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From Birth through Transition to Maturation: The Evolution of Technology-based Alliance Networks

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Abstract

This article considers the evolution of interfirm networks within a context of technological change. More specifically, it studies the evolution of structural and positional embeddedness in a network of technology-based alliances when it moves from an early period of invention creation to a subsequent period of new product development and commercialisation. Empirically, we study the evolution of technology-based alliance networks in the biopharmaceutical industry over a period of about 25 years, from 1975 until 1999. Examining inter-organizational networks over such an extended time period allows us to move beyond more static approaches that have characterized most network studies until now, and consider network evolution along its various phases of birth, growth,and early maturation instead. Our findings indicate that the evolution of both structural and positional embeddedness does not follow the common idea of a path of linear progression, but instead strongly exhibits non-linearity by resembling a sigmoid pattern. These findings have a number of implications. First, the break in the process of linear progression contrasts with the standing literature that (implicitly) assumes the informational and resource value of a network structure to remain constant over time or to evolve linearly from carrying low value to progressively higher value. Instead, our finding that the evolution of structural and positional embeddedness is non-linear echoes the speculative idea, as expressed by Gulati and Garguilo (1999), that network change may possibly be non-linear when seen on the long run. A second implication concerns the validity of standing insights from the social network literature such as Coleman's theory of social capital and Burt's theory of structural holes. These theories may not apply to the extent there are strong changes in environmental conditions like environmental uncertainty and/or munificence, such as during a transition phase as considered in this study.

Practitioners Points:

- How to adapt one's way of operating in networks when moving from stable times to turbulent times and vice versa;
- During turbulent periods, firms may benefit especially from direct and redundant ties to other firms;
- During stable periods, firms may benefit especially from non-redundant ties and a strategy of efficient brokering between them.

Keywords: Network evolution, technology-based alliances, structural embeddedness, positional embeddedness, new business development, pharmaceutical biotechnology.

1. Introduction

Since the pioneering work of Schumpeter (1942), research on the role and nature of technological change has proliferated (e.g. Dosi, 1982; Anderson and Tushman, 1990). In line with meanwhile well-established inquiries into the effects of technological change on industries (e.g. Astley, 1985) and organizations (e.g. Chandler, 1977), more recently studies have also started to explore how technological change affects the development and evolution of inter-firm networks (Soh and Roberts, 2003; Roijakkers and Hagedoorn, 2002; 2006; Rosenkopf and Padula, 2008). In this emerging literature on network evolution, most studies have focused on tie formation and considered to what extent tie formation is driven by alternative mechanisms at different stages of network evolution(Gay and Dousset, 2005; Powell et al., 2005; Rosenkopf and Padula, 2008). In this article we go beyond this focus on tie formation and will specifically consider the evolution of a network structure, once ties have been formed.[i] We start from the common idea that the formation of ties gives rise to the emergence of a network structure that becomes a vehicle for flows of assets, resources, information and status (Gnyawali and Madhavan, 2001). Furthermore, in their seminal study, Gulati and Garguilo (1999) emphasized the role of the entire network structure itselfas a key source of information on future partners and how it diminishes a firm's search costs and lowers risks of opportunism (Gulati and Garguilo, 1999). Two key mechanisms through which a network structure provides such key informationare structural and positional embeddedness (Granovetter, 1992). Structural embeddedness forms a network-level source of information and relates to indirect partners (partners of partners and beyond), which may constitute important channels of information, resources, status referralsand reputation (Uzzi, 1996; Coleman, 1988). Positional embeddedness also forms a network-level source of information and refers to the idea that, in the absence of first-hand information or third-party referrals, others can make inferences about a firm's quality and attractiveness based on its position in the network structure (Podolny, 1994; Stuart, 1998).[ii]

Despite widely shared agreement on the fact that the major advantages from networks lie in the (informational) value offered by structural and positional embeddedness, it still remains unaddressed in what specific ways each type of embeddedness evolves over time.

Conceptually, different views have been expressed. According to Baum and Ingram (2001), networks follow a 'natural path' from closure in early phases to structural holes in later phases. In contrast, Kenis and Knoke (2002) suggest an alternative path from non-density in the early phase to increasing density in a later phase. Although the two views represent alternative ideas on network evolution, their common denominator is formed by the (implicit) assumption of a linear process of network evolution. This idea of linearity is also what emerges from studies describing network evolution (Gulati and Garguilo, 1999; Eisenhardt and Schoonhoven 1996; Soh and Roberts, 2003). In a related vein, comparisons have been made as to what extent network dynamics or network characteristics differ between different phases, such as between the era of ferment and the era of incremental change (Rosenkopf and Tushman, 1998), before and after key industry events (Madhavanet al., 1998) or between an exploration phase and an exploitation phase (Gilsing and Nooteboom, 2006).Whereas these studies argue to what extent network dynamics and characteristics will differ between both phases, they abstract from the transitional process through which networks change from the former phase to the latter. As a consequence, it remains unaddressed to what extentthe transitional process, and network evolution more generally, forms a linear process or exhibits non-linearity instead.

From the literature on technological change, it becomes clear that a transitional process can be highly non-linear, as a consequence of specific shocks, disruptive technology or avalanche changes (e.g. Geels and Schot, 2007). The non-linearity stems from the fact that these technological transitions tend to lead to structural, stepwise changes of a permanent nature (Tushman and Anderson, 1986; Baum and Singh, 1994). These insights on technological transitions and technological shocks suggestthat their implications for network evolution may possibly be non-linear as well. To the extent that changes in structural and positional embeddedness are non-linear, the informational and resource value of the network structure will be much more subject to (discontinuous) volatility, which stands in contrast with the common idea of its linear progression (Gulati and Garguilo, 1999). To address this, the purpose of this article is to develop an understanding of the evolution of structural and positional embeddedness over a longer period of time. Empirically, we will consider a network of technology-based alliances in the biopharmaceutical industry. We consider a period of about 25 years in which the network structure evolves from an early phase with an emphasis on invention creation, and moves through a transition period to a subsequent phase with an emphasis on up-scaling and commercialization.

This article proceeds as follows. In section 2 we develop a theoretical framework and derive two propositions on the evolution of structural and positional embeddedness. In section 3we discuss our methodology and in section 4 we present an empirical study of their evolution in a network in the biopharmaceutical industry. In section 5, we discuss our key findings and draw a number of conclusions.

2. Theoretical framework and propositions

In this section we develop a theoretical understanding of the evolution of structural and positional embeddedness. To accomplish this, we first define and discuss structural and positional embeddness in some more detail (2.1), then argue how they evolve within a context of technological change (2.2), and finish by summarizing and the formulation of two propositions (2.3).

2.1 Structural &positional embeddedness: network-level sources of information

The central focus of this study is on the evolution of an entire network structure of technology-based alliances, through the lens of structural and positional embeddedness. In contrast to a dyadic relationship between two partners (i.e. relational embeddedness), structural and positional embeddedness do not result from individual relations between partners, but can only result from a network structure. Hence, a genuine network effect operates. For structural embeddedness, the focus shifts towards both direct partners and indirect ‘channels’ of information, reputation, and referrals. Structural embeddedness can be defined as the extent to which the organizations in a network structure are directly and/or indirectly connected to one another (Gulati and Garguilo, 1999). To the extent that first-hand experience with a prospective partner is absent, information based on an indirect connection is considered to be a good alternative (Podolny, 1994; Uzzi, 1996). Indirect ties may be brought to a firm’s attention by a common partner that - by connecting the two - can offer referrals. This information can reduce up-front uncertainty regarding the competences and reliability of the prospective partner, but also ex-post as it can receive information from the focal organization in case the partner would misbehave. Positional embeddedness refers to the position an organization occupies in the network, most notably its centrality (Gulati & Gargiulo, 1999). Positional embeddedness refers to the phenomenon that the position of a firm in a network affects its ability to acquire information about potential partners as well as its visibility and attractiveness to others. To the extent that first-hand experience with a prospective partner or information through a common partner is absent, a firm may rely on the centrality of a prospective partner's network position to make inferences about its quality and reliability.[iii]

To capture structural embeddedness at the network-level, we consider network connectivity of the network structure. An increase in connectivity of the network structure implies an increase in the number of firms that become directly or indirectly connected. Positional embeddedness at the network-level entails the distribution of centrality among network actors and indicates the degree in which the network is centralized into one or few actors. An increase in centralization of the network structure implies that there is an increase in positional embeddedness between firms, with one or few firms becoming more central while others becoming more peripheral.

2.2. The evolution of structural and positional embeddedness

In our theoretical analysis of the evolution of structural and positional embeddednes, we rely on the framework by Koka et al. (2006) and will follow their distinction between two key environmental conditions, namely environmental uncertainty and environmental munificence. Environmental *uncertainty* can be defined as the difficulty of firms to qualify the external environment and make predictions about its future state (Dickson and Waever, 1997; Bstieler, 2005). As far as environmental uncertainty is concerned, we will consider both technological uncertainty and market uncertainty (Lin, 2012). Environmental *munificence* refers to the extent in which (financial) resources are available for firms to undertake innovative activities (Koka et al., 2006; Philippen and Riccaboni, 2007). Following changes in the level of environmental uncertainty or munificence, Koka et al. (2006) specify the implications for tie-creation and tie-deletion at the firm level and distinguish among 4 types of network evolution: network churning, strengthening, expansion and shrinking. We build on their theoretical logic underlying these 4 types of network evolution, but also make an important and novel addition as we specify how these changing environmental conditions carry changing implications for structural and positional embeddedness at the network level.

To understand this evolutionary process, we distinguish among three phases. A first phase is characterized by an increase in technological uncertainty and munificence, exhibiting an increase in both structural and positional embeddedness. Second, a relatively short transition phase characterized by a decrease in technological uncertainty and munificence but an increase in market uncertainty, during which both structural and positional embeddedness decrease significantly. A third phase that is characterized by a decrease in market uncertainty and an increase in munificence, during which structural and positional embeddedness increase again. Finally, an important point of departure is that we consider the evolution of a network structure that develops from new inter-firm partnerships that have been formed in view of the creation of *de novo, disruptive* technology. As a consequence, firms and/or relations between firms that refrain from these new activities, by retaining a focus on *established* technologies, fall beyond the scope of the analysis.

2.2.1 First phase: discovery and variety creation

The first phase is characterized by the arrival of a technological discontinuity. Technological discontinuities generate high technological uncertainty as the established technology and its dimensions of merit and their measurement, are being challenged (Rosenkopf and Tushman, 1998). This triggers a process of technological discovery and experimentation during which firms attempt to come to grips with an incompletely understood and insufficiently mastered new technology (Tushman and Anderson, 1986). As technological discontinuities hold the future promise of sharp price-performance improvements, they also lead to an increase in munificence as can be witnessed by the entry of new firms and an inflow of financial resources by investors who hold high expectations of it (Tushman and Anderson, 1986; Powell and Brantley, 1992). Entering firms come from a variety of backgrounds and carry different types of expertise, pursuing different types of technological trajectories that yields a variety of preliminary, new product designs (Anderson and Tushman, 1990). In an attempt to reduce technological uncertainty, firms initiate collaboration with others to exchange technological knowledge and to define critical performance dimensions of the new technology (Rosenkopf and Tushman, 1998). Due to its specialized and tacit nature in this early phase, knowledge exchange and recombination between firms is only possible by means of direct interaction among a limited number of people (Gilsing and Nooteboom, 2006). Therefore, the size of these newly forming ‘exploration clusters’ is generally small, facilitating direct collaboration. Collaboration within these clusters yields initial technological norms and artifacts, which help to reduce technological distance and in this way improve the build-up of mutual understanding within these clusters (Nelson and Winter, 1982).

Whereas technological diversity within clusters diminishes, technological distance between these clusters tends to remain large given the emphasis on design competition and technological differentiation (Rosenkopf and Tushman, 1998). This results into a compartmentalized network structure among these different exploration clusters. This limits the spread of technological knowledge throughout the newly forming industry, which also constrains the growth of intra-industry legitimacy of the new technology (Aldrich and Fiol, 1994).

‘Network expansion’: implications for structural and positional embeddedness

The implications for structural embeddedness are as follows. Given the increase in technological uncertainty and munificence that characterizes this first phase, firms need to maintain their future options by the initiation of collaborative partnerships. The increase in (financial) resources enables them to accomplish this (Koka et al., 2006), leading to the formation of relatively small ‘exploration clusters’ with few linkages between them. As a consequence, the lion’s share of collaborative relationships is mostly formed by direct ties with few indirect ties. So, in this early stage, structural embeddedness is hardly present yet. The coherence within these isolated clusters decreases opportunities that partners have each other something new to tell (Björk and Magnusson, 2009). To find new information and expertise and to increase the number of future options, firms add new collaborations by initiating relations with firms in other clusters (Rosenkopf and Almeida, 2003; Dittrich and Duysters, 2007). As knowledge from other clusters tends to be generally more coherent, this may be easier when compared to knowledge from ‘isolates’(Schilling and Phelps, 2007). This leads to an increase in the number of tie creations with new partners, in a pattern of 'network expansion' (Koka et al., 2006; Philippen and Riccaboni, 2007). This leads to growing connectivity that allows for the reduction of transaction costs and the transitivity of trust (Gulati, 1995), which makes the formation of collaboration with indirect partners also easier. As a consequence, firms also become increasingly indirectly connected, giving rise to the emergence and growth of structural embeddedness.

For positional embeddedness, the implications are as follows. In the process of growing structural embeddedness, firms that possess highly specialized knowledge and that develop important inventions gain in status relative to others. These increasing differences in status make high(er) status firms become more attractive in the eyes of low(er) status firms that start to seek collaboration with them (Stuart, 1998). As a result, the former start to obtain more central positions whereas the latter will end up in more peripheral positions. This indicates the emergent role of positional embeddedness that conveys critical information on differences in the quality of firms' specialized knowledge and capabilities, supporting firms in learning more on those beyond their direct reach. This creates new opportunities for collaboration that also supports new tie creations, further boosting positional embeddedness.

Growing structural and positional embeddedness facilitate knowledge exchange and reduce technological distance between collaborating firms and in this way reduce technological uncertainty. This leads to the end of the first phase and initiates the arrival of the transition phase.

2.2.2 Arrival of the transition phase: selection

Whereas the transition phase is characterized by a decrease in technological uncertainty, there is also an increase in market uncertainty. Emerging industries whose new activities and long-term consequences are poorly understood, may face obstacles in gaining acceptance and approval by government agencies (Aldrich and Fiol, 1994). In addition, the economic substance of the new technology and its first tentative products still remains unproven, as it largely depends on socially constructed meanings of its future potential (Rindova and Fombrun, 1999). In addition, established industries that possibly feel threatened by the new technology may question the viability and legitimacy of the new technology through spreading rumors or inaccurate information (Aldrich and Fiol, 1994). This may lead to growing skepticism among potential customers and the wider public, signaling an increase in market uncertainty (Utterback, 1994).[iv] Because of this, (initial) investors may start to pull out from the industry, whereas new investors may be very reluctant to invest or only in small amounts. As a consequence, munificence decreases relative to the first phase. To address this, firms need to develop a deep understanding of the usefulness of the new technology for (future) users in order to convince potential stakeholders such as suppliers, customers, new investors and the wider public, in order to create inter-industry legitimacy and to be able to attract new resources in the future (Aldrich and Fiol, 1994). A decrease in technological uncertainty and munificence, and an increase in market uncertainty, leads to a pattern of 'network shrinking' first, which is then followed by a pattern of 'network churning'(Koka et al., 2006).

'Network shrinking': implications for structural and positional embeddedness

To build credibility among future customers and potential stake-holders and to establish inter-industry legitimacy, the capabilities of a firm´s existing partners may diminish in relevance. These established intra-industry network relations have been created with the main purpose of invention creation, whereas these partnerships generally do not qualify for the growing need for inter-industry legitimacy and future commercialization. In addition, firms also tend to economize on resources in response to decreasing munificence. As a consequence, firms become more inclined to terminate most of these established relations.

The implications for structural and positional embeddedness are as follows. A decrease in technological uncertainty and a decrease in munificence lead, through an increase in deletions of existing collaborations, to a pattern of 'network shrinking' (Koka et al., 2006; Huang et al., 2015). In this process, also indirect linkages between firms will be disappearing, and makes that the connectivity of the established network structure starts to diminish during the transition phase. As a result, structural embeddedness will decrease. With the disintegrating network structure, also established positions in the existing structure will increasingly disappear. Firms with initially high status, due to their technological accomplishments and prestige, lose their attractiveness as collaboration partners as they generally do have capabilities required for gaining legitimacy and commercialization. Hence, positional embeddedness will thus decrease accordingly.

‘Network churning’: implications for structural and positional embeddedness

To address the increase in market uncertainty and lack of inter-industry legitimacy, firms search for reliable relationships with firms from established industries (Aldrich and Fiol, 1994). Incumbents from established industries may have paid limited attention to what was mostly considered as a niche-innovation, until exogenous pressures have become strong enough that its growing importance can no longer be ignored (Suarez and Oliva, 2005; Geels and Schot, 2007). Their involvement becomes instrumental for creating awareness, interest and credibility with future users, suppliers, investors and the wider public (Rindova and Fombrun, 1999). In this way, collaboration with incumbents contributes to acquiring inter-industry legitimacy and confidence among governmental bodies, and serves as a basis for commercialization and the unlocking of future markets (Aldrich and Fiol, 1994).

The implications for structural embeddesness are as follows. After the early entrants from the first phase deleted most of their existing collaborations in the preceding pattern of ‘network shrinking’, they now selectively reinvest the resources becoming available from these deletions into new collaborations with incumbents. This is a pattern of ´network churning´ that is formed by a replacement of old collaborations with new collaborations, whereas the number of new tie creations may be largely on par with the number of tie deletions, leaving overall network connectivityat its low level.

The implications for positional embeddedness are as follows. The emerging collaboration with incumbents creates a potential for ‘churning’ of the network, which entails a dramatic shift in the holders of central and peripheral positions (Madhavanet al., 1998; Koka et al., 2006). Incumbents from established industries, formerly at the periphery of the newly emerging field, rapidly move into central positions at the expense of the early entrants from the first phase. The increasingly central positions by incumbents bestow legitimacy upon the new field and raise confidence among potential customers, suppliers and investors (Lange et al., 2009).

The outcome of this collaboration process between early entrants and incumbents is a selection of those novel technological findings that justify further investments in up-scaling and commercialization versus those that need to be terminated (Utterback, 1994; Peltoniemi, 2011). It is this increasing clarity that contributes to the commercial viability of the new technology and its growing inter-industry legitimacy. This provides the basis for a decrease in market uncertainty and leads towards the ending of the transition phase and the arrival of the third phase.

2.2.3 Arrival of the third phase: retention

The third phase is characterized by a decrease in market uncertainty, which is accomplished through the institutionalization of the newly created collaborations formed during the transition phase (‘network churning’) between firms ´from the first hour´ and incumbents. These partnerships are characterized by an increasingly structured collaboration process with an emphasis on market testing, up-scaling, and the undertaking of commercialisation (Utterback, 1994; Faems et al., 2005; De Luca et al., 2010). These are typically NPD collaborations that are aimed at the reliable development and delivery of new products targeted at a growing (mass) market, which contributes to further reducing market uncertainty (Talay et al., 2009). This increases confidence among investors, who will look for new investment opportunities, as well as among customers, other stakeholder and the wider public (van Lente et al., 2013).

Furthermore, there is a standardization of new technology creation through structuring of search activities into established search directions, which lowers technological uncertainty. In this process, the knowledge base becomes increasingly codified, diffuses more widely, and turns into a collective asset (Anderson &Tushman, 1990; Callon, 2002; Audretsch, 1987). This process also enables firms to rely increasingly on the network structure in order to locate, access and transfer knowledge that is scattered worldwide and that they need in their product development process (McDonough et al., 2006). This further reduces technological distance between firms whereas R&D intensity and skill intensity diminish, relative to the first phase (Audretsch, 1987). A decrease in market uncertainty and technological uncertainty further increases confidence among investors and leads to a further increase in resources, giving way to a pattern of ‘network strengthening’(Koka et al., 2006).

'Network strengthening': implications for structural and positional embeddedness

Decreasing technological and market uncertainty support firms in recognizing opportunities for (re)combining activities in one partof the network with other parts of the network. To pursue these opportunities, firms need to establish new collaborations that is supported by an increase in munificence, in a pattern of 'network strengthening' (Koka et al., 2006). As a consequence, there is an increase in the number of tie creations that leads to an increase in connectivity between firms throughout the network, either direct or indirect. Hence, structural embeddedness is developing and growing. The general focus in these new collaborations is on optimising and improving a selected set of those inventions that hold most potential for rapid commercialisation success, which is accomplished by a more routinized collaborative process (Rosenkopf and Tushman, 1998; Vanhaverbeke et al., 2012). This requires trust between partners (Gilsing and Nooteboom, 2006; Faems et al, 2007; Bstieler, 2006), which can develop through growing connectivity that allows for the reduction of transaction costs and the transitivity of trust (Gulati, 1995; Rosenkopf and Tushman, 1998). In this process, collaborations between former indirect partners are also increasingly being established, augmenting structural embeddedness of the network further.

For positional embeddedness, the implications of 'network strenghtening' are as follows. The focus on up-scaling and commercialization activities also increases the importance of process innovations. Process innovations induce a need for a highly structured collaborative process that delivers these process innovations in a predictable, speedy, and cost-effective way. To achieve this, collaborating firms need to act more in tune (Pullen et al., 2012). This induces the need for more central orchestrators that possess sufficient status and power to enforce compliance with emerging standards and industry recipes (Spender, 1989). At the same time, firms that have solved some of the critical issues as defined during the transition phase, and/or possess critical complementary assets, gain in status and will attract others that seek collaboration opportunities with them (Soh and Roberts, 2003). This enables them to stimulate efficient R&D collaboration and to enforce sanctions in case of defiant behavior (Burt, 1992). In this process, some firms increasingly come to occupy more central positions whereas others are pushed to more peripheral positions. As a consequence, firms become more and more differentiated in terms of their structural position and the number of direct and indirect ties they can reach (Gulati and Garguilo, 1999). This growing role of positional embeddedness leads to differences in firms' visibility and attractiveness to others, generating additional transparency in their capabilities and reputations. This further lowers uncertainty for setting up new partnerships and spurs the formation of new collaborations in the network (Gulati and Garguilo, 1999), mostly to the benefit of central firms (Stuart, 1998). So, growing structural embeddedness is followed by a growing differentiation in network positions, indicative of a further increase in the role of positional embeddedness.

2.3 Summary and propositions

Building on the theoretical framework by Koka et al. (2006), we have specified a process of network evolution across three distinct phases. The first phase is characterized by an increase in technological uncertainty through technological discovery and experimentation, and munificence through the inflow of financial resources. This leads to a pattern of 'network expansion' that exhibits an increase of both structural and positional embeddedness. Second, we find a relatively short transition phase that is characterized by a decrease in technological uncertainty and munificence, and an increase in market uncertainty due to growing skepticism among potential customers and the wider public. This transition phase entails a 'selection' process in which key problems for legitimacy and future commercialization are defined. This initiates a pattern of 'network shrinking', culminating into a drop in structural and positional embeddedness, and then gives way to a follow-up pattern of 'network churning'. Finally, we distinguished a third phase that is characterized by 'retention' through institutionalization of collaborative innovation. This phase is characterized by a decrease in market uncertainty, due to growing confidence among users in the technology´s viability,and an increase in munificenceby an inflow of financial resources, which leads to a pattern of 'network strengthening' and exhibits an increase in structural and positional embeddedness again.

Although the first and the third phase exhibit a similar increase, we expect the level of structural and positional embeddedness to differ between the two. The highly specialized and tacit nature of knowledge in the first phase (Audretsch, 1987) constrains its wider diffusion and creates large technological distances between firms. Large technological distances limit the potential for the set-up and continuation of partnerships between firms, let alone with partners of partners and beyond, constraining the level of both structural and positional embeddedness. In contrast, in the third phase, the codified knowledge base has diffused widely and has become a collective asset (Audretsch, 1987), which reduces technological distances between firms. Limited technological distance between firms supports the process of inter-firm learning in collaboration (Baum et al., 1998; Knudsen 2007) and contributes to the setting up of new and continuation of existing partnerships, boosting the level of structural and positional embeddedness. This suggests that the level of structural embeddedness and positional embeddedness will be higher in the third phase relative to the first phase.

Whereas the first phase (´expansion´) and third phase (´strengthening´) are similar in terms of increasing structural and positional embeddedness, the transition phase forms a clear break with this pattern. This implies that the transition phase constitutes a separate phase in its own right that needs to be an integral part of the analysis. This transition phase shows a *dual* pattern of network change, formed by first 'network shrinking' during which both types of embeddedness drop sharply, followed by 'network churning' during which both stabilize at a low level. As a consequence, once structural and positional embeddedness have stabilized in the transition phase, their level will be considerably lower when compared to the first and the third phase.

Overall, this suggests two propositions that specify the evolution of structural embeddedness and positional embeddedness from a first phase of invention creation,through a second phase of transition, to a third phase of up-scaling and commercialization.

Proposition 1:

Both in the first phase and in the third phase, structural embeddedness and positional embeddedness evolve from a very low level to a progressively higher level, whereas in the transition phase both first drop sharply and then stabilize at a low level.

Proposition 2:

The third phase has higher values of structural embeddedness and positional embeddedness than the first phase, whereas the transition phase has the lowest values.

3. Methodology

In this section, we discuss methods of data collection, the measurement of structural and positional embeddedness and the empirical identification of the three distinctive phases.

Data collection and measurement of key variables

We study network evolution in the biopharmaceutical industry during the period 1975-1999. R&D alliances are defined as technology-based inter-firm collaborations where two or more independent firms share part of their R&D activities (Hagedoorn, 1993). Boundary specification of the network that we study is formed by both firms and alliances that focused on the creation of new technology in the field of pharmaceutical biotechnology. This is in line with prescriptions for establishing network boundaries (e.g.Laumannet al., 1983) and in line with recent studies that have employed similar network construction criteria (Rowley et al., 2000; Rosenkopf and Padula, 2008). We primarily rely on data from the MERIT-CATI database, a comprehensive database that contains information on newly established R&D partnerships (see e.g. Roijakkers and Hagedoorn, 2002; 2006).We have selected those alliances from the MERIT-CATI database that operate in the pharmaceutical biotechnology industry, as indicated by their SIRD/NAICS classes reported by the NSF. In the CATI databank a total of 1469 global pharmaceutical biotechnology R&D agreements are recorded during this time frame.These alliances include partners that are active in biopharmaceutical research (i.e. primary two-digit SIC codes 87). We also included alliance partners from beyond biotechnology by including alliance partners from pharmaceuticals and chemicals (i.e. primary two-digit SIC code 28), making the total number of firms 890. In this way, we are also able to observe the indirect relationships between firms, important for measuring network connectivity. For the sake of thoroughness we have also manually checked all pharmaceutical-biotechnology R&D partnerships registered in this database for the period of our study. We have done so by using internetbased journals, reports, and articles. Some examples of these sources are company press reports, Ernst & Young Biotechnology reports, the Wall Street Journal, Pharma Business Week, and Signals magazine. In this way, we have been able to verify and cross-check the specifics of the majority of R&D partnerships included in the MERIT-CATI database.

Measuring structural and positional embeddedness

Following our theoretical argument, we measure structural embeddedness by network connectivity. *Network connectivity* forms a network level property and measures the degree to which network actors are connected. A network is fully connected when all its nodes are connected, directly or indirectly (Wasserman and Faust, 1994). If an existing connection disappears, network connectivity decreases. In contrast, when a pair of unconnected nodes becomes connected, network connectivity increases. We computed network connectivity by the use of UCINET VI (Borgattiet al., 2002).

Positional embeddedness is measured by *network centralization*. Whereas centrality is a firm-level construct, centralization indicates the distribution of centrality among firms in a network. In this way, network centralization provides a network measure for the degree to which firms are differentiated in terms of their structural position (Freeman, 1979). The extent to which there are differences between firms' structural positions indicates the degree in which there are differences between firms in terms of the perceived quality of their capabilities and hence their attractiveness as a (future) collaboration partner (Stuart, 1998). We computed the Network Centralization Index by the use of UCINET VI to measurethe centralization of the entire network (Borgattie.a, 2002). The general centralization index is defined as follows:

$$\frac{\sum_{i=1}^{g}[C_A(n^*) - C_A(n_i)]}{\max \sum_{i=1}^{g}[C_A(n^*) - C_A(n_i)]'}$$

where $C_A(n_i)$ forms an actor degree centrality index and $C_A(n^*)$ the largest value that occurs across the g actors in the network. The value of centralization varies between 0 (all have the same centrality) and 1 (when one actor is connectedt o all others who remain unconnected).

In addition to the measurement of structural embeddedness and positional embeddedness, we also developed graphical representations of the structure of research partnering networks in biopharmaceutical during the period 1978-1980 and 1983-1985, using a non-metric multidimensional scaling (MDS) technique. MDS is a technique that enables us to estimate similarities between pairs of data points and allows us to visualize these similarities in a two-dimensional space. In our case this means that companies that cooperate with the same partners are positioned close together. The graphical representation of the structure of the network as shown in figures 1 and 5, is developed with the help of the network visualization tool Najojo (owned by UNU-MERIT; Hagedoorn et al., 2004). The lines connecting pairs of companies in these figures represent R&D alliances within these two periods (1 new alliance is represented by dotted lines whereas 2 or 3 new alliances are represented by solid lines).

Identification of the three phases of network evolution

Following our theoretical framework, we make use of three criteria to identify the different phases in network evolution: technological uncertainty, market uncertainty and munificence. We measure technological uncertainty by examining the (de-)increase in the number of patent applications in the biopharmaceutical industry from its inception (1975 onwards). Market uncertainty will be measured by the extent to which companies allocate resources to R&D relative to commercialization activities. Munificence is measured by the degree of in/outflow of financial resources resulting from venture capital investments, which is particularly relevant in the biopharmaceutical industry (Pisano, 2002; Philippen and Riccaboni, 2007).

The first phase is characterized by a high level of technological uncertainty and an increase in munificence. This implies that the number of patent applications will be relatively low, not only because technological expertise tends to be more tacit in this stage but also as it is yet unclear what technological inventions need IP protection that justifies their patenting. An increase in munificence is indicated by an increase in financial resources from venture capital investments.

The transition phase is characterized by a decrease in technological uncertainty, an increase in market uncertainty and a decrease in munificence. A decrease in technological uncertainty is indicated by an increase in the number of patent applications, as during the transition phase risks and costs of technological search start to diminish due to a growing understanding which technological inventions are valuable and require IP protection, justifying a costly patent application. An increase in market uncertainty is indicated by an increase of commercialization expenses relative to R&D expenses. Following our theoretical framework, market uncertainty increases as the commercialization potential of the new technology needs to be proven, and firms will typically allocate more resources to commercialization activities relative to R&D. A decrease in munificence is indicated by a decrease of financial resources resulting from venture capital investments.

The third phase is characterized by a further decrease in technological uncertainty. This is indicated by a stronger growth in the number of patent applications as the direction of technological search has become clear making it easier to rapidly develop new technology, technology has become more codified whereas increasing competition puts more emphasis on the need for protection of commercially valuable technology. A decrease in market uncertainty is indicated by a stabilization of expenses for commercialization relative to R&D, as firms put more emphasis on maintaining a balance between invention creation and its commercialization in order to secure their market positions. In addition, this phase is also characterized by increase in munificence as indicated by an increase of financial resources resulting from venture capital investments.

Whereas we will mainly use these measures, we will also rely on a number of empirical studies on this industry over the same period for triangulation of the identification of the three phases (e.g. Kaplan, et al., 2003; Philippen and Riccaboni, 2007; Nightingale, 2000; Roijakkers and Hagedoorn, 2006; Pisano, 2002).

4. Empirical analysis and findings

In this section we present an empirical analysis of the process of network evolution in the biopharmaceutical industry, including a statistical test to validate propositions 1 and 2. We study the era from 1975 towards the end of the 1990s, as this period covers network evolution from early birth towards maturation (Pisano, 1991). First, in section 4.1, we provide the empirical analysis of the evolution of structural and positional embeddedness. In section 4.2 we discuss our key empirical findings and relate them to our propositions.

4.1 Network evolution in pharmaceutical biotechnology

The industrial birth of the biopharmaceutical industry is marked by the creation of rDNA technology by Cohen and Boyer in 1973 that opened up the door to genetically modified organisms (Pisano, 2002). At this very early stage of industry development, from 1975 towards 1980, a few of the pharmaceutical incumbents made attempts to collaborate with Dedicated Biotech Firms (DBFs) in order to engage in the exploration of biotechnology (Roijakkers and Hagedoorn, 2006). In figure 1 we see various isolated research clusters and a few isolated R&D collaborations, revealing the highly compartmentalized structure of the network. As a consequence, connectivity (structural embeddedness) and centralization (positional embeddedness) of the emerging network in this early period were very low. See also figure2 and 3.

---------- Insert figure 1 about here ---------

---------- Insert figure 2 about here ---------

---------- Insert figure 3 about here ----------

From the end of the 1970s towards the mid 1980s, however, the number of DBFs increased substantially relative to positions held by pharmaceutical and chemical incumbents. See also table 1.

---------- Insert table 1 about here ----------

During the early days in the 1970s, a few pharmaceutical and chemical companies entered R&D partnerships in the expectation that they could develop new products rapidly and then commercialize these accordingly. They soon found out that the newly developing knowledge base was highly specialised and at a large technological distance from their core technology of organic chemistry (Pisano, 1991). Collaborating with DBFs therefore required large investments in both basic and developmental research, with highly uncertain returns. During this period, the nature and technological implications of biotechnology were entirely non-obvious and there was little certainty if and in what ways the new technology would progress further, indicating the high level of technological uncertainty

(Kaplan et al., 2003). This is also reflected in the low number of patent applications in this early phase, as shown in figure 4.

---------- Insert figure 4 about here----------

Moreover, at this point in time, insights in the limitations of organic chemistry were not present yet and became only readily apparent towards the late 1980s and throughout the 1990s (Nightingale, 2000). As a consequence, most incumbents from established industries such as pharmaceutical and chemical companies adopted a wait-and-see attitude, and stayed out from the network or held highly peripheral positions. However, biotech entrepreneurs and investors such as venture capitalists had much less concerns and were increasingly optimistic about its future potential, leading to an inflow of financial resources into the industry from the late 1970s onwards (Kaplan et al., 2003). From the late 1970s until 1988, the inflow of venture capital in the biotechnology industry has grown from less than $100 million to about $1.5 billion (Bergeron and Chan, 2004). All in all, this shows that the first phase, characterized by high technological uncertainty and increasing munificence, runs until about 1988.

Meanwhile, R&D collaboration between DBFs, with a clear focus on technological discovery, began to take off and led to a growing number of relations in anetwork thatslowly started to lose its compartmentalized structure. See also figure 5.

---------- Insert figure 5 about here----------

Furthermore, we see that up until about 1987 – 1988, this coincided with an increase in network connectivity and centralization (see also figure 2 and 3). The increase in centralization indicated that some firms moved towards more central positions. Table 1 indicates that these central positions were mostly occupied by biotech companies such as Genentech, Biogen, Genetic systems, Genex, and others. Such central positions in an R&D network allow for combining different technologies from diverse parts of the network to create new technological innovations. As a consequence, isolated firms became increasingly also (indirectly) connected, which strengthened network connectivity even further.

Until about 1987 - 1988, the major focus of DBFs had been on the creation of new technologies whereas commercializing these technologies seemed to constitute a longer term issue. This resulted in that the technologies of biotechnology had been quite well established among DBFs by the late 1980s, leading to a decrease in technological uncertainty (Kaplan et al., 2003). This is also indicated by figure 4 showing an increase in the number of patents towards the later 1980s, due to increasing clarity in which technological domains to invest, heralding the arrival of the transition phase.

Meanwhile, however, there was growing uncertainty if and in what ways technology could be exploited, either as a source of a stand-alone drug with curing properties or as a research tool in order to improve the traditional drug discovery process (Kaplan et al., 2003). Another issue urgent issue became what type of products would be regulated and which safety tests would be required by the FDA (Pisano, 2002; Nightingale, 2000). This indicated the increase in market uncertainty. To address this, from the end of the 1980s onwards, the predominant focus on technological exploration by DBFs started to make room for an increasing focus on the build-up of legitimacy of a combined trajectory of molecular biology and organic chemistry, and its subsequent commercialization (Nightingale, 2000). This reflected a shift away from technological discovery towards an increasing focus on up-scaling and commercialization. This is illustrated by the gradual decrease of the R&D-to-Sales ratio from 4 to about 1 from 1990 onwards, which indicates the decrease in R&D intensity over time, in favor of an increasing emphasis on commercialization to address market uncertainty. See also figure 6.

---------- Insert figure 6 about here ----------

In this transition process, it also became increasingly clear that biotech companies proved to be unable to commercialize their novel findings independently. Instead, it became evident that for the build-up of legitimacy and for successful commercialization, key complementary assets were required such as capabilities to deal with (pre)clinical drug testing and regulatory approval procedures, as well as access to marketing and distribution channels (Pisano, 2002). DBFs lacked these skills and these could not be contracted for in the open market due to their highly specialized nature. As a consequence, the focus on biotechnology of venture capitalists and investors diminished as they increasingly lost confidence in its future market potential, which made them pulling out from biotechnology from the late 1980s and early 1990s onwards (Pisano, 2002; Roijakkers and Hagedoorn, 2006), leading to a decrease in the inflow of financial resources. From about $1.5 billion in 1989, the inflow of investments by VCs drops until about $0.5 billion in 1991 (Bergeron and Chan, 2004). Taken together, this decrease in munificence and in technological uncertainty, with an increase in market uncertainty, indicates that the transition phase started around 1988.

With the exit of venture capitalists, some first large pharmaceutical firms now entered the scene and started to cooperate with DBFs on an increasing basis (Pisano, 1991; Kaplan et al., 2003). They disposed over the specialized capabilities and skills that were required for getting drugs successfully tested and legally approved, in view of the build-up of legitimacy, and also provided access to established marketing and distribution outlets, in view of commercialization. Their entry was driven by an expiring pipe-line of potential ‘block-busters’ based on the traditional technology of organic chemistry (Nightingale, 2000). Their entry is also exhibited by figure 7 that shows a decrease in the number of intra-industry collaborations - among DBFs - and an increase in the number of inter-industry collaborations - between DBFs and pharmaceutical companies and/or diversified chemical companies.

---------- Insert figure 7 about here ----------

Table 1 provides further empirical evidence for what occurred during the transition phase. Whereas throughout the early phase, centralization was developing and growing, reflecting the central positions held by some DBFs, towards the end of the 1980s, it dropped sharply. In the period 1984-1986, at the end of the first phase, the top ranking is still formed by DBFs, such as Genentech, Biogen, and Chiron. However, the centrality of this group diminished towards the late 1980 onwards, with the arrival of the transition phase. We can see that large pharmaceutical companies were slowly improving their positions from the period 1987-1989 onwards. Centralization started to rise again slowly in the 1990s but now reflected the increasing centrality of large pharmaceutical companies (Roijakkers and Hagedoorn 2002; 2006). This trend continued and became even more pronounced in the early 1990s (1990-1992) and beyond, in which the top five positions are now held by large, incumbent firms.

This is the third phase that started around 1992. It is characterized by a further decrease of technological uncertainty, reflected in a strong increase of patents (figure 4), a decrease in market uncertainty, as mirrored in the stabilization of marketing expenses relative to R&D (figure 6), and an increase in munificence. From 1992 onwards, the inflow of VC investments increases from 0.5 billion to 3.5 billion in 1998 (Bergeron and Chan, 2004).

For the final years of our analysis, from 1996 to 1999, table 1 clearly portrays which incumbent companies formed the most central players, such as Roche, SmithKline Beecham, Pfizer, Bristol-Myers Squibb, GlaxoWellcome, Eli Lilly, and so on. These companies created many new partnerships especially from the mid 1990s onwards, stimulating an increase in network connectivity (see also figure 2). An important driving force here was formed by a second wave in the molecular biological revolution: genetic engineering. This new technology offered, among others, important possibilities for process innovations that may explain the growing importance in the network of a group of more chemically oriented firm such as Rhone-Poulenc, Hoechst and Bayer. These firms disposed over key process capabilities, which made the technological distance with genetic engineering not too large (Pisano, 2002). In line with this, the distribution of the growing number of network ties became increasingly asymmetrical, enabling firms that disposed over sufficient status and power to move into more central positions. This provided growing stability throughout the network and allowed for a systemic coordination by these firms, which could now enforce specific ways of operating in view of obtaining drug approval and subsequent commercialization. This is also mirrored in a further increase in network centralization throughout the 1990s (see also figure 3).

4.2 Key empirical findings in relation to propositions

In this section we discuss to what extent the empirical findings are in line with our propositions on the evolution of structural and positional embeddedness. Overall, the empirical findings are largely in line with proposition 1 on the evolution of both structural and positional embeddedness. From figures 2 and 3 it becomes clear that the general pattern is clearly one of increasing structural and positional embeddedness during the first and third period. The first period runs from the early years towards 1988 and is characterized by a pattern of ‘network expansion’ that leads to an increase in both types of embeddedness. In addition, the figures also show that both types of embeddedness exhibit a sharp drop between about 1988 and 1990 and stabilized at a low level until 1992. This indicates the transition phase that came with a break in both patterns of increasing structural and positional embeddedness. When looking at this transition phase in more detail, two different phases can be observed that clearly match with our theoretical framework. From 1988 until 1990, there is a sharp drop in both structural and positional embeddedness, in line with a pattern of ‘network shrinking’. From 1990 – 1992, both types of embeddedness stabilized and started to slowly increase again, in a pattern of ‘network churning’, by a prudent creation of ties to new partners (i.e. incumbents- see also figure 7) that leads to the formation of an entirely new network structure in which central network positions are now held by different firms than in the preceding period (Koka et al., 2006). This can clearly be seen from table 1 where from 1990 onwards the most central positions are primarily held by established pharmaceutical companies at the expense of DBFs. After 1992, in the third phase, growth of both structural and positional embeddedness accelerates rapidly, in line with a pattern of ‘network strengthening’.

Proposition 2 predicts different values of structural and positional embeddedness for each of the three phases. To test this formally, we employed a number of complementary statistical tests to measure whether group means of both variables differ significantly between these three phases. Here, the statistical tests show that there are three different periods that can be clearly distinguished, namely (i) 1976 – 1989, (ii) 1990 – 1992 and (iii) 1993 – 1998, differing significantly from each other with respect to centralization and connectivity.[v] The ANOVA tests indicate that the group means (i.e. the three different periods) of both connectivity and centralization differ significantly (F-ratio is 5.93 and significance is 0.009 for centralization and 8.44 and 0.002 for connectivity). Given that the sizes of the periods are not equal we applied the so-called Welch and Brown-Forsythe statistics, which show that we can reject the null hypothesis with 95% certainty (there is no difference in the mean scores) for centralization as well as connectivity. However, this result does not tell us *which* groups are significantly different from each other, so we used the post hoc test result of Games-Howell. This test indicates that all three phases are significantly different from each other, both for connectivity and centralization[vi]. More specifically, we find that the mean values for connectivity and centralization are higher in the third phase relative to the first phase. This is consistent with proposition 2 predicting that the third phase has higher values of structural embeddedness and positional embeddedness than the first phase. Furthermore, the 2nd period in the transition phase, after the preceding disintegration of the established network structure in a pattern of ‘network shrinking’, is formed by ‘network churning’ in which both types of embeddedness demonstrate a much lower mean value for centralization and connectivity than the first and third period. This is in line with proposition 2 predicting that within the transition phase the values of structural embeddedness and positional embeddedness are the lowest[vii].

5. Discussion and conclusions

Whereas in the emerging literature on network evolution the dominant perspective taken is that of tie formation, we have considered network evolution once ties have been formed. The common (implicit) idea is that network evolution forms a linear process, leaving it unaddressed to what extent it may possibly be non-linear when seen over a long(er) period. To address this, this article has considered the evolution of structural and positional embeddedness in a network of technology alliances in the biopharmaceutical industry over 25 years, when it moves from inception through transition to a maturation stage.

Following our propositions and findings, a number of results stand out. First, the evolution of structural and positional embeddedness forms a process of linear progression in both the first phase and third phase. In both phases, structural and positional embeddedness evolve from an initially (very) low level to a progressively higher level, through a pattern of ‘network expansion’ (first phase) and a pattern of ‘network strengthening’ (third phase). Second, during the transition phase, both structural and positional embeddedness drop sharply and then stabilize at a low level. More specifically, we first observe a disintegration of the established network structure through a pattern of 'network shrinking' before it transformsinto a new structure through a pattern of 'network churning'. Third, we find different values for structural embeddedness and positional embeddedness per phase, indicating a break in the evolution of both structural and positional embeddedness. So, a key conclusion from our study is that whereas network evolution within the first phase and the third phase network resembles a linear process, it forms a highly non-linear process in the transition from the former to the latter.

These findings have a number of implications. First, the break in the process of linear progression contrasts with the standing literature that (implicitly) assumes the informational and resource value of a network structure to remain constant over time (Coleman, 1988; Burt, 1992; Ahuja, 2000), or to evolve linearly from carrying low value to progressively higher value (Gulati and Garguilo, 1999). Instead, our findings imply that the value of a network does not remain constant over time nor changes linearly, but changes non-linearly instead. This is an important conclusion and echoes the speculative idea, as expressed by Gulati and Garguilo (1999) that network change may possibly be non-linear when seen on the long run. This new insight also explains an unexplained finding in a key study by Eisenhardt and Schoonhoven (1996). Whereas they predicted a linear decrease in the rate of alliance formation when industries move from an emergent stage through a growth stage to a mature stage, they unexpectedly found the rate of alliance formation to be lowest in the growth-stage, the transition-stage between the emergent stage and mature stage. Our analysis of structural and positional embeddedness suggests that a sharp decrease in structural and positional embeddedness in-between the early and later stage strongly reduces the value of the existing network structure as a key source of information and resources. This makes it much more difficult and riskier for firms to identify new partners and form ties with them. This then explains that at the dyad level tie formation drops, as reported by Eisenhard and Schoonhoven (1996).

A second implication concerns the validity of standing insights from the social network literature such as Coleman's theory of social capital and Burt's theory of structural holes. Both theories implicitly assume a stable structure, carrying a constant informational and resource value. However, the disintegration of structural embeddedness during the transition phase basically leads to the dissolution of Coleman 'rents' such as cohesionbased benefits stemming from direct and indirect relations. Whereas Burt's normative theory suggests to create linkages to non-redundant contacts, based on the information stemming from differences in positions, the large drop in positional embeddedness eliminates the room to do this. As a consequence, neither Coleman's nor Burt's theory on network embeddedness provide any useful clues during this transition period when the existing structure itself is disintegrating. This suggests that current theories on inter-firm relations and network embeddedness may apply when there is a stable structure, implicitly assuming a stable inflow of resources or the absence of exogenous uncertainty. However, these theories may not apply to the extent there are strong changes in environmental conditions like environmental uncertainty and/or munificence, such as during a transition phase as considered in this study.

Third, these theoretical implications point to a number of managerial implications. However, as we have taken a network-level perspective in this study, and abstracted from an individual firm-level perspective, we have to be somewhat cautious when specifying a number of concrete, hands-on managerial implications. What our study offers though is a future research agenda that addresses how managers should operate in networks when moving from stable times to turbulent times and vice versa, which still forms an overlooked issue in the literature until now. We will elaborate on these directions for future research below.

A first topic is as follows. Especially during the transition phase, access to scarce complementary assets and knowledge held by incumbents from established industries, is critical for the build-up of legitimacy. However, the drop in structural and positional embeddedness during the transition phase leads to a loss of 'protective' embedded relations. This suggests that it becomes essential to reach out to these established players directly, rather than indirectly by brokering through others. This then suggests that during this phase, direct and possibly *redundant* access to key players with the relevant knowledge and scarce resources is far more critical than a strategy of efficient brokering between them that may provide only indirect access to their specialised expertise or possibly no access at all. Furthermore, for the unequivocal absorption of novel knowledge from the established players, at a potentially large technological distance, having redundant contacts may also contribute to the build-up of and extension of absorptive capacity (Phelps, 2010). Whereas these managerial implications for dealing with the high uncertainty in the transition phase seem to follow from our findings, they differ profoundly from Burt's ideas that actors should rely on an efficient brokering strategy among *non-redundant* contacts, providing only indirect access to key resources at best. A second interesting avenue for future research may be formed by exploring how tie formation takes place during a highly uncertain (transition) period, in which established embeddedness cues have lost their relevance. Current theories on network embeddedness and tie formation are based on the (implicit) assumption of a stable structure with constant informational and resource value, and seem to be therefore less well equipped to explain tie formation under conditions of environmental uncertainty. New theoretical perspectives are welcome here.

Overall, these suggestions for managerial implications and future research issues point to a key underlying issue, namely in how far firms may need to carefully consider their network strategies in different periods of network evolution? Depending on the changes in different types of environmental conditions, the focus of firms' network strategies may need a different emphasis on connecting with particular types of players ('*who you reach'*) relative to a focus on establishing particular types of (indirect) ties ('*how you reach'*). Whereas these notions carry potentially far-reaching managerial implications, future research is warranted first before this can be further substantiated.

When interpreting the results of our study, we should remain conscious of some of its limitations. One limitation is that we have considered a setting of technology-based collaboration. Our theory and empirical findings may not be replicated for networks of which the origins cannot be traced back to a technological breakthrough or for networks without any role for technology-based collaboration whatsoever. A second limitation is that we have considered a context in which complementary assets cannot, due to their specialized nature, be contracted for in the open market by the new players. This raises the question to what extent network evolution resembles the process as studied in this article, in case complementary assets are generic and hence established players may not be needed to build-up legitimacy. This suggests an interesting direction for future research.

Overall, we contribute to the literature by developing a more in-depth understanding of network evolution as a sequence from early birth through transition to maturation, as this process still remains poorly understood but is increasingly being voiced as an important direction for future research (Powell et al., 2005). By doing so, we also contribute to an emerging stream of literature on how networks may change, which still remains an understudied topic, rather than how they stay the same that has been the dominant focus in the literature until now (Kokaet al., 2006; Rosenkopf and Padula, 2008). Our study of the evolution of structural and positional embeddedness contributes to the beginning of an understanding of these unexplored issues.

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Table 1. A comparison of the top ten firms with the most R&D partnerships in biopharmaceutical in 1975-77, 78-80, 81-83, 84-86, 87-89, 90-92, 93-95, 96-99 (numbers in brackets), source: MERIT-CATI.

1975-77		1978-80		1981-83		1984-86	
1. Ciba-Geigy	(3)	Institut Pasteur	(4)	Genentech*	(9)	Genentech*	(11)
2. Marion Laboratories	(3)	Ciba-Geigy	(4)	Biogen*	(8)	Biogen*	(11)
3. Procordia Nova	(2)	Genex*	(4)	Genetics Systems Corp*	(5)	Johnson & Johnson	(10)
4. Bayer	(1)	Genentech*	(3)	Collaborative Research*	(5)	Chiron*	(10)
5. Böhringer-Ingelheim	(1)	Baxter-Travenol Labs	(2)	Syntex*	(5)	Pharmacia	(9)
6. Chugai Pharmaceutical	(1)	Elf Aquitaine	(2)	AMGen*	(4)	Dai-Ichi Kangyo Bank (DKB) Group	(7)
7. Genentech*	(1)	Genetics Systems*	(2)	Cetus*	(4)	Procordia Nova	(7)
8. LaboratoiresServier	(1)	Johnson & Johnson	(2)	Green Cross	(4)	Eastman Kodak	(7)
9. Merck & Co	(1)	Procordia Nova	(2)	Mitsubishi	(4)	Sumitomo	(7)
10. Sandoz	(1)	Rhône-Poulenc	(2)	Genex*	(3)	Hoechst	(6)

* Companies with an asterisk added - * - indicates that it is a dedicated biotechnology firm (DBF). Otherwise, it is a pharmaceutical/chemical company.

Table 1. continued. A comparison of the top ten firms with the most R&D partnerships in biopharmaceutical in 1975-77, 78-80, 81-83, 84-86, 87-89, 90-92, 93-95, 96-99 (numbers in brackets), source: MERIT-CATI.

	1987-89		**1990-92**		**1993-95**		**1996-99**	
1.	American Cyanamid	(9)	Merck & Co	(8)	Chiron*	(19)	Roche Holding	(32)
2.	Chiron*	(7)	Ciba-Geigy	(7)	Ciba-Geigy	(18)	SmithKline Beecham	(18)
3.	Johnson & Johnson	(7)	Eli Lilly & Co	(7)	SmithKline Beecham	(16)	Bristol-Myers Squibb	(16)
4.	British Biotech*	(7)	SmithKline Beecham	(6)	Hoechst	(13)	Eli Lilly & Co	(15)
5.	California Biotechnology*	(6)	Dow Chemical	(6)	Glaxo Holdings	(12)	Pfizer	(15)
6.	Dow Chemical	(6)	Genentech*	(4)	Pfizer	(12)	Rhône-Poulenc	(13)
7.	SmithKline Beckman	(6)	GeneLabs*	(4)	Rhône-Poulenc	(10)	Merck & Co	(11)
8.	Merck & Co	(6)	Eastman Kodak	(4)	Eli Lilly & Co	(10)	Oxford Molecular Group*	(11)
9.	Hoffmann-La Roche & Co	(6)	Glaxo Holdings	(4)	Johnson & Johnson	(9)	GlaxoWellcome	(11)
10.	Sandoz	(6)	Enzon	(4)	GlaxoWellcome	(9)	Arqule*	(11)

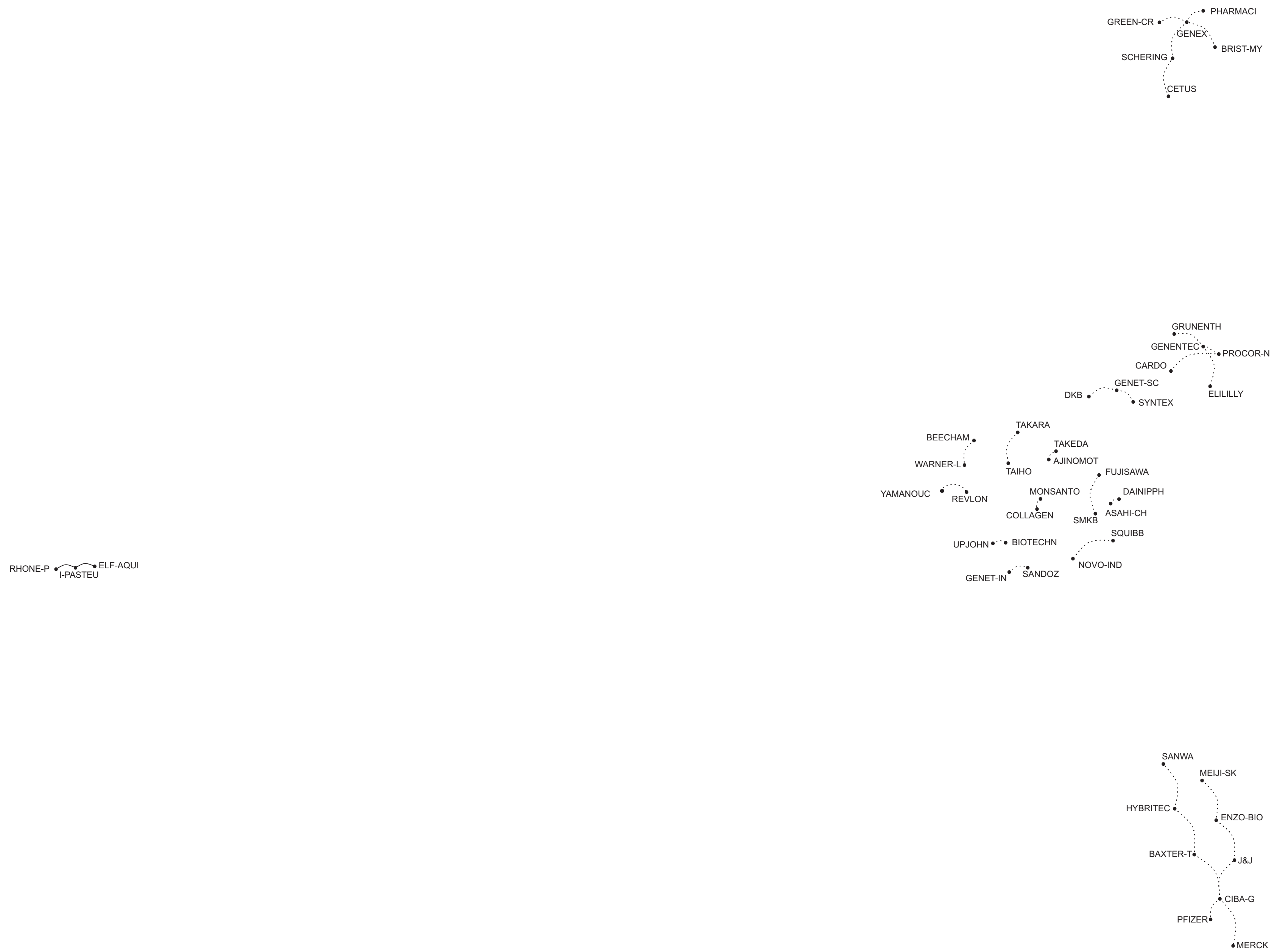


Figure1. Inter-firm R&D partnerships amongst cooperating companies in pharmaceutical biotechnology, 1978-80; *source:* MERIT-CATI.

Figure 2. Changes in network connectivity, three year moving averages, 1975-99, source: MERIT-CATI.

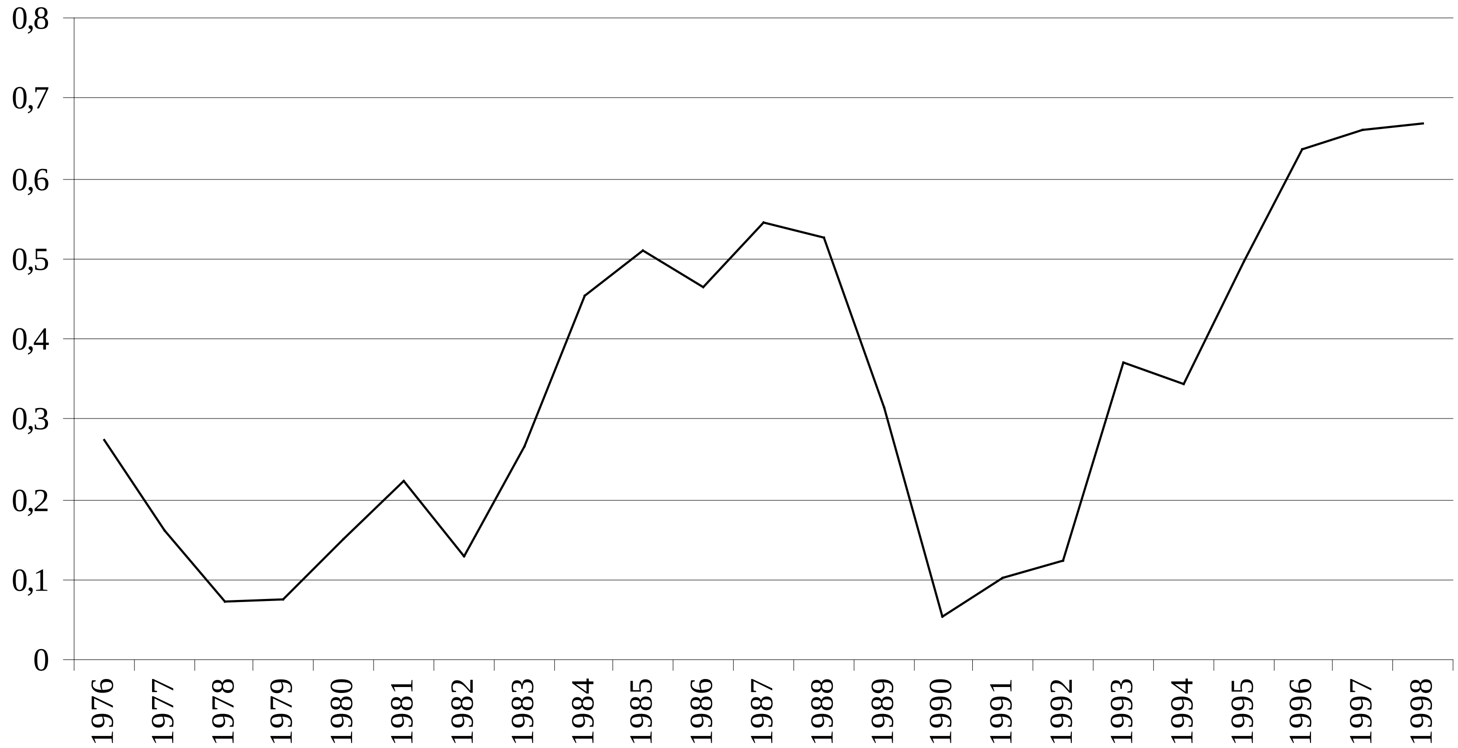


Figure 3. Changes in network centralization, three year moving averages, 1975-99, source: MERIT-CATI.

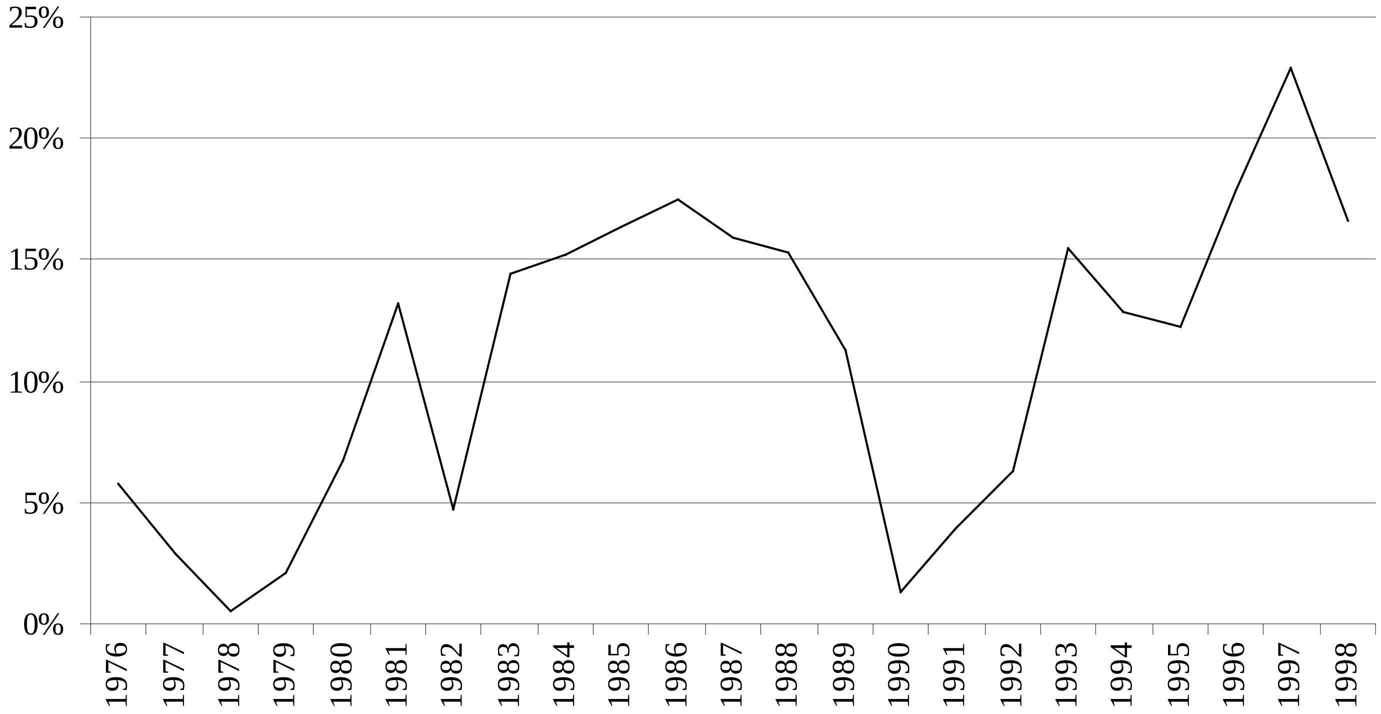
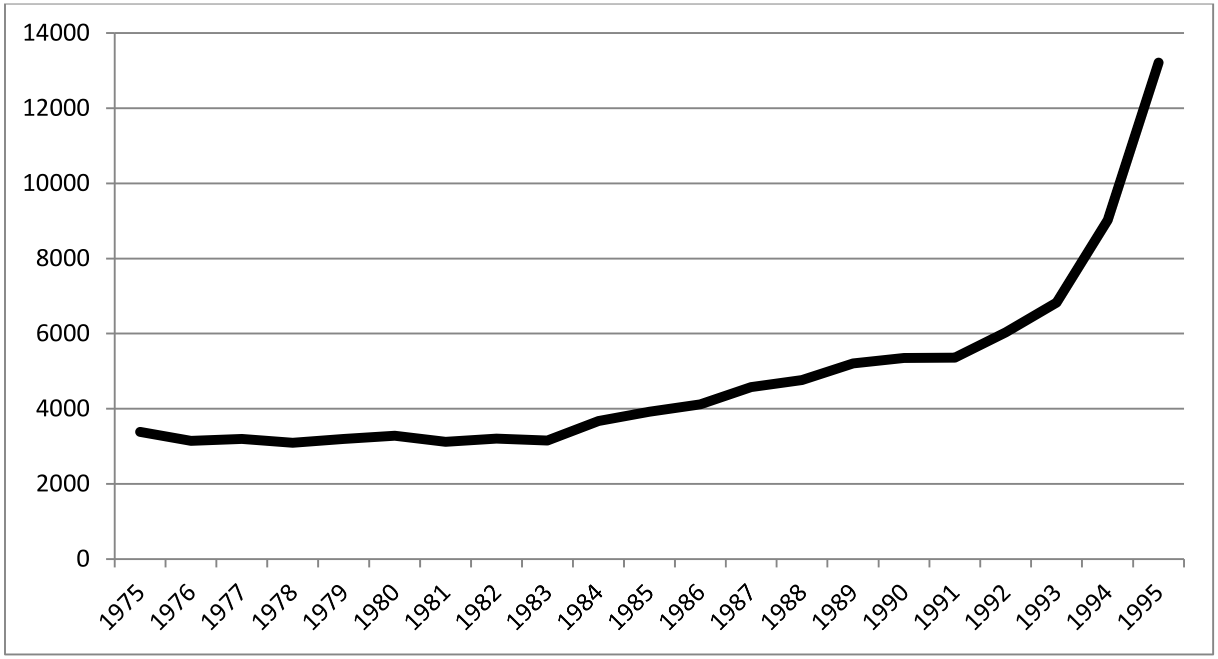


Figure 4. Number of patent applications in the pharmaceutical biotechnology industry per year, source: USPTO.



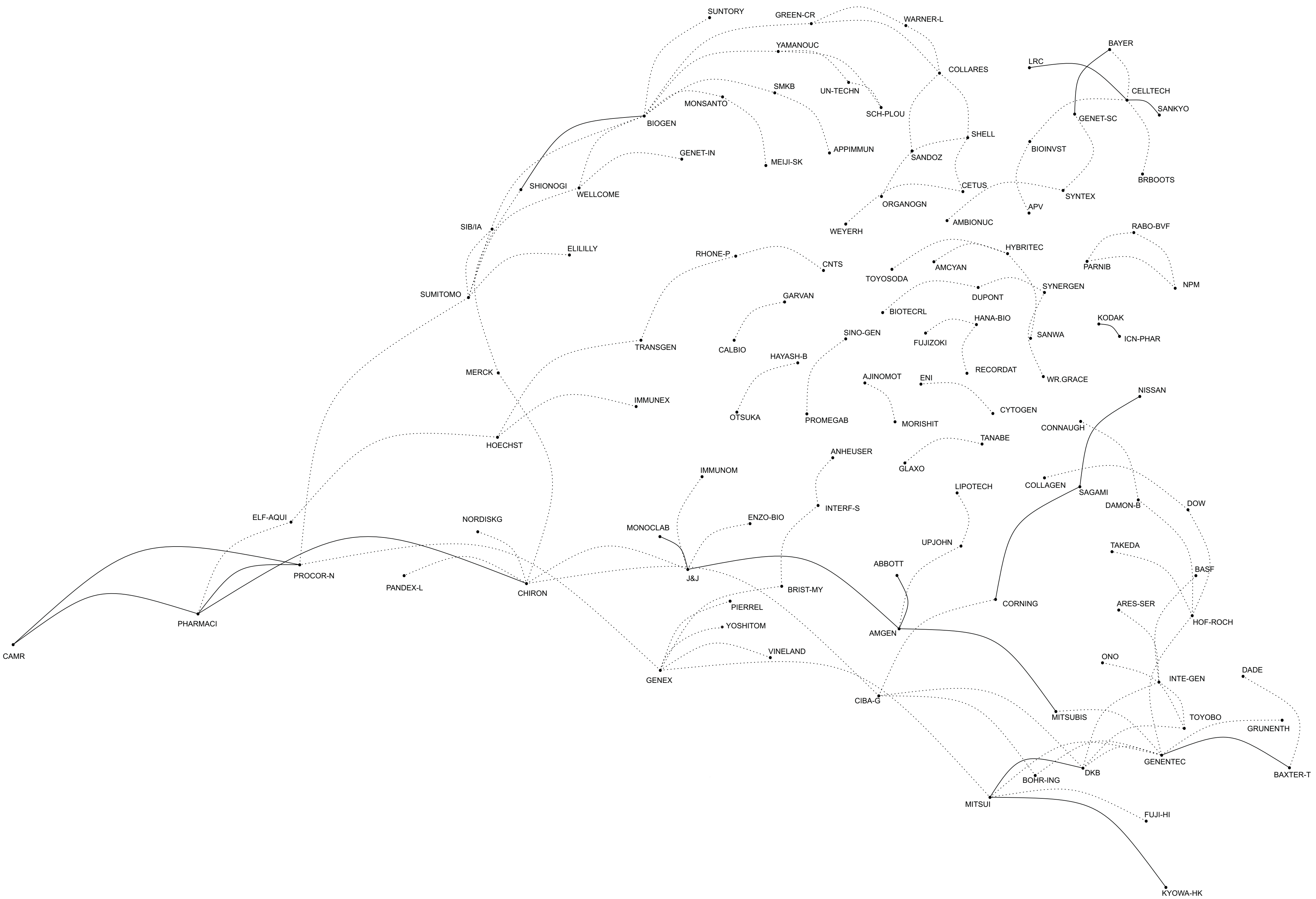


Figure 5. Inter-firm R&D partnerships amongst cooperating companies in pharmaceutical biotechnology, 1983-85; *source:* MERIT-CATI.

Figure 6. R&D expenses as a proportion of selling expenses for both pharmaceutical companies and biotechnological firms, 1985-1998, source: Osiris and Worldscope databases.

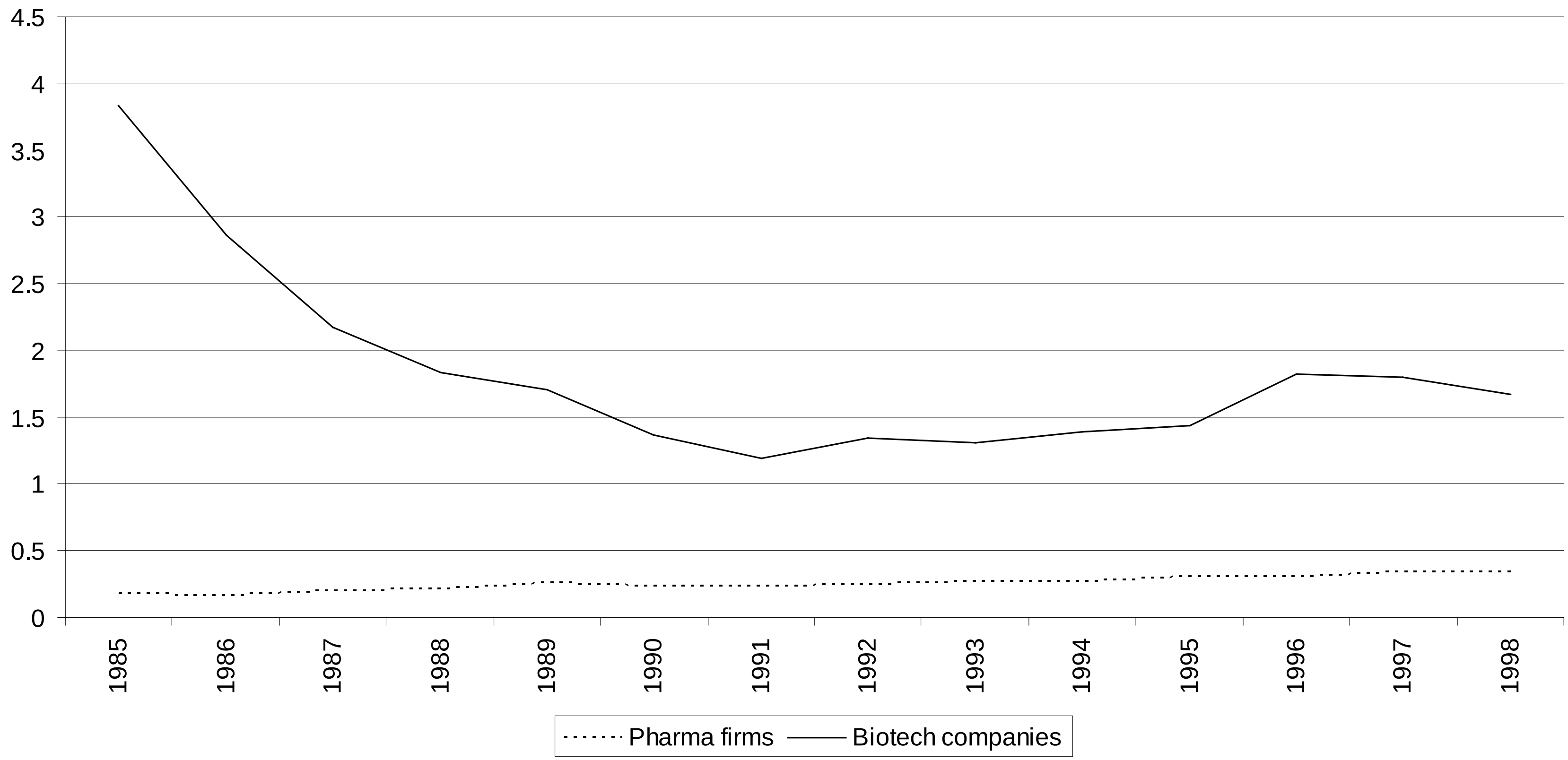
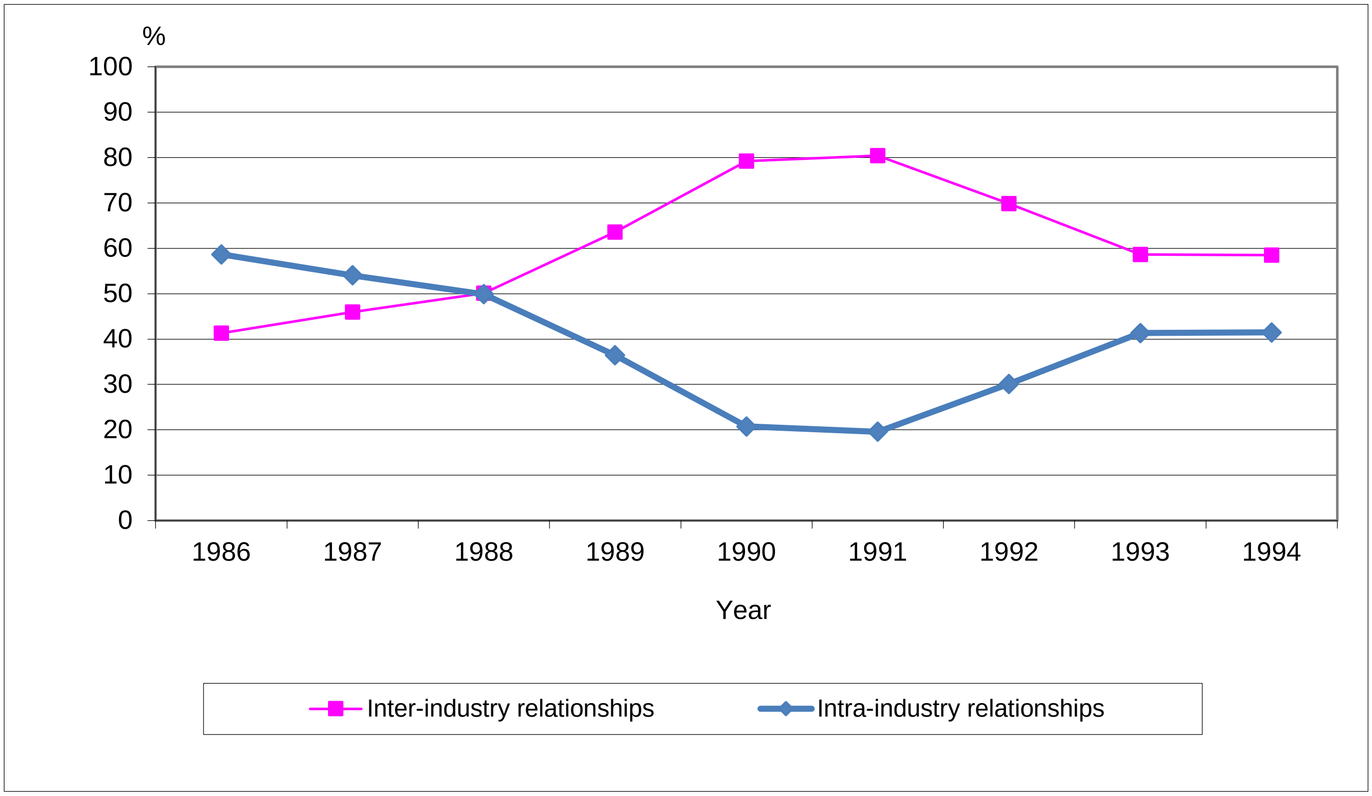


Figure 7. Intra-industry relationships and inter-industry relationships, 1985-1994, source: MERIT-CATI.



Note: we have defined alliances between DBFs as intra-industry relationships (primary SIC code 87) and alliances between DBFs and large pharmaceutical companies & diversified chemical companies as inter-industry relationships (cooperation between firms operating in primary two digit SIC codes 28 and 87).

Endnotes

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[i] There is also a growing literature on the performance consequences of collaboration, once these collaborative ties have been formed (see e.g. Ahuja, 2000; Faems et al., 2005; Vanhaverbeke et al., 2009). However, within this stream of literature the evolution of these relations is not considered.

[ii]The central focus of this study is on the evolution of the entire network structure. Both types of embeddedness can only result from a network structure, not from individual relations between partners. Hence, we do not consider such relational embeddedness (RE) as it forms a *dyad-level* source of information.

[iii]The distinction between structural and positional embeddedness is related to the distinction between two 'rules of attachment', namely cohesiveness and prominence. Cohesiveness refers to pairs of firms with direct or indirect ties in existing interfirm networks that form sources of information (Coleman, 1988), whereas prominence refers to the degree in which a firm occupies a central network position that signals its attractiveness to others (Burt, 1992; Podolny 1994; Powell et al., 1996).

[iv]This phenomenon is also described in the emerging literature on 'technological hypes' that typically result from inflated expectations (e.g. van Lente et al., 2013). When these expectations do not match with actual accomplishments, the ensuing disappointment is marked by a period of disillusionment that may be followed by a slow recovery.

[v]We take the period of 1990 - 1992 of the transition phase because this is the period during the transition phase of 'network churning' that reflects a process of structure loosening change. This profound change in key network positions between DBFs and pharmaceutical companies should be mirrored in different values for connectivity and centralization relative to the 1st and 3rd phase.

[vi]Group means of connectivity and centralization for the three different periods.

Period	Centralization	Connectivity
1976-1989	0.101	0.298
1990-1992	0.038	0.094
1993-1998	0.163	0.426

[vii] Following the idea of a counterfactual analysis (see e.g. van den Ende and Dolfsma, 2005), one might have expected the values for structural and positional embeddedness in the first phase to be smaller, and hence the difference with the third phase to be larger. A possible explanation may be as follows. The highly specialized nature of knowledge and high technological uncertainty in this phase may lead firms to not only engage in partnerships with technologically close firms (at relatively small technological distances) but also to initiate relations with firms from highly different technological backgrounds. This strategy of building a portfolio of different partners may support them in spreading risks and hedging bets in order to cope with highly specialized knowledge at large technological distances under high environmental uncertainty. At the network level, this results into a higher level of structural embeddedness and positional embeddedness than we theoretically anticipated.