versus the strength of the ties between this supplier and other buyers, the lower the negative impact of suppliers' centrality in the network of buyers on buyer's innovation output.

I have presented the line of reasoning underlying my four hypotheses. In general, the underlying conceptual frame showing how the knowledge flows to the focal buyer involves the elements shown in the figure below. Basically, the focal buyer's payoff results from how information flows to it, how much access to information it has, and how information flows in the external network.

Fig.3 Total knowledge flow to the focal buyer

CHAPTER IV - Research Design

4.1 Methods and Model specification

The thesis aims to assess the effect of the supplier's network on the buyer's innovation using quantitative methods, by adopting social network analysis (SNA) and a regression model. The first one led to the identification of network characteristics and actors' positions through the computation of network variables. After the network analysis, traditional estimations of the effects that network variables have on a firm's innovation have been implemented through a regression model.

The hypotheses developed in chapter three identify one dependent variable: the innovation performance of the focal buyer. I specify the equation that ensues from the aforementioned theoretical model. In the equation, the dependent variable, the focal buyer's patent count, is regressed against the vector of

explanatory variables including both hypothesized effects and controls. I use a longitudinal research design and therefore all variables are indexed over firms (i) and over time (t). Using a pooled cross-sectional notation, the regression equation can be written as follows.

FB Patents $_{it}$=
$\beta_0 + \beta_1$ **(Centrality S1-S2)$_{it-1}$ + β_2 (Tie Strength FB-S1)$_{it-1}$ + β_3 (Centrality S1-S2) * (Tie Strength FB-S1)$_{it-1}$ + β_4 (Centrality S1-B2)$_{it-1}$+ β_5 (Relative tie strength FB-S1/S1-B2)$_{it-1}$ + β_6 (Centrality S1-B2)*(Relative tie strength FB-S1/S1-B2)$_{it-1}$ + β_7 (controls)$_{it-1}$ + ε_{it}**
Specifying the controls it becomes:

FB Patents $_{it}$=
$\beta_0 + \beta_1$ **(Centrality S1-S2)$_{it-1}$ + β_2 (Tie Strength FB-S1)$_{it-1}$ + β_3 (Centrality S1-S2) * (Tie Strength FB-S1)$_{it-1}$ + β_4 (Centrality S1-B2)$_{it-1}$ + β_5 (Relative tie strength FB-S1/S1-B2)$_{it-1}$ + β_6 (Centrality S1-B2)*(Relative tie strength FB-S1/S1-B2)$_{it-1}$ + β_7 (ROA)$_{it-1}$ + β_8 (R&D intensity)$_{it-1}$ + β_9 (Current ratio)$_{it-1}$ + β_{10}(Debt to equity)$_{it-1}$ + β_{11}(Emp)$_{it-1}$ + β_{12}(Patents S1)$_{it-1}$ + β_{13}(Supply ties FB-B)$_{it-1}$ + β_{14}(Horizontal ties FB-B)$_{it-1}$ + β_{15}(SH efficiency)$_{it-1}$$\beta_{16}$(Presample patents)$_{it-n}$ + ε_{it}**

where FB = focal buyer, S = suppliers, B = buyers, just motor-vehicle assemblers. Specifically S1 are suppliers located at distance one from the focal buyer, while S2 and B2 are suppliers at distance two and buyers at distance two from the focal buyer respectively.

The four hypotheses are tested looking at the sign and significance of the following variables: Hp1: (Centrality S1-S2); Hp2: (Centrality S1-S2) * (Tie Strength FB-S1); Hp3: (Centrality S1-B2); Hp4: (Centrality S1-B2) * (Relative tie strength FB-S1/S1-B2).

I used a lag of one year between the dependent variable and the regressor values: the dependent variable is computed at time t, while all the regressors are computed at time t-1. The variable Presample patents is the presample computed by cumulating the focal buyer's patents preceding the period under analysis and it is based on a three-year window.

The dependent variable, innovation output, as represented by patent counts, is a count variable and takes only non-negative integer values. The linear regression model assumes homoskedastic normally distributed errors. Because these assumptions are violated with count variables, a count model will be used, either a Poisson or negative binomial regression depending on the presence of overdispersion in the data (standard deviation of data exceeds the mean) (Hausman et al. 1984).

4.2 The empirical setting

The empirical analysis is carried out in the U.S. Motor Vehicle Industry. The choice of the motor-vehicle industry as the empirical setting has multiple motivations primarily related to the type of product marketed in it and to the presence of inter-firm networks.

First, product development ensues from the interaction of different parties. It is basically collaborative in nature because of the product characteristics, in particular the complexity typical of a "fabricated-assembled" product. Second, the motor-vehicle industry is a prominent example of a sector where one encounters inter-firm networks on a large scale (e.g., Dyer, 1996; Fine & Whitney, 1996). In particular supplier-buyer relationships are of great importance. Moreover, the choice of the motor vehicle industry is valuable in terms of contribution to the network literature. In fact the empirical setting of current network-based studies has remained quite narrow, in spite of claims to generalizability. Institutional contexts where relational explanations are favored (e.g. biotechnology) were preferred by researchers, while relatively fewer studies focus on mature industries characterized by vertically integrated processes of mass production and distribution (Lomi & Pattison, 2006).

The motor-vehicle industry is unique in that it brings together an extremely complex set of components from multiple sources. A motor vehicle is made of approximately 15.000 components per vehicle and from 60 to 80 percent of a vehicle is sourced externally. The buyer of a motor vehicle is buying a product to which several thousand companies have contributed.

Product development in this industry has peculiar characteristics derived from the simultaneous complexity of two elements: the *product* and the *process/project* to develop a new product.

The complexity of a product can be defined along two dimensions: (1) complexity of internal structure (i.e. product with a high number of distinct components - a hierarchy of parts, components, systems, and modules -and high interdependence among components implying internal coordination and technological challenges); and (2) complexity of user interface or external complexity (i.e. the product gives rise to several different performance dimensions, most of which are subjective, indefinite criteria, difficult to translate into technical specifications. The user interface is multifaceted in that a vehicle can satisfy customers in a number of ways beyond basic transportation).

The complexity of the process/project is given by the number of different stages it includes (concept, feasibility, design, pilot, ramp-up and commercialization), by the number of diverse actors it involves, and by the level of interdependence required among stages and among actors.

Supplier involvement in the design and development of a vehicle can take place in different ways corresponding to different components (*supplier proprietary parts*, *black box parts*, *detailed controlled parts system*). There are several reasons for manufacturers to rely on supplier collaboration. First, as vehicle complexity (e.g., electronics) has increased, it has become extremely difficult for a manufacturer to maintain the necessary competencies to design, develop, and manufacture many systems, thereby creating the need to look outside. Second, supplier capabilities have increased significantly in recent times. Therefore, suppliers continue to enhance their innovation efforts and share of vehicle development such that three-quarters of the cost of a vehicle is coming from suppliers.

In general collaborative relations between suppliers and buyers are widespread, even if in the past decades and in the different countries, different models and strategies have been followed by the motor vehicle companies with respect to supplier-buyer relationships.

The last remark I want to point out regards the external validity of the study, meaning the applicability of the same predictions and mechanisms to other industries. Many of the critical problems in developing a new motor vehicle show up in the development of most "fabricated-assembled" products, even in process-intensive industries such as steel, aluminum, and engineered plastics these problems are applicable.

4.3 Sample and data collection

The overall empirical process started with the sampling procedure, consisting of data collection, execution of cleaning procedures, and final identification of the firms in the sample. Subsequently collection and elaboration activities were implemented in three principal fields: relational data through network analysis, patent data, and financial data. All the data collected have been elaborated, matched, and exploited through extensive use of Microsoft Access.

4.3.1 The sample: data collection and identification of the nodes

The sample includes all the suppliers operating in the United States and their customers, which are motor-vehicle companies and other suppliers. To obtain the final sample the following procedure was followed.

(1) First a list of all the suppliers established in the US was drawn up using as a main source the directory *ELM Guide of US Automotive Sourcing.* The *ELM Guide* is a reliable source that is acknowledged in the industry and that has been already used in the literature by several authors (e.g., Chung, Mitchell, & Yeung, 2003; De Jong & Nooteboom, 2001; Martin, Mitchell & Swaminathan, 1995; Delmas & Montiel, 2009). Its use in a wide network context is a somewhat new application. I retrieved suppliers' lists for five years: 1994, 1996, 1998, 2001, 2004, corresponding to the years of publication of the *ELM Guide* volumes. The printed version of the data was transposed into an electronic database. Companies that produce machine tools or raw materials and those that produce primarily for the aftermarket are not part of the ELM database.

The data in the ELM Guide are expressed at the company level, meaning typically the subsidiary level. On the contrary, for the purposes of this thesis, the study is executed at the corporate level of analysis. The information in the guide useful for the current empirical work includes parent company name and ownership. However, to make sure that they were correct, and also that the parent company mentioned

from the supplier was the ultimate parent and not an intermediate parent company, I conducted a search in other sources, more focused and specialized in providing that kind of information. The principle underlying this choice is to use the most suitable data source for each specific type of data and to use, whenever possible, multiple comparable sources.

(2) Therefore the second stage of the process to get the final sample consisted of the identification of the ultimate parent company, for each supplier under analysis, for each of the five years. I carried out this activity using two complementary sources: *Who Owns Whom: Directory of Corporate Affiliations* volumes by Dun and Bradstreet and the *Corporate Affiliations* database by LexisNexis. These sources report the corporate hierarchy of the companies over time, listing all the subsidiaries of a given parent company. By recording the parent companies in the different periods, I also recorded changes in the ownership structure of the companies and different subsequent parent companies for the same supplier over time. To check for these cases I integrated the aforementioned data sources with the *Merger Track* section of LexisNexis. The cases of mergers were also isolated and taken into account. Moreover, I searched newspapers and online libraries for information about ownership changes regarding those firms that did not appear in any of the aforementioned sources.

(3) The third step for the identification of the nodes consisted of the coding of the corporate entities identified. The coding obviously passed through a preliminary activity of standardization of names. Dealing with the difference in the spelling of the same name in different sources or even in the same source over time was the first hindrance to overcome. Beyond the spelling issue it was important to find all the cases in which a change in the company name occurred. In these cases the same unique identifier of the company had to be assigned to the multiple names. This name changes could occur at the subsidiary and at the parent level, both of which were verified. A subsidiary's name change was mainly discovered through the *ELM Guide*, a parent name change through *Corporate Affiliations* by LexisNexis, that records parent names over time, and by checking for the cases in which a subsidiary changed parent overtime.

This above procedure was followed for all the firms considered: (i) suppliers in the original ELM list (original equipment manufacturers, [OEMs]), and (ii) customers that are in turn divided in two categories: (a) customers that are motor-vehicle companies, namely assemblers, and (b) customers that are other suppliers. A different type of code was assigned to each of the three categories to keep them clearly recognizable in the various data elaboration activities.

(4) The fourth step included the exclusion from the sample of some of the corporate entities identified through the aforementioned steps. Specifically, among the customers, I excluded from the assemblers those entities not operating in the motor-vehicle industry and from the suppliers the aftermarket businesses. These two types of nodes are beyond the scope of the present study. Finally, I was forced to exclude a few suppliers that did not provide the list of their customers.

Moreover, I executed two alternative models that differ in the sample composition of the motor-vehicle assemblers and that function as a robustness check. In one case I used the whole sample resulting from the aforementioned procedure; in the other case I identified and excluded from the sample, and consequently from the network, motor-vehicle companies having no operating activities in the US, to avoid a bias in the model with an incorrect causal relation for two reasons. First, the U.S. suppliers could not be sufficiently representative of the overall supplier base of a motor-vehicle company that is not operating in the United States at all. Second, this study is investigating social exchanges and it could be more difficult to justify or presume the occurrence of a social exchange in the presence of a substantial distance between a supplier and a buyer.

In the end in the model excluding the motor-vehicle companies not operating in United States the sample includes 1,089 nodes in 1994, 1,177 nodes in 1996, 1,120 nodes in 1998, 1,052 nodes in 2001, and 1,007 nodes in 2004.

As a prerequisite to facilitate the subsequent data collection activities, I carried out the partition of companies into private and public companies year by year. In fact, patent data and financial data collection involve different opportunities and procedures in the case of public or private companies. I draw this information from the *ELM Guide*, LexisNexis, and the Compustat North America and Compustat Global lists of companies accessed through the Wharton Research Data Services (WRDS) web site. I identified around 380 public companies considering the years as a whole; for these companies I recorded identification codes, such as *cusip* or *gvkey*, that were useful then for linking the different sections of the dataset.

4.3.2 The relational data and the building of the network

I summarized the different types of ties in a continuous measure that is the strength of the tie, assigning a specific value to each type of tie (supply tie, alliance, supply and alliance). Even though I used an aggregated tool of analysis, the two networks (supply network and alliance network) had to be built separately and subsequently merged.

Supply ties have been obtained, from the *ELM Guide*, which provides for each year for each supplier a section including its customers: all the buyers listed in the survey by the supplier. This information allowed construction of the five supply networks, one for each of the five years, through the following process. First, I collected data on the supplier-customer ties from the volumes. These data are expressed at the subsidiary level both for the supplier and the customer. Second, since in a previous step I identified the parent companies of all the firms, I executed a match between the original parties involved in a tie (subsidiaries) and the list that associates each subsidiary with its parent company, to transpose the original ties into ties expressed at the parent level. Third, I excluded the few ties listed from the suppliers as tier-two relations with a buyer without specifying the intermediate direct node of connection because I could not establish the direct relations in these cases. Finally, I uploaded nodes, relations, and attributes - namely, whether the node is a motor-vehicle company or not - into UCINET VI and I was able to build the supply network for each year.

In the network, the ties have been considered as symmetric (even if they are supply ties with a clear direction where one party supplies the other one) because the subject of interest is the social interaction of people connecting with people. These supplier-customer ties can involve as customers both another supplier and a motor-vehicle company. However I specify that in the development of the hypotheses and also in the regression model the buyer is intended to be understood as the final product assembler.

Alliance ties have been found using the *SDC Platinum* database, provided by Thomson Reuters, specifically the *Joint Venture/Strategic Alliances* section. This database provides substantial archival information on inter-firm agreements and it currently represents one of the most comprehensive sources of information on alliances, widely used in alliance research, reliable and consistent with other sources (e.g., Li et al., 2010; Chang, 2004; Anand & Khanna, 2000; Oxley & Sampson, 2004; Reuer & Ragozzino, 2006). A careful review of the coverage of SDC reveals that the data are widely diversified with different firm sizes and types (public, private, and subsidiary) (Aydogan & Chen, 2008).

For each of the companies in the sample, all the alliances in the period under analysis have been found in *SDC Platinum.* First, to retrieve the alliances of a given firm a way to unequivocally identify the firm was needed. In SDC each name is associated to a CUSIP. For the public companies listed in North America, I was able to upload the already identified CUSIP inside SDC and get the corresponding alliances. For the private companies and for the public companies listed globally I needed to conduct a search for them by name, one by one, and to record the CUSIP assigned by SDC. Second, I queried the system to extract all the alliances associated with those codes, selecting as criteria both "Participant Cusip" and "Participant Ultimate Parent Cusip" to make sure that all the alliances of the ultimate parent company as well as those of its subsidiaries were included in the output; this yielded a spreadsheet with all the ties. Third, since the focus is on the impact of the ties on a firm's innovative performance, I filtered the output to keep just the alliances of selected types, namely R&D agreements, manufacturing agreements, supply agreements, and licensing and cross-licensing agreements. Also, I applied a filter to select just certain status details of the agreement, namely completed/signed or renegotiated (thus excluding letter of intent, pending, etc.). Fourth, as for the date of the alliance, a "date announced" and a "date effective" are provided. I always utilized the effective date unless it was missing. Alliances were collected that were effective between 1994 and 2004. Alliances typically last for more than one year, but alliance termination dates are rarely reported. This requires the researcher to make an assumption about alliance duration. Since the choice of a fixed window of some years (e.g., Stuart, 2000) seems to be equally arbitrary, I used the assumption that the alliance lasts from the date of establishment through the last year of the period analyzed (Gulati, 1995).

Only those alliances aimed at developing innovations potentially useful to the motor-vehicle industry were of interest. Therefore I matched all the actors involved in the alliances found in SDC with the nodes of the sample; then I selected the alliances involving at least two nodes of the sample, the supply network, in the year under analysis. At this point, I was able to build the five alliance networks, one for each year.

Finally, I superimposed the two networks - supply network and alliance network - to create a sole multiplex network to conduct the subsequent analysis and compute the network variables. First, I transformed the two matrices representing the two networks into matrices of the same size. Then I joined the two networks to create a multiplex network through UCINET VI program. The resulting network is a valued network assigning a different value for each kind of relationship (e.g., 1 = supply tie, 2 = alliance, 3 = alliance + supply tie). Subsequently I dichotomized the resulting network to have a network reporting a tie if there was at least one kind of relationship (asking for a 1 in the matrix for values >=1). In this way each cell of the matrix has been covered by the *Kij* indicator, which represents the relationship between actor j and i and is equal to "1" if there is at least one kind of the three aforementioned relationships, "0" if there is not. The subsequent step was the computation of the network variables. The network analysis is focused on the ego-networks of the motor-vehicle companies.

4.3.3 Patent data collection

Patents data have been collected from the U.S. Patent and Trademark Office (USPTO) using the National Bureau of Economic Research (NBER) files. I used this source also for firms headquartered outside the United States to allow consistency, as each national patenting system has different rules and standards for application and granting (Griliches, 1990) that could have introduced a bias.

I collected patent data for the years 1990-2005. The first years were used to compute the pre-sample variable. The last year enabled to apply a lag between alliance network structure and patent output. I obtained patent counts for each firm through the following procedure.

(1) First, I matched the names of the parent companies in the sample and of all the subsidiaries of each of them with the patent assignees. For the public North American companies, I used NBER files that include the match between Compustat firms and patent assignees names and other sources used for the other firms. In all, the files assign to a given company the patents of all its subsidiaries over time. Therefore using these files combined and elaborated through Microsoft Access, I was able to associate the public North American firms (Compustat North America firm names) of the sample to their subsidiaries, namely patent assignees names and codes, pdpass. For non-matched firms, for public companies listed globally, and for private companies, I prepared a list of the divisions and subsidiaries for each of the years under analysis using *Who Owns Whom* by Dun and Bradstreet (several countries' editions) and *Corporate Affiliations* by LexisNexis or the *ELM Guide* (for the private companies, due to the high number of them, the list of parent companies and of the subsidiaries present in the *ELM Guide* was prepared). afterwards, I executed a word-matching procedure to match the subsidiary names found with the assignees' names. It was possible to specify the desired percentage of similarity between the words and this yielded the list of the patent assignees corresponding to parent companies.

(2) Second, I got all the patent data for the assignees identified, using the NBER files. They record all the patents and includes all the patent data associated with each "pdpass", providing information (e.g. date of application, date of granting, identification number, technological category, class and subclass, etc.). Using the list of the "pdpass" corresponding to the sample and matching them with the "pdpass" inside the NBER file, I was consequently able to extract all the patent data. Merging the results on the patents from all the sections yielded patents different from zero for 785 distinct firms (across the different years of the study).

(3) Third, I filtered patent data according to specific needs, namely the years of interest and the technological classes chosen. The first implied just a filter on the application date. For the second, I filtered the obtained results to keep just the most appropriate technological classes, the ones strictly related to the motor-vehicle industry. I computed the frequency distribution of patents across classes for this sample of patents. I then ranked the classes by the number of firms in the sample that had patents in the specific class. Thus, the highest-ranked class by this criterion was the class that had the largest number of firms patenting in it. The logic for this was that if most of the sample firms are patenting in a class such a class would naturally be relevant for motor-vehicle firms. I identified 120 classes that accounted for about 68% of the patents of the firms and included the patenting efforts of 687 of the 785 firms in the sample; and used these classes to conduct the patent analysis. I also examined the distribution for natural "cut-points": beyond this threshold the marginal rate of increase in the percentage of patents covered does not increase. I also considered an alternative method: to keep just the classes that were ranked highest both in terms of

number of firms and number of patents and delete the others. However, looking also at the content and description of the patents, it turned out that there are classes with a high number of firms patenting in them but with a low number of patents in them that are strictly related to the core automotive industry. This phenomenon is due to the specificity of knowledge and to the different degrees of potential innovativeness in a given field. This outcome shows the usefulness of keeping the high number of firms in the class as the principal driver for the choice.

(4) Fourth, I computed each firm's patent count for each year following two methods with regard to the co-patenting issue functioning as a robustness check. I identified the patent codes that were attributed to more than one firm, i.e. case of co-patenting (i.e., patents issued jointly to the firm with some other firm). In the first method I assigned 1.0 and in the second I assigned 0.5 to the patents. I added these up, obtaining two different count measures. To apply a count model, in the first case I rounded the patent count off to the next integer. In this way, in the first case the firm was assigned all patents issued to the firm; in the second case the firm was assigned all patents issued solely to the firm and half of the patents issued jointly to the firm with some other firm.

4.3.4 Financial data collection

The main sources I used to collect financial data are Compustat North America and Global and Worldscope, two widely acknowledged and reliable tools. I looked through other datasets such as OneSource, Orbis, and Mergent Online but their use was reduced to preserve consistency among the data of different companies. Afterwards, I adjusted the data for inflation using the Producer Price Index. Then, since the data were originally expressed in each country's currency, I converted values to U.S. dollars using the archival exchange rates contained in the Compustat Global currency translation information.

When financial data were not available for some years (e.g., R&D expenditures), I used a regression imputation procedure (Little & Rubin, 1987) to impute missing values for the missing variable and complete the data. When it led to negative or improbable values, I attributed the last available data. I retrieved data on all the public companies, both suppliers and motor-vehicle companies, even though for the purposes of the present work, I utilized data on the motor-vehicle companies only. In the end, I excluded the motor-vehicle companies for which it was impossible to find financial information in any of the years under analysis.

4.4 Variables and Measures

1) Dependent variable. It is the *focal buyer's innovation output* (*FB Patents $_{it}$*). It is measured through the *patents count*, the number of successful patent applications or patents granted for a firm *i* in a given year *t*. The literature provides good reasons to use this measure as well as inherent limitations.

I follow other researchers who have considered patents as valid and robust indicators of knowledge creation (Trajtenberg, 1987), as useful statistics for measuring economically valuable knowledge (Hausman et al.,1984, Kortum, 1993), as excellent indicators of technological competence (Ahuja, 2000). Empirical studies have shown that patent counts correlate well with new product introductions and invention counts (Basberg, 1987). All the same, limitations of patents measures are known. Some patents are never exploited commercially; products can be not patentable or not patented for strategic reasons. The economic value of patents is highly heterogeneous (Cohen & Levin, 1989). As Ahuja (2000) underlines the degree to which these factors are a problem varies significantly across industries (Levin et al.. 1987; Cohen and Levin, 1989). Limiting the study to a single industrial sector in which patents are a meaningful indicator of innovation minimizes such problems, as the factors that affect patenting propensity are likely to be stable within such a context. The propensity to patent may also differ due to firm characteristics (Griliches, 1990). I attempted to control for this kind of heterogeneity in two ways: I introduced a covariate, Presample Patents; I ran the regression using both firm-fixed and random effects in my estimations.

I used the application year as the reference year for the patent count: granted patents were counted using the year of application. I followed this procedure in order to control for differences caused by delays that may occur in the patent-granting processes. I considered a lag of one year with respect to regressors.

2) Independent variables

The independent variables in the model are network variables. The dependent variable is focused on the *ego* or the focal buyer. Therefore, one could presume the adoption of an ego network analysis, typically involving the ego's direct ties and the ties among the ego's direct ties (Kilduff &Tsai, 2003). However, the aim here is to go beyond the ego network and relate the ego innovation output with partners of the ego's partners. I basically dealt with nodes up to a path distance of two from the focal buyer.

a) Centrality S1-S2: it measures the average number of suppliers connected to the focal buyer's alters that are suppliers. It expresses the average centrality of the supplier connected to the focal buyer *i* , among other suppliers. *Centrality S1-S2* can be measured as the number of S nodes reached in two steps by the focal buyer divided by the number of S nodes reached in one step by the focal buyer. I refer to this measure as *Reach Efficiency_S*, which can be computed with the following ratio:

$C_{FBi\ (S1\text{-}S2)}$ = REACH EFFICIENCY $_{FBi\_}$S = 2 STEP REACH_S / 1 STEP REACH_S

$$C_{FBi\ (S1\text{-}S2)} = \sum_{j=1}^{n} S2_j \Big/ \sum_{j=1}^{n} S1_j$$

S2 = suppliers at path distance 2 from the focal buyer FB_i ; S1 = suppliers at path distance 1 from the focal buyer FB_i

Network reach measures the degree to which any member of a network can reach everyone else in the network. Two-step reach calculates the number of actors that a node can reach in the network in 2 steps; One-step reach calculates the number of actors that a node can reach in the network in 1 step.

Reach efficiency is a measure that shows how many secondary contacts can be reached through each unit of primary contact (Hanneman & Riddle, 2005), and consequently it is very suitable for the analysis of the incoming and outgoing flow of knowledge to the focal buyer through the supplier.

In the *Centrality S1-S2* variable, two-step reach is computed including all the nodes at a path distance of two, irrespective of a simultaneous presence of a direct tie between the focal buyer and the node at distance two. As a robustness check, I also specify an alternate measure for the variable *Centrality S1-S2*. It has the same formula but the specification of S2 is different: S2 includes just the nodes that are exactly at a path distance of two from the focal buyer.

b)Tie strength FB-S1 : It measures the average strength of the direct ties between the focal buyer and suppliers connected to other suppliers.

$$TS_{FBi\ (FB\text{-}S1'')} = \sum_{j=1}^{n} w * R''_{ij} \Big/ \sum_{j=1}^{n} R''_{ij}$$

w = strength of the tie R''_{ij}

R''_{ij}= tie between the focal buyer FB *i* and the supplier *j* (S1'') connected directly to the focal buyer. It is the tie between node *i* and node *j* of the network. The measure includes just the suppliers S1'' (among the totality of S1) that are connected to other suppliers at the second level (S2). The underlying reason is that this measure is computed to analyse the impact of tie strength with reference to the supplier's centrality among suppliers (S2) on the buyer's innovation (and not also among buyers, B2).

The numerator is the weighted sum of ties between the focal buyer and the suppliers at a path distance of one, connected to other suppliers, while the denominator is just the sum of these ties. In other words, sum of tie strengths FB-S1 / number of ties FB-S1.

c)Centrality S1-S2 * Tie strength FB-S1 : It is the interaction of the two measures presented above and is aimed to test the effect of moderation of the direct tie strength of the focal buyer-supplier on the main relation between the supplier's centrality among suppliers and the buyer's innovation.

It can be measured as the multiplication of the aforementioned variables:

$C_{FBi\ (S1\text{-}S2)} * TS_{FBi\ (FB\text{-}S1'')}$

d) Centrality S1-B2: It measures the average number of buyers connected to the focal buyer's alters, that are suppliers. It expresses the average centrality of the supplier connected to the focal buyer i, among other buyers. Centrality S1-S2 can be measured as the number of B nodes reached in two steps by the focal buyer divided by the number of S nodes reached in one step by the focal buyer. I refer to this measure as *Reach Efficiency B*, which can be computed with the following ratio:

$C_{FBi\ (S1-B2)}$ = REACH EFFICIENCY $_{FBi\_}B$ = 2 STEP REACH_B / 1 STEP REACH_S

$$C_{FBi\ (S1-B2)} = \sum_{j=1}^{n} B2_j / \sum_{j=1}^{n} S1_j$$

B2 = buyers at path distance 2 from the focal buyer FB_i ; S1 = suppliers at path distance 1 from the focal buyer FB_i

Network reach measures the degree to which any member of a network can reach everyone else in the network. Two-step reach calculates the number of actors (i.e., buyers) that a node can reach in the network in 2 steps; One-step reach calculates the number of actors (i.e., suppliers) that a node can reach in the network in 1 step. The same considerations pointed out about *reach efficiency* in the subsection regarding *Centrality S1-S2* are valid here as well. The concept underlying the two variables is the same; they only differ in that *Centrality S1-B2* considers assemblers at the second level, instead of suppliers.

e) Relative tie strength FB-S1/S1-B2 It measures the relative average strength of the ties linking the focal buyer to direct partners that are suppliers versus the average strength of the ties linking these suppliers to the other buyers at a path distance of two. It can be expressed in the following manner:

$$RTS_{FBi\ (FB-S1'/S1'-B2)} = TS_{FBi\ (FB-S1')} / TS_{FBi\ (S1'-B2)}$$

where

$$TS_{FBi\ (FB-S1')} = \sum_{j=1}^{n} k*R'_{ij} / \sum_{j=1}^{n} R'_{ij}$$

$$TS_{FBi\ (S1'-B2)} = \sum_{j=1}^{n}\sum_{p=1}^{n} q*G'_{jp} / \sum_{j=1}^{n}\sum_{p=1}^{n} G'_{jp}$$

Therefore:

$$RTS_{FBi\ (FB-S1'/S1'-B2)} = (\sum_{j=1}^{n} k*R'_{ij} / \sum_{j=1}^{n} R'_{ij}) / (\sum_{j=1}^{n}\sum_{p=1}^{n} q*G'_{jp} / \sum_{j=1}^{n}\sum_{p=1}^{n} G'_{jp})$$

k = strength of the tie R'_{ij}

R'_{ij} = tie between the focal buyer FB i and the supplier j (S1') connected directly to the focal buyer. It is the tie between node i and node j of the network. The measure only includes the suppliers S1' (among the totality of S1), which are, in turn, connected to buyers at the second level (B2). The underlying reason is that this measure is only computed to analyze the impact of tie strength with reference to the supplier's centrality among buyers (B2) on the buyer's innovation (and not also among suppliers, S2).

q = strength of the tie G'_{jp}

G'_{jp} = tie between the supplier at step one j (S1') and the buyer at step two p (B2). It is the tie between node j and node p of the network.

$\sum k*R'_{ij} / \sum R'_{ij}$, respectively, are the sum of tie strengths and the number of ties between the focal buyer and suppliers at a path distance of one that are connected to buyers at a path distance of two. These

can also be expressed as the weighted and not weighted degrees of the focal buyer with respect to suppliers connected to buyers at the second step.

$\sum \sum q * G'_{jp} / \sum \sum G'_{jp}$, respectively, are sum of tie strengths and number of ties between suppliers at a path distance of one from the focal buyer and buyers at a path distance of two from the focal buyer.

Therefore, in $RTS_{FBi \ (FB-S1'/S1'-B2)}$, the average strength of the ties between the focal buyer and its alters— suppliers— connected to other buyers is divided by the average strength of the ties between these suppliers and other buyers. A positive ratio implies an average tie in the first step stronger than the average tie in the second step. In the first step, only suppliers connected to buyers at the second step are included in the measure.

f) Centrality S1-B2 * Relative tie strength FB-S1/S1-B2

This variable is the interaction of *Centrality S1-B2* and *Relative tie strength FB-S1/S1-B2*

which is aimed at testing the effect of moderation of the relative strength of the direct ties focal buyer-supplier versus the strength of the ties supplier-other buyers on the main relation between the supplier's centrality among buyers and the buyer's innovation. It can be expressed as follows:

$$C_{FBi \ (S1-B2)} * RTS_{FBi \ (FB-S1'/S1'-B2)}$$

3)Control variables

<u>S1</u>: It is the one step reach, the number of nodes (in this network, namely suppliers) in the ego network of the focal buyer, and it is needed in the model to control for the effect of direct ties on buyer's innovation. Even if the focus is on indirect ties at step two, these connections at step one are still in place and can have an effect. It is the size of the ego-network minus one.

<u>SH Efficiency:</u> It measures the structural holes in the ego-network. As density in the ego network decreases, more structural holes are likely to open inside the ego network. This can impact innovation output because it determines the level of coordination inside the ego network and therefore the likelihood of successful and quick implementation of innovative ideas. Hence, I need to control for the level of structural holes. I use *efficiency* as a measure of structural holes. This is based on the *effective size* of the network. The effective size of the network is the number of alters that ego has, minus the average number of ties that each alter has to other alters. Efficiency norms the effective size of ego's network by its actual size. That is, what proportion of ego's ties to its alters are "non-redundant." Efficiency expresses how much contribution ego is getting for each unit invested in using ties (Hanneman & Riddle, 2005).

<u>ROA:</u> It is the measure of profitability. It controls for the possibility that higher innovation is driven by higher profitability. This is measured as the ratio of income to total assets.

<u>R&D Intensity:</u> R&D expenditures are likely to be a significant determinant of innovative outcomes. R&D intensity is computed as the ratio of a firm's R&D investment to its revenue.

<u>Current ratio</u>: It measures liquidity. It is computed as the ratio of current assets to current liabilities.

<u>Debt to equity:</u> This value reflects the leverage characteristics of a firm and controls for financial motivations that impact innovative performance. It is measured as the ratio of total liabilities/(total assets - total liabilities).

<u>Emp:</u> It is the number of employees, and it is a measure of size used in prior research (e.g., Goerzen and Beamish, 2005). Firms of different sizes innovate differently. In the classical Schumpeterian argument, companies' innovation performance increases more than proportionally with firm size because large firms simply have more resources.

<u>Patents S1:</u> It represents the patents count of the suppliers linked directly to the focal buyer in the ego network of the focal buyer. This control is aimed at considering the technical capabilities and innovativeness of the supplier independently from its network variables. This is in line with the supplier-buyer literature, which focuses on the firm-level characteristics of the supplier.

<u>Supply ties FB-B:</u> This variable measures the number of supply ties between two motor vehicle companies. In the sample, there were very few cases in which one motor vehicle firm supplies another one using its internal component manufacturing division. I have kept these cases separate, in the form of a control variable, because they are an exception that could have the effect of mixing up too many components in the network and alter the significance and interpretation feasibility of the network variables.

Horizontal ties FB-B: This variable measures for each motor vehicle firm, the number of alliance ties (horizontal ties) with other motor vehicle companies in which it is involved. These ties have been kept as a control variable and removed from the network for at least four reasons. First, the focus of the analysis is the impact of the supplier's network on the buyer's innovation output; therefore, this involves buyer-supplier ties and supplier-supplier ties but not buyer-buyer ties. Second, I maintain consistency with the removal of the supply ties between two motor vehicle companies in the superimposition of the supply and alliance network. Third, without a single kind of actor in the direct tie with the focal buyer, too many different effects could have been in place simultaneously. Fourth, while considering the competition of other buyers mediated by the supplier, we think about the flow of knowledge and the leakiness of knowledge. If we introduce direct alliance ties between motor vehicle companies, some competitor buyers will be no longer considered as reached at the second step through the supplier. However, while in a direct tie, the parties can safeguard against direct transmission of knowledge by stipulating norms for information exchange in a contract, limiting the scope of collaboration and creating rules about what can and cannot be discussed and shared, the parties will have little control on an indirect transmission through a shared supplier. Therefore, the buyer should in any case be considered a node reached at step 2. Being aware of a strong assumption, I have built the network by also keeping these relationships inside and I ran the regression models. The results are unchanged in terms of signs and significance.

Presample patents: It is the number of each firm's patents in the three years before the sampling period. This is a measure of past innovativeness. As pointed out by Ahuja (2000), the choice of a three- to five-year time frame to measure technical capital is consistent with studies of R&D depreciation (Griliches, 1984). This variable it is a measure of past innovativeness that serves as a fixed effect for the underlying innovativeness of the firm (Ahuja & Katila, 2001).

CHAPTER V - Results

5.1 The model

I have included six statistical specifications, following Cameron and Trivedi (2010) indications on panel models for count data (as explained in the Robustness Checks section).

Poisson regression is the standard or base count response regression model (Hilbe, 2007). Since the model plays a central role in count response modeling, I began with that. This provided a base case for comparison with more sophisticated models. A primary assumption of this model is the equidispersion or the equality of the mean and the variance functions. In our data the mean of the dependent variable does not equal the variance. Therefore, we can suspect the presence of overdispersion.

The overdispersion issue, causing Poisson standard errors to be smaller than they should and recognizing the coefficient as significant even when that is not the case, can be tackled in three basic ways: reducing the error variance, correcting the standard errors, and adopting the negative binomial model.

For instance, for the error variance, overdispersion can occur when the model omits important explanatory predictors. One remedy for a model when faced with apparent overdispersion is adding an appropriate predictor. I applied this by introducing the variable *Presample patents* to capture unobserved heterogeneity in the firm's propensity to innovate.

The negative binomial regression is the standard way to deal with overdispersion. Every application of the negative binomial model is in response of perceived overdispersion in a Poisson model (Hilbe, 2007). The negative binomial model allows for the variance that exceeds the mean. After the Poisson, I ran a negative binomial specification to check for the presence of overdispersion by determining if the value of the dispersion parameter α was statistically different from zero. If α was not statistically different from zero, then data are to be modeled as Poisson; if there is a statistically significant difference, then a negative binomial model specification provided a better fit with the data (Greene, 1995). In our case, the parameter α is positive and significant—with a value of 2,013—indicating that the data are characterized by overdispersion, and the Poisson specification is possibly inaccurate. Therefore, I used the negative binomial specification to test the hypotheses. The result is that the pattern of signs and significance are not altered with respect to the Poisson estimations.

Even when adopting the negative binomial estimations, choice of the utilization of random effect (RE) or fixed effect (FE) has to be done. To decide, I ran the Hausman Test. The test is not significant (with a resulting Prob > chi2 = 0.9997). This implies that the use of random effect is allowed. I will focus on these results to test the hypotheses.

As the tables at the end of the section shows, the results support the hypotheses. The sensitivity to statistical approach test reveals that all the six estimations produced similar results in terms of signs and significance with respect to the hypothesized regressors; this strongly support the predictions made in the hypotheses.

5.2 Descriptive statistics and Correlation Matrix

In the main model that excludes motor-vehicle companies not operating in the United States, the network includes 1,089 nodes in 1994, 1,177 nodes in 1996, 1,120 nodes in 1998, 1,052 nodes in 2001, and 1,007 nodes in 2004. However, since the dependent variable is related to the motor vehicle companies, the regression has been implemented just on the motor vehicle assemblers. In the end, after the deletion of firms presenting missing values in all the years of the panel, I obtained 37 assemblers and 156 observations over the five years analyzed.

As a general remark, the results of the correlation matrix are in line with what one would expect. The correlation between the independent variables amongst themselves is not particularly high, except for the correlation between the interaction variables and the variables of the main effects. The correlation is high between the variables of hp1 and hp2; i.e. *Centrality S1-S2* and (*Centrality S1-S2*Tie strength FB-S1*)= 0.977 and between the variables of hp3 and hp4, i.e. *Centrality S1-B2* and (*Centrality S1-B2*Relative tie strength FB-S1/S1-B2*)=0.985. This raises the possibility of high collinearity and low power in the testing of the hypotheses.

To check for multicollinearity, I mean-deviated the two variables *Centrality S1-S2* and *Tie strength FB-S1,* as well as the two variables *Centrality S1-B2* and *Relative tie strength FB-S1/S1-B2* before entering them into the interaction. I recomputed the components of the interaction, subtracting the mean from their values, updating the resulting value of the interaction and executing the model again. The correlation between the two components remains unchanged, but the correlation between the interactions and *Centrality* decreases, changing from 0.977 to 0.356 and from 0.985 to 0.238 (as shown in Table 1.3). The significant outcome is that the results of the model are unchanged in the pattern of signs and significance. This new model is reported in the Robustness Checks section of the chapter in Table 1.8, column 5. This shows that the problem of multicollinearity is overcome.

5.3 Hypotheses Testing

The key results are summarized in the following table.

Hypothesis	Dependent Variable	Independent Variable	Predicted	Summary
One	Patents	Centrality S1-S2	+	Supported
Two	Patents	Centrality S1-S2 * Tie strength FB-S1	-	Supported
Three	Patents	Centrality S1-B2	-	Supported
Four	Patents	Centrality S1-B2 * Relative tie strength FB-S1/S1-B2	+	Supported

Table 1. Summary of key Results

All the hypotheses are based on the same dependent variable; that is, the focal buyer's patents count.

The first and the third hypotheses investigated the impact of the supplier's centrality in the network of suppliers and buyers on the buyer's innovation output. These two main effects are supported by the statistical analysis. Hypothesis One predicted that the supplier's centrality in the network of suppliers

would be associated to superior buyer's innovative output. This hypothesis was supported, being the resulting coefficient positive and significant at level $p < 0,01$. Hypothesis Three predicted that the supplier's centrality in the network of buyers would be associated to the lower buyer's innovative output. The hypothesis was strongly supported, with a negative coefficient that is highly significant at level $p < 0,001$.

Two moderation effects were predicted to intervene in this process. Hypothesis Two predicted that the strength of the direct tie between the focal buyer and the supplier would negatively moderate the main effect presented in Hypothesis One. The hypothesis is tested with an interaction term and is supported. The hypothesis found support, and the coefficient is negative and significant at level $p < 0,01$. Therefore, the higher this strength, the lower the positive impact of the supplier's centrality on buyer's innovation output.

Hypothesis Four predicted that the relative strength of the tie between the focal buyer and the supplier versus the strength of the ties between this supplier and other buyers positively moderates the main effect shown in hypothesis Three. The hypothesis found strong support, with a positive coefficient that is highly significant at level $p < 0,001$. In conclusion, the theoretical framework is supported by the data.

The table of the results is included at the end of the section.

As for the control variables in the full model (column 6 of Table 1.5, or Table 1.4), *Patents s1*, *Presample patents*, and *Horizontal ties* are significant at level $p < 0.001$. *Patents s1* is positive, and it is the count of the patents granted to suppliers directly linked to the focal buyer. The higher the innovativeness of the suppliers connected to the buyer, the higher the buyer's innovations. This result is in line with what is broadly shown in previous literature that identifies firm level characteristics of the supplier, such as technical capability, as determinants of the buyer's performance. *Presample patents* represents the past innovativeness of the focal buyer. It explains the unobserved firm's propensity to invent; it is positive, and its significance proves that it has been wise to introduce this additional predictor inside the model to control for the firm's unobserved heterogeneity. *Horizontal ties FB-B* is the number of horizontal alliances of the focal buyer with other buyers; that is, other motor vehicle companies. The impact is negative. This finding can be further investigated; the underlying principle explaining the effect could be that the less-innovative firms tend to connect with other assemblers to enhance their innovative skills. Moreover, the variable *ROA* is positive even with a very low significance ($p < 0.1$). Firms with high financial performance are able to achieve higher innovation output due to more availability of resources.

Finally, the coefficient related to the strength of the ties, which are the components of the two interaction terms *Tie strength FB-S1* and *Relative tie strength FB-S1/S1-B2*, are both insignificant. This seems quite understandable because we are dealing with a complex network in which strength has an impact on the extent to which the supply can or cannot convey certain kinds of benefits to the focal buyer. The effect of the strength is a function of other specifications regarding the supplier, such as its contacts and the knowledge it can consequently provide; therefore, it has an effect when in combination with an indicator of the supplier's centrality.

I introduce the variables of the hypotheses successively in the negative binomial RE model, which has proven to be the most appropriate for reasons that I will explain later. In the negative binomial specification, I first introduce the variables regarding the two main effects on the buyer's innovation output (investigated by hp 1 and 3); subsequently, I add the moderation effects (investigated by hp 2 and hp4). Sign and significance of the coefficients remain steady when adding new variables to the first one.

I ran the Log Likelihood-ratio test. The test statistic used in the test, approximately Chi-squared distributed with degrees of freedom (df) equal to the difference of the degrees of freedom of the compared model (df2-df1), is always statistically significant. Therefore the less restrictive models, i.e. those with the introduction of more variables, fit the data significantly better than the more restrictive models.

5.4 Robustness checks

The basic estimation was supplemented by robustness checks, along three main dimensions: sensitivity to statistical estimation (tested through the execution of the regression according to different statistical specifications (e.g., Poisson, negative binomial, etc.), sensitivity to construct measurement (tested considering alternative measures for the key variables) and sensitivity to sampling choices (tested by running the regression using different samples, excluding or including some types of firms), to control for potential biases.

Two additional checks have been carried out.

First, computation has been carried out on the dependent variables in two different ways with respect to co-patenting: assigning 1.0 or 0.5 to each joint patent. In the chapter, the main model is implemented using 0,5, to avoid spurious inflation of patent counts through double counting of patents, the computation with 1.0 is included in the robustness checks.

Second, the correction for multicollinearity between the key variables and the interaction terms (explained in descriptive statistics section) has been carried out, by mean-deviating the variables and running the model again.

The overall findings of the five types of checks provide strong evidence that the model is robust to alternative specifications, that led essentially the same pattern of coefficients and significance.

The sensitivity to statistical estimation is something I have applied to all the models: to the main models as well as to the models for robustness check. In fact, for each table, there are six columns corresponding to different estimations I introduced following Cameron & Trivedi (2010) on panel models for count data: pooled Poisson with cluster-robust errors, panel Poisson random effects (RE), panel Poisson fixed effects (FE) , panel population-averaged Poisson, negative binomial random effects (RE), negative binomial fixed effects (FE). These analyze the pattern of sign and significance to ascertain if it remained constant.

Sensitivity to construct measurement was tested examining an alternative measure for the centrality construct. I re-estimate the model, replacing the measure of variable *Centrality S1-S2* with a different measure than to the one in the main model. The variable is measured by *Efficiency S = 2 step reach / 1 step reach.* In the original model, the 2 step reach was computed including all the nodes at path distance two, irrespective of a simultaneous presence of a direct tie between the focal buyer and the node at distance two (the node in the 2 step reach can be reachable by the focal buyer in one step and in two step simultaneously). On the contrary, this alternative measure was computed including just the nodes that were exactly at path distance of two from the focal buyer, implying that if the nodes were at distance two from the focal buyer but were also connected to it directly they were excluded from the computation. This check was done for two main reasons: first, to ensure that the measure was not mixing two effects - namely, the supplier's centrality and the density in the ego network of the buyers - since higher coordination in the ego network can provide benefit for the implementation of the innovative ideas. Moreover, since a structural holes variable is also included in the main model, I wanted to ensure that I was not introducing harmful duplications in the model. Second, this measure stresses the role of the contacts outside the ego network so that the supplier being central among them is spanning a hole between the focal buyer and the supplier at path distance of two. I wanted to isolate the impact of the external environment and the role of gatekeeper of the supplier.

Sensitivity to sampling choices was tested running the regression using a sample different from the main model. In the main model, I excluded all motor vehicle companies having no operating activities in the United States on the basis of two main motivation: US suppliers in that case would be not representative of the total number of suppliers connected to the focal buyer, and the social exchange would be lower due to low level of proximity. I ran the regression again with the total sample to be consistent with the original source of data, the ELM guide, and to check that my two assumptions were not incorrect and resulting in an eventual bias in the estimation.

I ran the regression with both sensitivities analyses simultaneously (sampling choices and construct measurement), too.

In sum, the overall findings provide evidence that the model is robust to alternative specifications.

Table 2 - Model 1 - Full Model

	Pooled Poisson	Panel Poisson Fe	Panel Poisson Re	Panel Poisson Population-averaged	Panel Negative Binomial Fe	Panel Negative Binomial Re
Variable						
Centrality S1-S2	0,989**	0,759***	0,761***	0,986*	0,502***	0,446**
	(0,366)	(0,054)	(0,053)	(0,406)	(0,156)	(0,144)
Tie strength FB-S1	-0,580	1,242°	1,315*	-0,092	-0,316	0,233
	(0,862)	(0,671)	(0,655)	(0,297)	(0,867)	(0,829)
Centrality S1-S2 * Tie strength FB-S1	-0,802*	-0,679***	-0,681***	-0,866*	-0,416**	-0,342**
	(0,330)	(0,051)	(0,050)	(0,377)	(0,141)	(0,129)
Centrality S1-B2	-2,530*	-2,158***	-2,174***	-2,952**	-1,633***	-1,494***
	(1,113)	(0,175)	(0,174)	(1,111)	(0,477)	(0,422)
Relative tie strength FB-S1/S1-B2	5,012	-2,376***	-2,416***	-0,629	0,190	0,017
	(4,182)	(0,663)	(0,656)	(3,953)	(2,091)	(2,003)
Centrality S1-B2 * Relative tie strength FB-S1/S1-B2	2,141*	2,115***	2,127***	2,739**	1,501***	1,303***
	(1,011)	(0,167)	(0,165)	(1,009)	(0,452)	(0,389)
Constant	-6,022		4,690***	2,096	-0,328	-1,398
	(4,779)		(0,673)	(3,426)	(2,037)	(1,858)
SH efficiency	3,864	-0,437	-0,408	1,786	0,847	1,602
	(3,690)	(0,428)	(0,426)	(2,146)	(1,379)	(1,219)
S1	-9,2e-04	0,005***	0,004***	-0,001	3,7e-04	-0,002
	(0,001)	(7,2e-04)	(7,0e-04)	(0,001)	(0,001)	(0,001)
ROA	5,573*	1,858***	1,828***	2,596°	-0,683	1,499°
	(2,588)	(0,297)	(0,296)	(1,349)	(1,184)	(0,848)
R&D Intensity	18,916°	1,988	2,201	8,400	0,567	3,046
	(9,974)	(1,598)	(1,592)	(5,955)	(7,374)	(6,211)
Current ratio	0,104	-0,241***	-0,250***	-0,035	-0,029	-0,319
	(0,258)	(0,068)	(0,068)	(0,203)	(0,242)	(0,230)
Debt to equity	-0,007	-0,015***	-0,015***	-0,010	-0,029*	-0,005
	(0,015)	(0,004)	(0,004)	(0,006)	(0,014)	(0,009)
Emp	-0,001	-0,003***	-0,003***	-7,9e-04	-1,7e-04	-0,001
	(0,001)	(3,6e-04)	(3,5e-04)	(0,001)	(0,001)	(9,0e-04)
Patents s1	2,2e-04**	2,7e-04***	2,7e-04***	2,5e-04***	2,6e-04***	2,8e-04***
	(7,8e-05)	(8,9e-06)	(8,8e-06)	(4,7e-05)	(4,1e-05)	(3,3e-05)
Supply ties FB-B	0,006	-0,020***	-0,018***	0,008	-0,007	-0,005
	(0,029)	(0,005)	(0,005)	(0,019)	(0,028)	(0,013)
Horizontal ties FB-B	-0,056	-0,228***	-0,228***	-0,148***	-0,126**	-0,232***
	(0,055)	(0,009)	(0,009)	(0,046)	(0,048)	(0,036)
Presample patents	8,9e-04***		0,001*	8,6e-04***		0,001***
	(1,0e-04)		(5,2e-04)	(1,15e-04)		(3,9e-04)
N, obs	156	145	156	156	145	156
Log Likelihood	-6216,928	-1055,206	-1280,508		-417,485	-646,142

° p<0,1 ; * p<0,05 ; ** p<0,01; *** p<0,001. Standard errors are in parenthesis

$\alpha = 2,013$ Hausman Prob>chi2 = 0.9997